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SILICON MATERIALS TASK OF THE LOW COST SOLAR ARRAY PROJECT (PHASE II)

Effect of Impurities and Processing on Silicon Solar Cells

Phase II Summary and Eleventh Quarterly Report

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July 1978

Work Performed Under Contract No. NAS-7-100-954331

Westinghouse Research and Development Center
Pittsburgh, Pennsylvania

U.S. Department of Energy

MASTER

Solar Energy

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and
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Contract No. 954331

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1.0 SUMMARY

This is the summary report for the Phase II effort under the Silicon Materials Task of the LSA Project. The object of Phase II of the program has been to investigate the effects of various processes, metal contaminants and contaminant-process interactions on the performance of terrestrial silicon solar cells. The study encompassed a variety of aspects including thermal treatments, crystal growth rate, base doping concentration (low resistivity), base doping type (n vs. p), grain boundary structure, and carbon/oxygen-metal interactions (float zone vs Czochralski growth). The work is now completed; some of the highlights are given below.

We have studied the effects of various metallic impurities, introduced singly or in combination into Czochralski, float zone and polycrystalline silicon ingots and into silicon ribbons grown by the dendritic web process. The metals were added in controlled and reproducible fashion along with a primary boron or phosphorus dopant. Subsequently all crystals were analyzed chemically, microstructurally, electrically and via solar cell fabrication and testing.

The totality of the solar cell data (comprising over 4000 cells) indicate that impurity-induced performance loss is primarily due to reduction in base diffusion length. Based on this assumption an analytical model has been developed which predicts cell performance as a function of metal impurity content. The model has now been verified for p-base material by correlating the projected and measured performances of solar cells made on 19 ingots bearing multiple impurities. Only Fe, Cu and Ni deviate from the model assumptions; detailed I-V studies coupled with metallography indicate the variance is due to junction excess currents induced by precipitates. The model also describes the performance of n-base solar cells bearing single impurities; no correlation with multiple contaminants has yet been attempted. It is notable that many metal contaminants, e.g. Ti, V, Cr, and Mn, produce considerably less cell performance reduction in n-base devices than in the p-base cells.

Examination of comparative solar cell data indicate that both low (0.2 Ωcm) and high (4 Ωcm) resistivity p-base solar cells exhibit similar efficiency reductions when identical impurity concentrations are introduced in the silicon. However, the detailed mechanisms of the performance reductions differ. Apparently in the low resistivity material band gap narrowing combined with the creation of excess numbers of traps (compared to the high resistivity material) compromise the beneficial effects of the larger open circuit voltage.

Three impurities, Ti, Cr, and Al were studied at similar doping levels in FZ and CZ ingots in an effort to deduce any beneficial effects of growth technique. The Ti and Cr-doped cells produced essentially the same performance reduction due to lowered bulk lifetime in both Fz and Cz ingots. However a 20% improvement in cell performance for Al-doped Fz ingots was observed. The result is tentatively ascribed to the low levels of carbon/oxygen in the FZ ingots.

Preliminary studies on polycrystalline ingots containing impurities indicate that solar cell behavior is species sensitive, and that a large fraction of the impurities may be segregated to the grain boundaries. For Mn cell performance of the poly devices was erratic but junction degradation appeared dominant. Detailed I-V analysis of the Ti-doped poly cells suggested that bulk lifetime was better than might be expected for the amount of Ti present. This beneficial effect was offset by enhanced junction excess current and reduced collection efficiency.

In the processing area we demonstrated that gettering at 900 or 1000°C is a viable means to raise the bulk lifetime in ingots containing Al, Cr, Ti, and Mn. If multiple gettering cycles are employed the major enhancement in lifetime occurs in one cycle, further cycles actually producing some lifetime degradation. DI rinsing appeared to be the most effective treatment for minimizing prethermal cycle contamination and an optimum rinse time can be defined.

Modeling of solar cell efficiency-impurity relations makes it possible to do tradeoff analyses at various stages of the process sequence between the feedstock and the end product cells. It appears unlikely that feedstock impurity concentrations in excess of one part per million for elements like Ti or 100 parts per million for more benign impurities like Ni will be tolerable even with crystal growth methods like Czochralski or silicon web which exhibit large melt segregation effects. The exact value of the acceptable impurity content for Solar Grade Silicon depends on tolerable cell efficiency, crystal growth method, melt replenishment strategy and cell process sequence.

2.0 INTRODUCTION

This report is a summary of the activities conducted under Phase II of JPL Contract 954331, titled an Investigation of the Effects of Impurities and Processing on Silicon Solar Cells. The objective of the study is to define the effects of impurities, processes and impurity-process interactions on the properties of silicon and on the performance of terrestrial silicon solar cells. The results form a basis from which silicon producers, wafer manufacturers and cell fabricators can develop appropriate cost-benefit relationships for the use of less pure, less costly Solar Grades of Silicon.

The overall approach-detailed in earlier reports[1-3] - has been to establish what concentrations of commonly encountered impurities can be tolerated in typical solar cells fabricated on 4 Ω-cm p-type silicon (Phase I). From this foundation the study was broadened to include the influences of thermal processing (like gettering), crystal growth rate, base doping concentration (low resistivity), base doping type (n vs p), grain boundary structure, and carbon/oxygen interactions. The results of these activities, based on the detailed analysis of 128 silicon ingots, form the bulk of this document.

In preparing this summary our intent has been to make the report sufficiently comprehensive and up-to-date that it supercedes previous quarterly reports and can stand, essentially on its own, as a "handbook" of impurity effects in silicon as we now understand them. The report format is designed to emphasize three major topics - experimental methods, analysis of impurity effects in silicon, and considerations in the use of Solar Grade silicon. The reader, depending on interests, may utilize the sections independently. (We have reiterated some earlier discussions of the development and application of impurity evaluation techniques because we believe the subject is important in its own right and of considerable general interest.) Much actual data has been included in the report, either in tabular or graphical form to facilitate application by a variety of potential users. Earlier analytical results and device data have been revised to reflect the most recent findings.

The study represents the work of numerous individuals; the major areas in which each contributed were:

R. H. Hopkins - Program Manager and Silicon Web Studies.
P. D. Blais - Processing Studies and Lifetime Measurements.
J. R. Davis - Device Testing, Data Synthesis, and Modeling.
A. Rohatgi - Detailed Device Analysis and Deep Level Spectroscopy.
M. H. Hanes - Deep Level Spectroscopy.
P. Rai-Choudhury - Device Processing.
J. R. McCormick - Czochralski Ingot Preparation and Evaluation.

The successful completion of the experimental effort depended on the capable technical assistance of H. F. Abt, J. C. Neidigh, D. N. Schmidt, C. S. Seiler, A. M. Stewart and B. F. Westwood. D. Labor prepared the report typescript.

3.0 EXPERIMENTAL METHODS

3.1 Impurity Matrix and Crystal Preparation

3.1.1 Impurity Considerations

The choice of impurity elements for this investigation was based on the following considerations: 1) the presence of the element in metallurgical grade silicon, a starting product in several of the low cost processing programs, 2) the potential for the impurity to be introduced in a particular polysilicon process, and 3) materials of construction which might be used for silicon refining or crystal growth equipment. This provides a data base covering most user needs.

Typical impurity concentrations found in metallurgical grade silicon are shown in Table 1.[4] When materials of construction are also considered we arrive at the impurity matrix shown in Figure 1. The matrix is not yet complete, e.g additional work is required in the area of n-type ingots, low resistivity p-type material, and in evaluating some additional materials of construction. In establishing the range of impurity concentrations to be investigated, the following factors were taken into account.

1) results obtained in previous programs[5]
2) the solid solubility limit of the impurity elements in silicon[6]
3) maximum melt concentrations which allow single crystal growth[7]
4) concentrations required to permit accurate analysis of the impurity concentration
5) maximum impurity concentrations for which no solar cell performance degradation is observed.

Table 1. Typical Impurity Concentrations Found in Metallurgical Grade Silicon

Impurity Element	Concentration (ppma)
Al	1300
B	11
Ca	250
Cr	390
Cu	60
Fe	4200
Mg	< 5
Mn	120
Ni	100
P	10
Ti	500
V	230
Zr	30

Figure 1 . Impurity Matrix Under Investigation

Impurity Element	Approximate Concentration Range Investigated $\times 10^{15}$ atoms per cm^3 ††		
	4 ohm-cm p-type	0.2 ohm-cm p-type	1.5 ohm-cm n-type
Aluminum*	3 - 50**		3 - 50
Boron*			
Calcium	0.1		
Carbon	20 - 500+		47 - 83
Chromium	0.1 - 1.1	0.5	0.3 - 1.0
Copper	0.4 - 60	2.3	2.5 - 10
Iron	0.02 - 1.5	0.8	0.3 - 1.0
Magnesium	0.003 - 0.03		
Manganese	0.01 - 1.3	0.7	1.0
Molybdenum	.000046 - 0.0042		
Nickel	0.4 - 4.0		2.3
Oxygen	500 - 1700+		
Phosphorus*	1.0 - 140	100	
Sodium			
Titanium	0.00036 - 0.36	0.2	0.07 - 0.36
Tantalum	~0.0008 - 0.004		
Vanadium	0.0004 - 0.4	0.4	0.4
Zinc+	<0.001		
Zirconium	<0.0007		<0.0007

†† $5 \times 10^{16} cm^{-3} \approx 1$ ppma

* Boron, phosphorus and aluminum are electrically active impurities and therefore cause variations in resistivity when used as a secondary impurity.

** Uncertainty in exact range due to discrepancy between electrical and SSMS measurements.

\+ Oxygen and carbon concentrations measured in approximately 50 ingots doped with additional impurities. Two carbon doped ingots prepared to determine effect of carbon.

In general items 2) and 3) above established the maximum impurity concentration which was introduced into first generation ingots while 5) fixed the completion of investigation for a particular impurity.

3.1.2 Crystal Growth

Except for five float zone crystals all ingots were prepared by Czochralski pulling. Phase I ingots were grown in an NRC-2805 Crystal Growth Furnace. To provide a larger number of silicon wafers the majority of ingots prepared for Phase II were grown in HAMCO CG-800 Crystal Growth Furnace. A new quartz crucible was used for each run; all graphite elements were baked out prior to loading the furnace.

Number-one Dow Corning semiconductor grade silicon nuggets or one piece crucible charges were used throughout the entire program. Typical characteristics of this material are shown in Table 2. The impurities in this material are sufficiently low in concentration that cell performance is unaffected. Undoped baseline audit ingots were prepared throughout the program to evaluate both charge material and potential contamination from the growth furnaces. No variation in cell performance from any of this material has been observed.

The purity and melting point of the elemental dopants are indicated in Table 3. Impurities with high melting points and low vapor pressures are added to the curcible charge prior to melt-down. Those with a melting point below that of silicon or high vapor pressure are added to the molten silicon prior to initiation of crystal growth. The amount of impurity added to the melt was based on the target impurity concentration in the ingot and the best available value for the effective segregation coefficient. Values of K_{eff} have been modified as the program has proceeded. Best estimates of K_{eff} for the elements investigates are compiled in Appendix 1.

Table 2. POLYCRYSTALLINE SILICON ANALYSIS

Analytical Method Impurity	NAA (ppba)	Mass Spec (ppba)	Mass Spec/Freeze Out (ppba)
Cr	$<4 \times 10^{-2}$	<3	~0.01
Cu	6×10^{-3}	20	~0.01
Fe	<2	<30	~0.1
Mn	<1.5	< 3	~0.01
Ni	<0.2	<30	ND
Ti	<4	<5	ND
V	--	<3	ND
Zn	--	<5	ND
Zr	--	<12	ND

Mass Spec/Freezeout

Al ∼ 4.8 ppba; C 100 ppba - 500 ppba

Table 3. CHARACTERISTICS OF DOPANT MATERIALS

Impurity Element	Purity (%)	Form	Melting Point (°C)
Aluminum	99.99	wire	660
Calcium	99.9	block	851
Carbon	99.999	graphite rod	3550
Chromium	99.999	pellets	1900
Copper	99.9997	zone refined ingots	1083
Iron	99.999	sponge	1535
Magnesium	99.99	Ingot	651
Manganese	99.99	flake	1244
Molybdenum	99.98	pellets	2610
Nickel	99.98	sponge wire	1455
Titanium	99.95	crystal	1668
Tantalum	99.99	polycrystal rod	2996
Vanadium	99.9	dendrite	2190
Zirconium	99.99	foil	2127

Growth conditions were as follows: pull rate-7 to 8.5 cm/hr, ingot diameter -1.2 to 1.5 cm, crystal rotation ∿ 10 rpm, crucible rotation ∿ 3 rpm, growth atmosphere-argon. All crystals were oriented on <111> . For a limited number of ingots pull speeds as low as 2 cm/hr and up to 15 cm/hr were employed to evaluate rate effects. At the higher rates effective segregation increased by a factor of about 1.4.

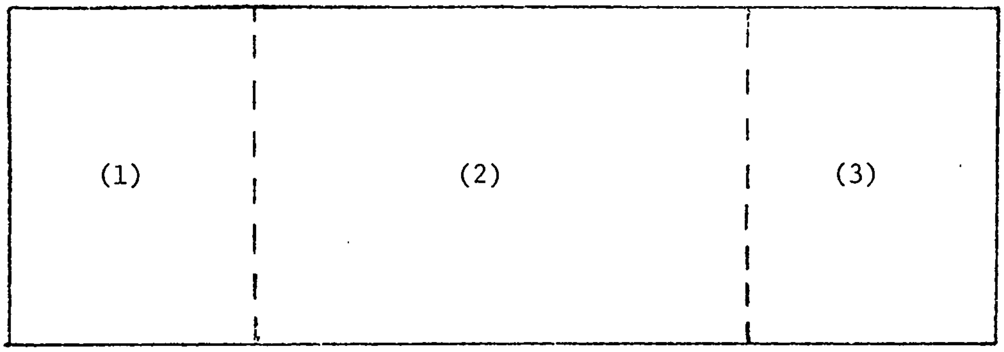
Five ingots were grown using a Siemens VZA-3 float zoner. One baseline ingot was prepared from previously grown Czochralski ingot as feedstock. The other four ingots were grown using doped polycrystalline silicon as feedstock. No problems were encountered when chromium and aluminum metals were used as dopants. Use of titanium metal directly as a dopant proved to be impossible. When the molten zone passed through the titanium region it was disrupted sufficiently for the ingot to lose crystal structure. A vacuum cast heavily doped polycrystalline silicon rod was later prepared and a section of it welded into the polycrystalline feedstock rod to be zone refined. This technique proved to be successful and a titanium-doped ingot was prepared.

Nearly 50 dendritic web[1] runs were performed to examine the effects of impurities on growth and cell performance. The crystals, about 1.5 cm wide, were pulled from 60g silicon charges at 78 cm/hr. The same polysilicon and metal dopants used in the Czochralski experiments were employed.

All ingots were centerless ground to 1.2 cm then etched to remove saw damage. Analytical samples were cut from the ingots by O.D sawing, wafers for electrical evaluation and cell fabrication were cut by ID sawing.

3.2 Silicon Ingot Analysis

A battery of analytical methods was employed to analyze the as-grown ingots. The sampling procedure is schematically illustrated in Figure 2. Specimens for etch pit density, IR transmission, spark source mass spectroscopy (SSMS), and neutron activation (NAA) were taken primarily from region (1) although some analyses were also performed on material



(1). 3 cm seed analytical material.

(2). 12.5 cm cell blank wafering.

(3). 3 cm tang analytical material.

Ingot Wt. 0.3-0.6 kg.

Charge Wt. 0.85-1.5 kg.

Figure 2 Location of Ingot Samples.

from region (3). All wafers came from region (2). The weight of ingot used through the seed end analytical material and solar cell blank slices was limited to approximately 25 percent of melt weight. This insured small variation of the impurity concentration along the length of material evaluated. Neutron activation analyses of seed and tang end samples from copper and manganese doped ingots indicated total changes in impurity concentration along the length of the ingot of 25 percent and of 47 percent, respectively. Variation within the region devoted to solar cell blanks would be significantly less than these extremes.

3.2.1 Resistivity

Resisitivity was measured on the seed and tang end of each ingot with a Siltec-1000 four point probe. Longitudinal resistivity measurements were also made at 1 cm intervals along the ingot length.

3.2.2 Etch Pit Density

The etch pit density was taken on seed and tang specimens following Sirtl etching.[8] The slices examined were taken from the extreme ends of regions (1) and (3), Figure 2. The etch pit density of the solar cell blanks was most comparable to that of the seed material.

3.2.3 Carbon and Oxygen Analysis

Carbon and oxygen concentrations were measured by infrared absorption. The amplitude of the absorption peak for carbon at 606 cm^{-1} and oxygen at 1107 cm^{-1} are proportional to the elemental concentrations. Constants of proportionally for this work were 2.2 for carbon and 9.6 for oxygen.

3.2.4 Impurity Analysis

Precise and accurate determination of impurity concentrations posed the most formidable task encountered during the program. The maximum melt concentration which could be achieved for the majority of elements studied was in the range of $1x10^{20}$ atoms cm^{-3} to $4x10^{20}$ atoms cm^{-3}. Higher melt concentrations resulted in polycrystalline ingot growth. This concentration limit coupled with the extremely small effective segregation coefficients for many of the impurities (see Appendix 1) produces ingot concentrations ranging from less than 10^{12} atoms cm^{-3} to values as high as $1x10^{16}$ atoms cm^{-3}, corresponding to required detection limits of from 0.02 parts per billion to 200 parts per billion. Only spark source mass spectrographic and neutron activation analytical techniques are applicable in these ranges. Typical detection limits for these two methods are shown in Table 4. (refs. 9 and 10). (Also shown in the table are the detection limits for the electrically active impurities based on resistivity measurements as well as carbon and oxygen as measured by infrared absorption.) Neutron activation analysis coupled with radiochemical separation and measurement provides the lowest detection limits. Due to budgetary constraints and the relatively long times required for the measurements, this latter method could not be widely used in this program. The development of more sensitive analytical methods by the National Bureau of Standards may improve this situation in the future.[11]

Each ingot was analyzed by SSMS, NAA or a combination of both methods. A vacuum cast sample was also collected from the residual melt of each growth run. This quenched material was analyzed by emission spectroscopy or atomic absorption to provide the melt impurity concentration. Segregation coefficients determined for the most heavily doped ingots were used to calculate the ingot impurity concentration in cases where the ingot impurity level fell below the detection limits of all the analytical methods.

3.3 Electrical Measurements

A major endeavor of this program is to quantify the relations between the impurity content of silicon and the electrical characteristics of the contaminated material. To accomplish this objective required the development and/or application of sophisticated measurement techniques sensitive to trace impurity levels in the material. The correlation of data from recombination lifetime studies, deep level transient spectroscopy, and detailed I-V analysis coupled with standard solar cell I-V measurements is one aspect of the approach described below. A second aspect, the development of a model to predict the behavior of solar cells

Table 4. Typical Detection Limits of Analytical Techniques Employed in this Investigation

Method of Analysis Impurity	Resistivity (ppba)	Infrared (ppba)	Mass Spec (ppba)	NAA (ppba)/ Routine (ppba)
Aluminum	4		50	----
Boron	<1		3	----
Carbon		$\sim 5 \times 10^{2}$	500	----
Chromium			3	0.04/5
Copper			15	0.006/3
Iron			30	$\sim 1/20 \times 10^{3}$
Magnesium			5	$\sim 20/3{,}800 \times 10^{3}$
Manganese			3	.002/2
Molybdenum			10	0.01/5
Nickel			30	$0.2/8 \times 10^{3}$
Oxygen		~ 100		
Tantalum			10	0.001/5
Titanium			5	0.5/-
Vanadium			3	$\sim 20/-$
Zinc			5	3/600
Zirconium			12-15	0.5/200

containing single and multiple contaminants is presented in section 4.

3.3.1 Recombination Lifetime Measurements

3.3.1.1 Photoconductive Decay (PCD)

PCD measurements require only low temperature specimen preparation and have been shown to correlate well with solar cell performance.[1] Thus we have used the technique extensively to track the response of impurity-doped silicon to various thermal and gettering treatments and to compare the properties of as-grown and diffused wafers. Originally we used an LPE GaAs IR emitting diode as the pulsed light source for measurements.[1] That approach suffered from the relatively high absorption of the 0.94 μm radiation in silicon, the low radiation intensity of the source and the rather long radiation decay time of the pulse. We replaced the LED with a YAG:Nd laser to facilitate the analysis of low resistivity and low lifetime specimens.[12,13]

A schematic diagram of the laser excited PCD apparatus is shown in Fig. 3. The monochromatic radiation wavelength is 1.06 μm, a spectral location for which the absorption coefficient, α, for high purity silicon is 11.70 cm^{-1} at 298°K.[4] The 1/e depth for intrinsic silicon is, therefore, 0.85 mm (34 mils) and the internal radiation after passing through a 10 mil wafer is 75 percent of that at the incident surface. Absorption due to free carriers is small at 1.06 μm and may be neglected for resistivities greater than 0.07 ohm-cm. The absorption coefficient does, however, increase with temperature.

The system arrangement is similar to that employed for the LED source, the most significant change being the trap light. The maximum intensity of the trap light[1] was increased approximately ten fold to insure that all traps remain filled even for Mn or V impurity concentrations as large as 10^{15} cm^{-3}. The trap light source is a 300 watt quartz iodine incandescent lamp (General Electric Type ELH-120 volt) powered by a dc regulated power supply.

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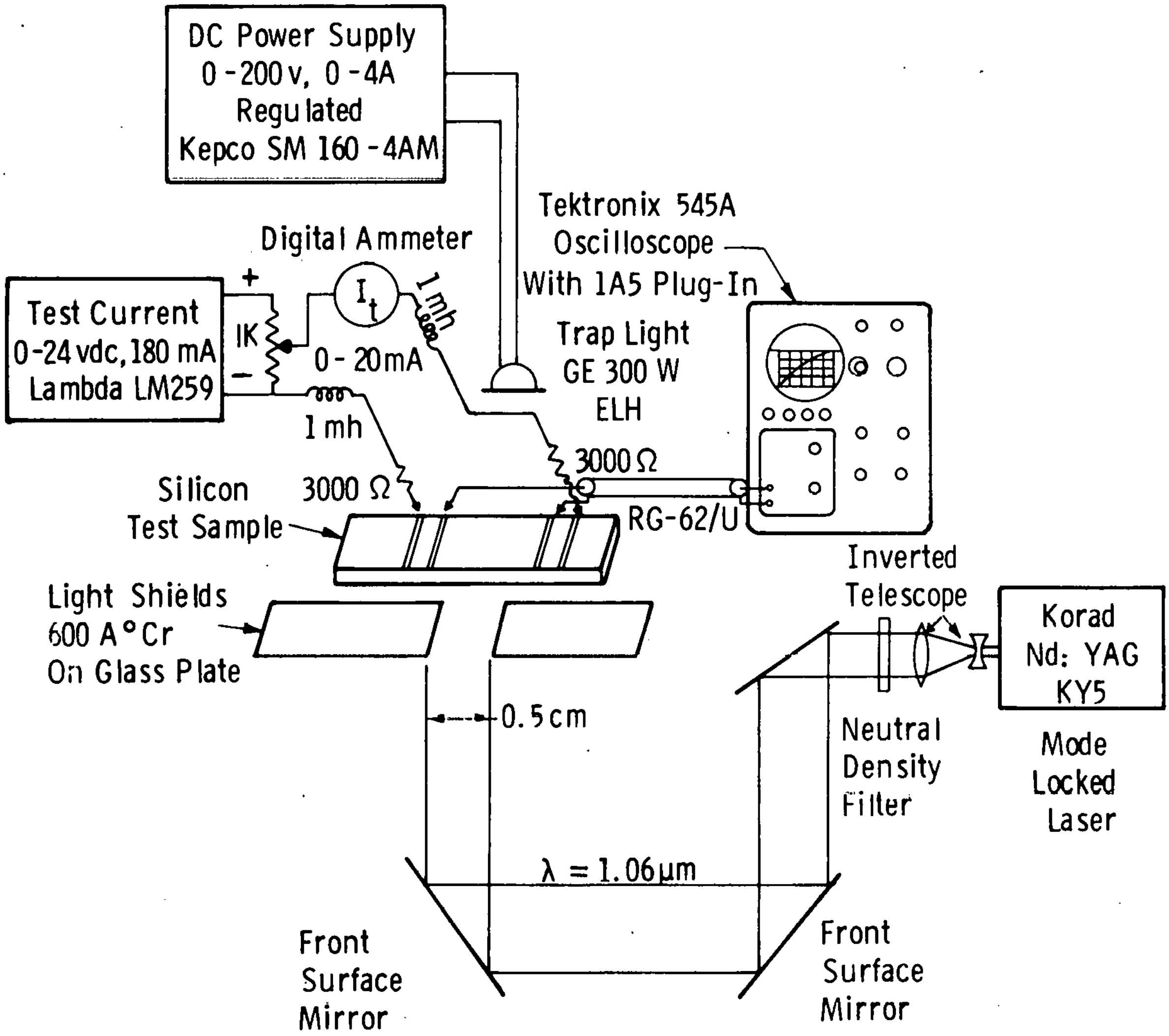


Fig. 3 Schematic diagram of laser excited photoconductive decay lifetime measurement apparatus.

In practice the system was calibrated by measuring the effective bulk lifetime τ_r' as a function of thickness for a number of specimens then determining S, the surface recombination velocity mathematically from a curve fit of the data. Experimental conditions are then chosen to minimize errors from the decay of higher order bulk modes and obtain the correct injection levels. For example, errors due to the electric field will be less than 5% when the field is limited to 1.0 volt/cm. Errors due to injection level will be less than 5% when the injection ratio is limited to $5\text{x}10^{-3}$. Errors due to the effects of higher modes $[\tau_r' = (\tau_{1/2}-\tau_{1/4})/\ell n2]$ can be kept in the range +0-50% when the ratio $(1/\tau)/(1/r_{ooo})$ is greater than 1.0. With the leeway allowed in the electric field and injection level τ_r' can be accurately determined after the higher modes have decayed or the signal has decayed to less than 10% of initial signal at $t = o$. From the surface recombination velocity and the measured τ_r' reliable values of the bulk recombination lifetime τ_r can be derived. Detailed procedures appear in references 12 and 13.

3.3.1.2 Open Circuit Decay

In addition to the photovoltaic I-V data collected by the methods described in section 3.4, measurements were made of minority carrier lifetime in the solar cells themselves. The measurements were made using the open circuit voltage decay method.[1] Data are taken using a Tektronix type-S plug-in. The forward current injection level was set at 20 mA/cm^2 which results in a base carrier concentration approximately equal to that produced by 100 mW/cm^2 illumination. Under these conditions we obtained reliable base lifetime data which were in good agreement with those obtained using the photoconductive decay method.

3.3.2 Electrical Characterization by Detailed I-V Analysis

The mathematical model we recently developed (section 4) predicts quite well the effect of multiple contaminants on silicon solar cell efficiency; however, it cannot, because of its phenomenological nature, be used to analyze a number of process-induced effects which influence solar cell behavior. Nor can the nonlinear effects of impurities such as copper, nickel and iron be completely explained within the context of the model. For this reason we set out to develop a practical analytic and experimental technique which would allow separation of the junction and base region effects from each other and from effects due to contacting and resistance phenomena. The technique, which represents a synthesis of our ideas as well as some which have appeared over the years in the literature, is described below. We believe the approach provides a powerful tool for assessing both impurity and process dependent effects on solar cells so the discussion is presented in some detail with the hope that it will prove valuable to others working in the field. Application of the analysis to specific impurity related problems is covered in Section 4.

Dark I-V characteristics of a p-n junction solar cell are equally important as the photocurrent because they determine how much of the electrical energy developed by the cell will be available at the output terminals and how much will be lost as heat. The dark I-V characteristics depend on various current transport mechanisms along with the series (R_s) and shunt (R_{sh}) resistances. The two most dominant current mechanisms are the diffusion and recombination in the quasi-neutral regions and recombination in the space charge region. These will be referred to as bulk current (I_b) and junction excess current (I_j), respectively. Surface leakage current (I_{sh}) is usually represented by a shunt resistance across the junction. Thus the dark I-V characteristic of a p-n junction can be expressed more accurately as[14]

$$I_d = I_b + I_j + I_{sh}$$

$$= I_{01}\left[e^{q(V-IR_s)/KT} - 1\right] + I_{02}\left[e^{q(V-IR_s)/nKT} - 1\right] + \frac{V-IR_s}{R_{sh}} \qquad (1)$$

where I_{01} is the reverse saturation current which for the most simple conditions of uniform doping, no surface recombination and large quasi neutral region width compared to diffusion length, can be written as[15]

$$I_{01} = q\sqrt{\frac{D_n}{\tau_n}}\frac{n_i^2}{N_A} + q\sqrt{\frac{D_p}{\tau_p}}\frac{n_i^2}{N_D} \qquad (2)$$

where D, τ, N_A, N_D and n_i have their usual meaning. The expression for I_{01} is much more complex in the presence of drift field or back surface field.[15] For a uniformly distributed impurity center having a single energy level near the middle of the band gap, I_{02} can be written as[14]

$$I_{02} = \frac{qWn_i}{2\tau_0} \qquad (3)$$

where W is the width of space charge region and τ_0 is the effective minority carrier lifetime.

Thus the equivalent circuit of a p-n junction in the dark can be represented by Figure 4.

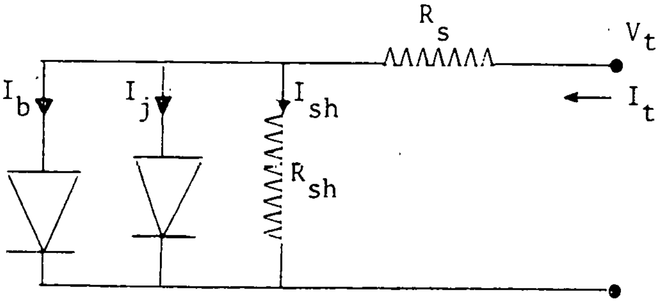


Fig. 4

The simplest equivalent circuit of a solar cell (p-n junction under illumination) is shown in Figure 5, where the photocurrent is represented by a current generator I_L.

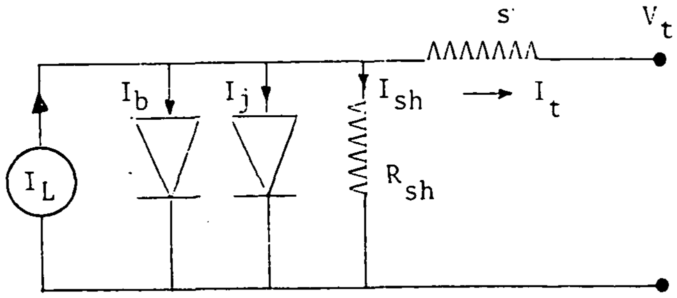


Fig. 5

Terminal current of the solar cell is given by

$$I_t = I_L - I_d \tag{4}$$

where I_d is given by Eq. (1). In principle, one can take six or more I-V data points and make them fit to Eq. (1) by a computer technique to get the device parameters. However, Eq. (1) represents a one-dimensional lumped approximation model while the distributed parameters in a real device may have considerable anisotropy. If the device does not submit to this model it may not be possible to obtain the computer solution. This section describes how to obtain device parameters experimentally with reasonable accuracy by the I-V analysis.

First step in the I-V analysis deals with the determination of series and shunt resistances. The series resistance is determined from the measured dark and lighted I-V data in the high current segment ($V >$ .5 volts, $I \simeq I_{sc}$) where the diode current-voltage characteristics can be approximated by

$$I_d = I_{t1} = I_0 \left[e^{q(V_{t1} - I_d R_s)/nKT} - 1 \right] \quad \text{in dark} \tag{5}$$

$$I_d = I_L - I_{t2} = I_0 \left[e^{q\{V_{t2} \quad (I_L - I_d) R_s\}/nKT} - 1 \right] \quad \text{under illumination} \tag{6}$$

where I_t and V_t are the terminal currents and voltages. For the same current (I_d flowing through the diode in the dark and the lighted conditions, Eq. (5) and (6) give

$$R_s = \frac{Vt_1 - Vt_2}{I_L}$$

$$\text{or } R_s\Big|_{I_d=I_L} = \frac{V_{t_1}\Big|_{I_d = I_L} - V_{oc}}{I_L} \tag{7}$$

Thus R_s can be obtained within reasonable accuracy by the knowledge of V_{oc}, I_L ($\simeq I_{sc}$) and a dark I-V data point at $I_d = I_L$. Even small values of series resistances, in the range of 0.5 to 1Ω for 1 cm^2 cell can result in approximately 5 to 10% reduction in the cell efficiency. The series resistance does not affect the open circuit voltage but it lowers the fill factor to hurt the cell performance. Large series resistances can lower the short circuit current below the photocurrent and can be easily seen as curvature in the high current segment (V> .5 volts) of the measured log I-V plot (Fig. 6). The series resistance becomes increasingly important at high currents, high intensities and high temperatures.

Unlike the series resistance large shunt resistance is desirable. The shunt resistance has to be very small, less than ≃ 1000Ω, in order to hurt the cell performance.[16] Such low shunt resistances can be observed as curvature in the low current segment (V< .4 volts) of the measured log I vs V plot (Fig. 6). If the shunt resistance is small enough to hurt the cell performance, then under reverse bias condition most of the current will flow through the shunt resistance ($I_{sh} >> I_{02}$) and R_{sh} can be determined within reasonable accuracy by[17]

$$R_{sh} = \frac{|V_R|}{I_R} \tag{8}$$

Curve 692231-A

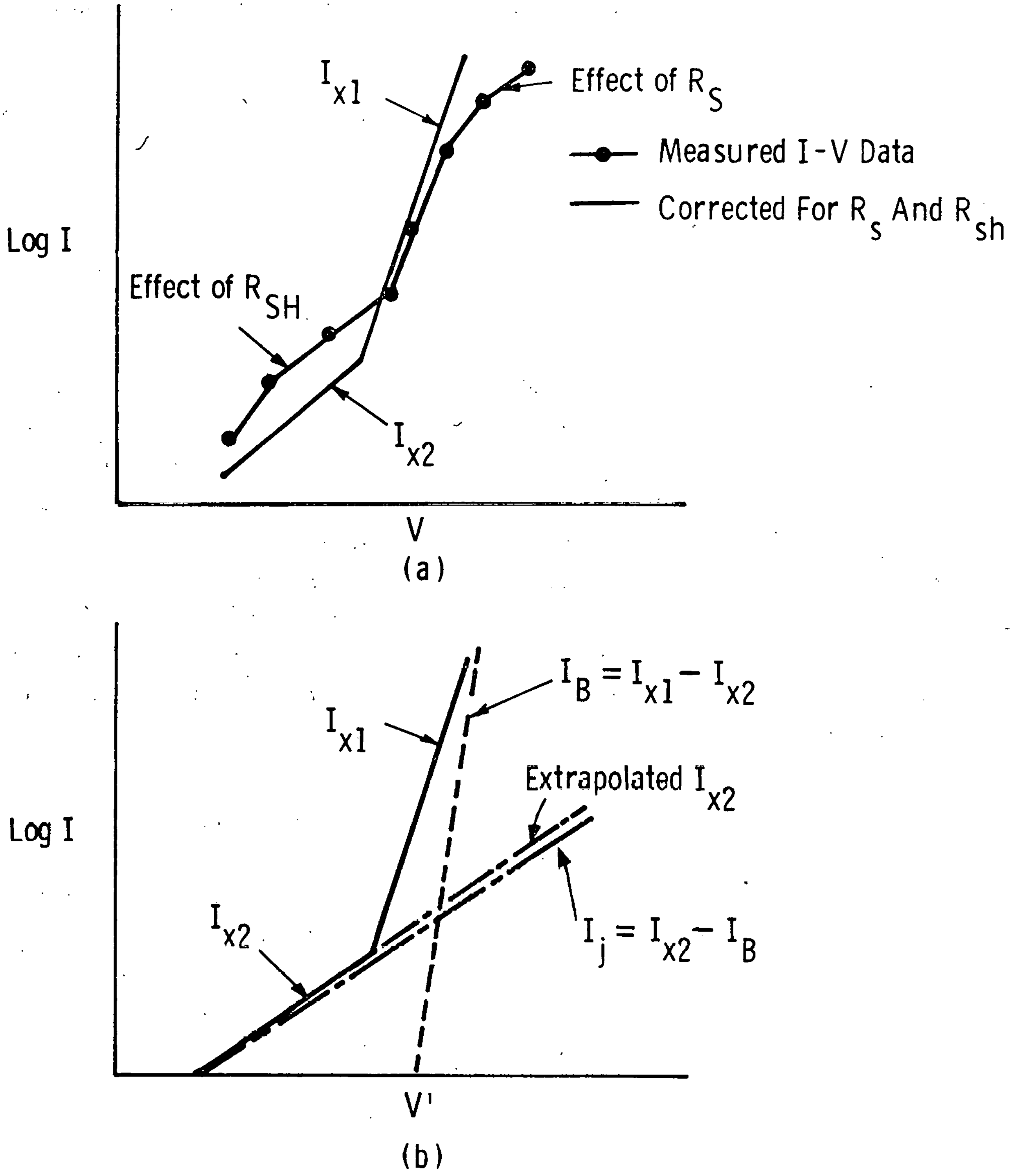


Fig. 6 Schematic diagram of the procedure to transform the measured dark I-V data into its constituents

If the shunt resistance is large ($R_{sh} \geq 20K$), then R_{sh} determined by the above method will not be as accurate because I_{02} may become appreciable component of the reverse current.

Once R_s and R_{sh} are known, then following transformations are made in Eq. (1) to remove their influence (see Figure 6).

$$V' = V - IR_s \tag{9}$$

$$I' = I - \frac{V - IR_s}{R_{sh}} \tag{10}$$

If the influence of R_s and R_{sh} is negligible, then the above transformation is not necessary.

The next step in the I-V analysis involves separating I_B and I_j, i.e., the response of the bulk and the junction region, respectively. This can be carried out exactly by computational methods; however, an acceptably accurate graphical method is illustrated in Figure 6b, where

$$I_B(V) - I_{x1}(V) - I_{x2}(V) \tag{11}$$

$$I_j(V) = I_{x2}(V) - I_B(V) \sim I_{x2} \tag{12}$$

The validity of this method depends on the fact that for most devices $I_j >> I_B$ when $V < .3$ volts as indicated in Eq. (12). Therefore, the parameters of I_j (I_{02} and n) can be determined in this voltage range ($V < \sim .3$) and Eq. (11) provides I_B. High I_j is undesirable because its value at the peak power point is the measure of the photo-current lost in the space charge region which lowers the cell voltage and the fill factor.

Once I_b has been separated from the measured I-V curve, I_{01} can be obtained from the intercept of log I_B at V = 0. For n+p junctions, I_{01} can be approximated by Eq. (13) to determine the lifetime

$$I_{01} = \frac{Aqn_i^2}{N_A} \sqrt{\frac{D_n}{\tau_n}} \tag{13}$$

The above approximation includes several assumptions stated earlier in the discussion of I_{01}. The doping concentration N_A in the base can be more accurately determined from the measured reverse-biased C-V characteristics.[18] Published data[19] can then be used to find the mobility (μ_p) and finally Einstein relationship $D = \frac{1}{\mu} \frac{KT}{q}$ can be used to determine the diffusivity D. Thus if I_B slides up, it indicates a decrease in the bulk lifetime and the upward movement of I_j suggests increased junction recombination, and vice versa. The transformed I-V plots will be used later in the discussion to describe the impurity effects qualitatively.

3.3.3 Impurity Analysis by Deep Level Transient Spectroscopy (DLTS)

Deep level transient spectroscopy provides a means to evaluate the type and concentration of electrically active contaminants present in silicon at levels well below the limits accessible by standard chemical methods such as those discussed in section 3.2. The method offers potential for assessing both silicon ingots and solar cells, as well as for observing changes in impurity activity due to processing. We outline below the manner in which DLTS measurements are made, analysis of the data, and procedures for specimen preparation; recent experimental results appear in section 4.

3.3.3.1 The DLTS Technique

The DLTS measurements were performed with the help of a double-boxcar integrator. In most cases a 100 μsec pulse ranging from 8 volts reverse bias to 2 volts forward bias was used to fill the minority and the majority traps in the reverse biased depletion region. When the minority and the majority trap peaks showed a considerable overlap, only a reverse bias pulse (-8 to -2 volts) was used to study the majority traps. At the end of each pulse a capacitance transient is observed as the filled traps begin to empty by thermal emission. The sample was pulsed continuously while being heated from liquid N_2 temperature to 50°C at a rate of 1°C/sec. Due to the heating the time constant of the capacitance transient and the emission rate ($e={}^{1}/\tau$) changes monotonically. The double boxcar integrator processes the capacitance transient to give an output which corresponds to the average difference of the capacitance amplitude at sampling times t_1 and t_2. The boxcar output achieves a maximum when the time constant of the capacitance transient, which is changing continuously with the temperature, passes through the rate window (t_2-t_1). Changing the rate window shifts the peak to a different temperature, Figure 7. The rate window was varied by changing the boxcar time base t_B from 0.5 to 100 m secs and setting the gate delays t_1 and t_2 at 10% and 90% of the time base. Thus $t_1 = 0.1\ t_B$ and $t_2 = 0.9\ t_B$.

3.3.3.2 Analysis of the DLTS Data

Figure 7 shows a typical DLTS output for a majority trap obtained from the sample P-Ti-008 (P indicates p-type, N represents n-base material in this discussion). Minority traps exhibit inverted peaks above the zero level. The DLTS data was analyzed using Lang's approach[20] in which the capacitance transient is assumed to be exponential

$$C(t) = \Delta C(o)\ \bar{e}^{\ t/\tau} \qquad (14)$$

where $\Delta C(o)$ is the capacitance change due to pulse at $t = 0$, and the normalized DLTS output signal at any temperature is given by

$$S(T) = \frac{C(t_1)-C(t_2)}{\Delta C(o)} \qquad (15)$$

The time constant at the peak temperature is determined by solving for the following condition

$$\frac{d\ S(T)}{d\tau} = 0 \qquad (16)$$

Curve 695415-A

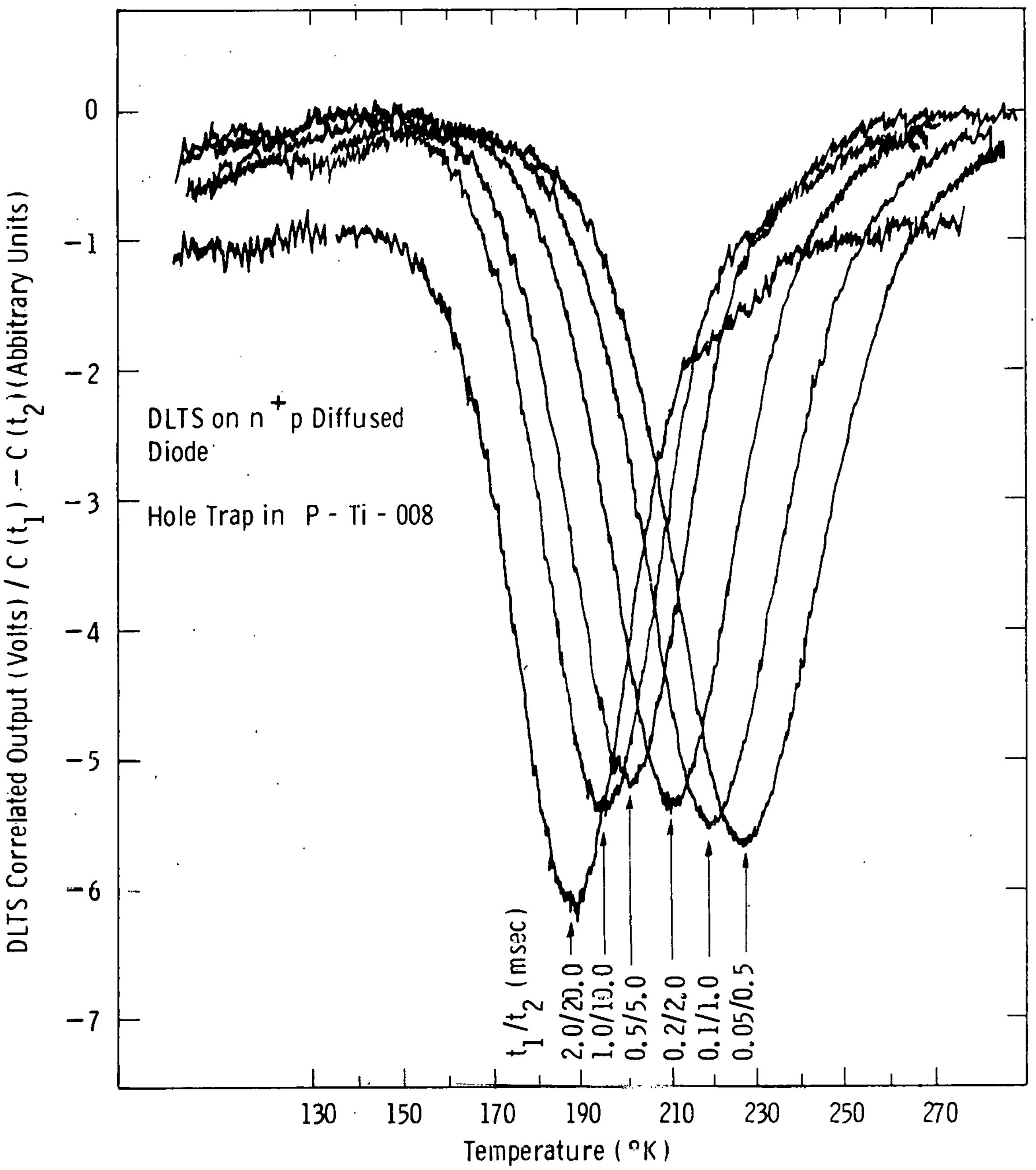


Fig. 7 Typical Experimental DLTS Spectra for Hole Trap in p-type Silicon with Ti Impurity.

which gives $\tau_{max} = (t_1 - t_2)\ (\ln {}^{t_1}/t_2)^{-1}$ (17)

The emission rate (e) at the peak temperature is obtained from

$$e = \frac{1}{\tau_{max}} = \frac{1}{(t_1 - t_2)\ (\ln t_2/t_2)}^{-1} \qquad (18)$$

since $t_1 = 0.1\ t_B$ and $t_2 = 0.9\ t_B$

$$e = {}^{2.75}/t_B$$

Thus each peak gives an emission rate at the peak temperature. The emission rate, in general, is given by

$$e = \frac{\sigma V_{th} N_c}{g} \exp\ (-{}^{E/}kT) \qquad (19)$$

where σ is the capture cross section of the trap, V is the thermal velocity, N_c is the density of the states in the band to which the thermal emission takes place, g is the degeneracy of the trap level, E is the energy level of the trap with respect to the band edge to which thermal emission occurs, k is the boltzman constant and T is the absolute temperature. Using the following expressions

$$V = (3kt/m^*)^{1/2} \qquad (20)$$

$$N_c = 2M \left(\frac{2\pi m^* kT}{h^2}\right)^{3/2} \qquad (21)$$

the appropriate values of the parameters for Si, and assuming g = 1 leads to

$$e = C\ \sigma\ T^2 \exp\ (-E/kT) \qquad (22)$$

where $C = 6.4 \times 10^{25}$ for the conduction band

and $C = 1.0 \times 10^{25}$ for the valence band

Assuming the capture cross section to be temperature independent one gets

$$e = C\,\sigma_o\,T^2 \exp(-E/kT) \tag{23}$$

or

$$\ln\left(\frac{e}{T^2}\right) = \ln C + \ln\sigma_o - E/kT \tag{24}$$

Thus the energy level can be obtained from the slope of ln $(^e/T^2)$ vs $^1/T$ and the intercept gives the cross section. It is important to recognize that this is only a very approximate method of getting the capture cross section. Miller et. al[21] pointed out that capture cross section can have sharp temperature dependence and then this method may give more than an order of magnitude higher values. The electric field in the depletion layer also may affect the capture cross section.

Figure 8 shows the ln $(^e/T^2)$ plot for titanium and vanadium hole traps. When Arrhenius plots are made they are scaled to the conventional plotting variables $y = \ln\left(\frac{300^2}{T}\right) \cdot e$ and $x = 1000/T$. A computer program calculated these variables from the input data and then plotted them as shown in the figure. The program also finds the slope (B) and intercept (A) for the best linear fit to give the energy level and the cross section (σ_o). The confidence limits for the estimated energy and the cross section are calculated from

$$s = \frac{\Sigma\,(Y-A\ BX)^2}{N-2} \tag{25}$$

where N is the number of data points. the error limits for the energy are

$$\Delta E = \frac{s\ t\ (N-2,\ 1-L)}{(\Sigma\,(x-Xm)^2)^{1/2}} \tag{26}$$

Curve 695416-A

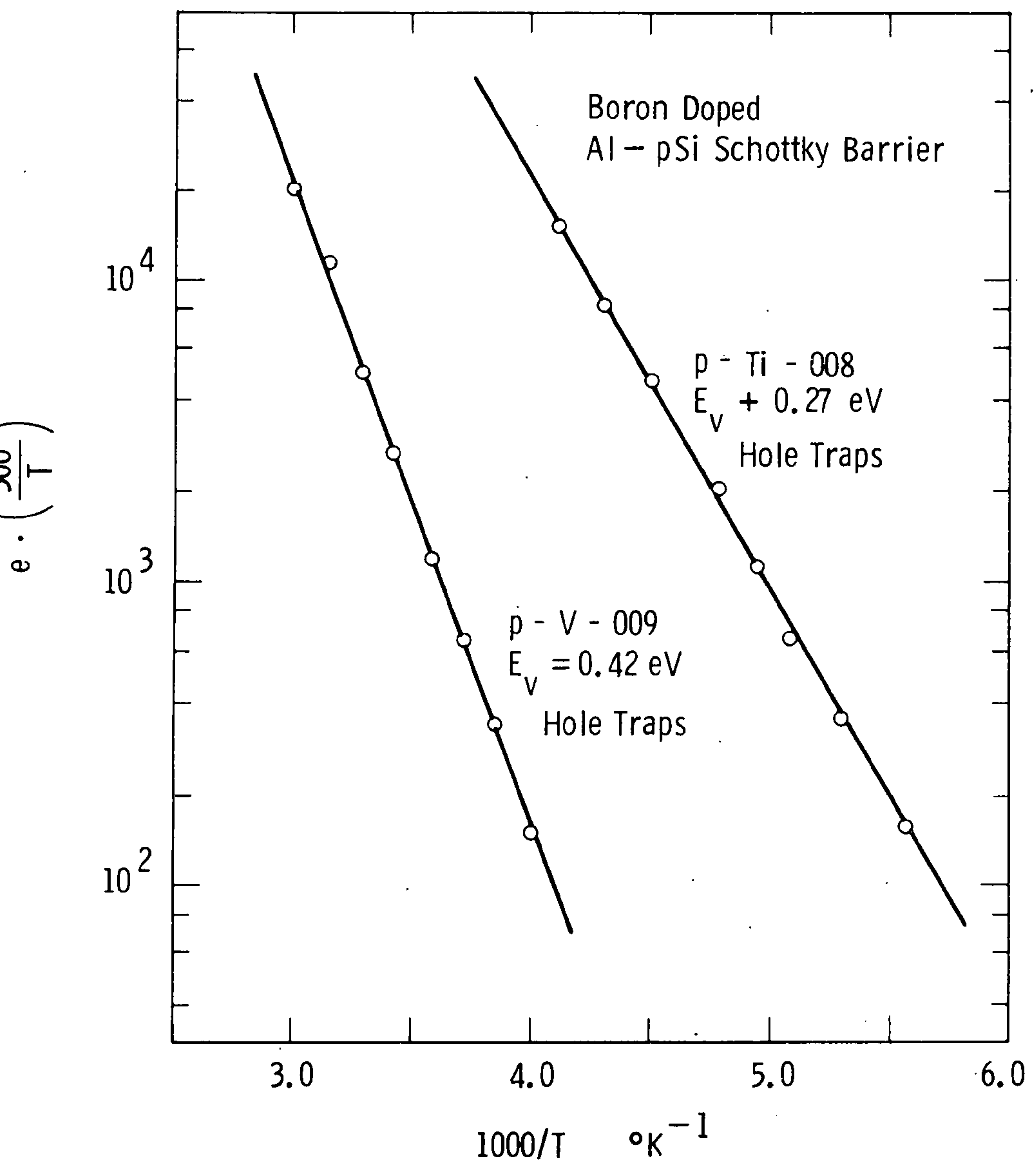


Figure 8 Arrhenius plot of trap levels in p-type silicon containing Ti or V.

where t is the distribution parameter for N-2 degrees of freedom and fractional error L and X_m is the mean value of x.

The trap density was found by increasing the pulse width until no change in the peak amplitude was detected, indicating the saturation of the trap. The trap density is then

$$N_T \simeq 2 \frac{\Delta C(o)}{C} (N_D - N_A) \tag{27}$$

where N_T is the trap density

C is the junction capacitance at the reverse bias

$N_D - N_A$ is the net doping density $\simeq 5 \times 10^{15}$ cm^{-3}

$$\Delta C(o) = \frac{C(t_1) - C(t_2)}{S(T)} = \frac{\text{Peak amplitude in capacitance units}}{e^{-t_1/\tau_{max}}\ e^{-t2/\tau_{max}}}$$

since $t_1 = 0.1\ t_B$, $t_2 = 0.9\ t_B$ and $\tau_{max} = \frac{t_B}{2.75}$

$$\Delta C(o) = 1.48(\text{Peak Amplitude})$$

3.3.3.3 Sample Preparation

For DLTS measurements sample devices should have sufficiently low capacitance to permit balancing the measurement bridge. The device also should have relatively low surface leakage current. Because the 1x1 cm solar cells we have used to study impurity effects exhibit too **great** a capacitance and leakage current ($I_{sh}|_{V} = 8$ volts $\gtrsim 100\ \mu A$) to facilitate DLTS, small areas were mesa etched from the original solar cells for the measurements. The front metal contact (Ti-Pd-Ag-grid) was removed while the back contact was retained. Ti-Au was then evaporated on the front surface. (Electron beam evaporation was used first to evaporate 300 A° Ti and then 20000 A° Au on top of it) Thirty mil dots were mesa etched using the photoresist technique. The smaller junction obtained had a leakage current of the order of 10-100 ηA at approximately

8 volts reverse bias. A set of three 30 mil dots was scribed from each cell and mounted on a TO5 header, as shown in Fig. 9. Sapphire was used to isolate the sample from the header. The measurements were then conducted as noted above.

3.4 Solar Cell Measurements

3.4.1 Cell Fabrication

Solar cells were fabricated by a conventional process. The precleaned wafers were phosphorus diffused at 850°C for 50 minutes for n+p cells and p+n cells were boron diffused at 875°C for 30 minutes. This resulted in a junction depth of 0.35μm for both n and p-base cells. The corresponding sheet resistances were 60 and 90 ohms/square. The cells with an area of 1.03 cm^2 were mesa-etched and metallized with Ti-Pd-Ag using an electron beam system. The front pattern was a five-finger grid with 5.4% area coverage.

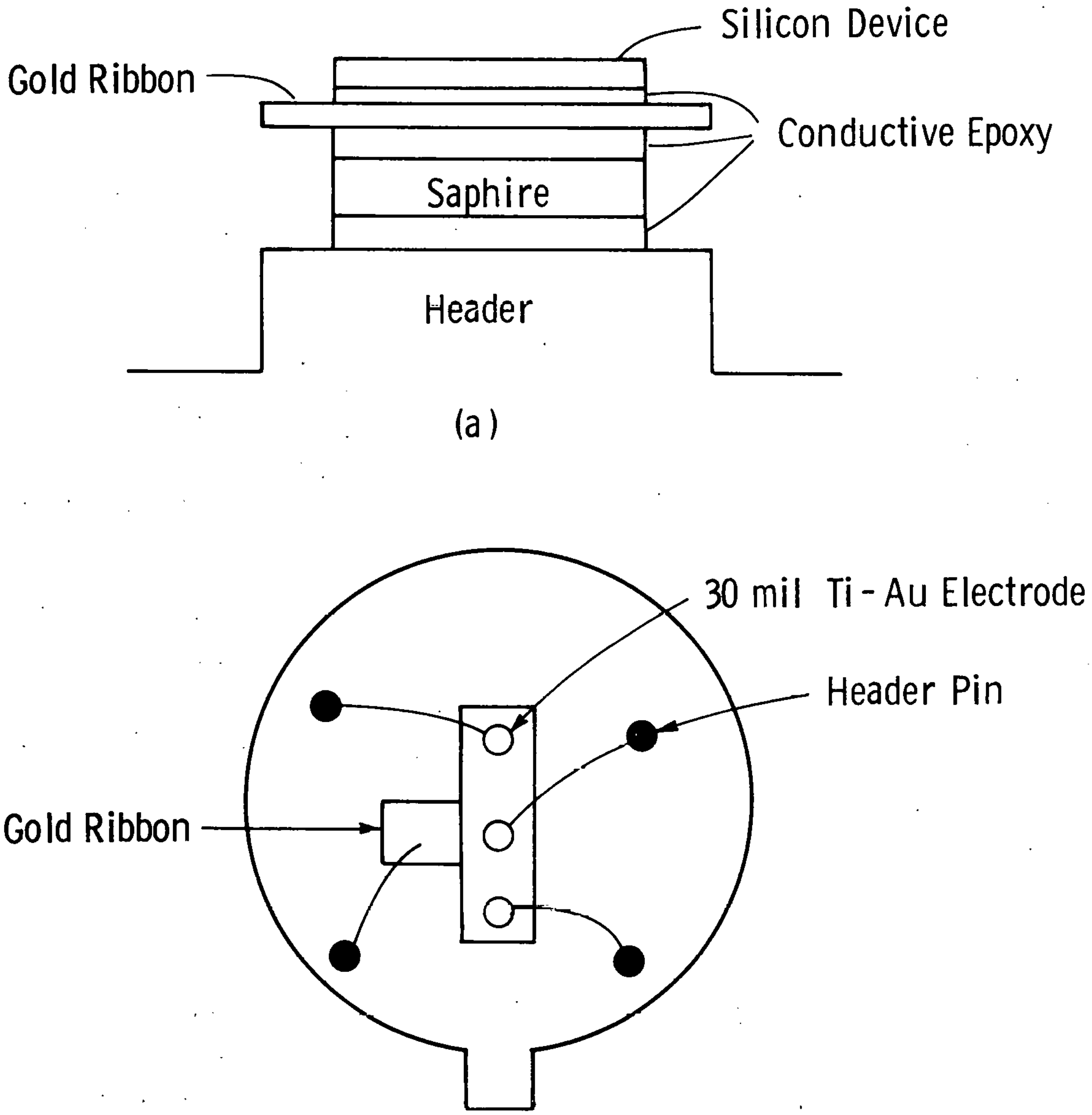
Contacts were sintered at 550°C for 15 minutes in hydrogen. The average efficiency of base-line cells (no added impurities) was about 10% without anti-reflection coatings. With coatings the average efficiency was 14.1%. The usual experimental run consists of 15 to 25 wafers from the metal-doped ingots along with 5 to 8 uncontaminated baseline wafers.

3.4.2 Solar Cell Characterization

Current-voltage measurements were made under illumination from a quartz-iodine (ELH) simulator. The light level was set at 91.6mW/cm^2 for the AM1 spectrum based on the calibration of a NASA standard cell. The lighted I-V data was obtained digitally and stored in a computer data base. A number of data reduction programs were used to examine various cell properties. The primary method of analysis was based on the single-exponential model:

$$I = I_{sc} - I_o' \left[\exp((V + IRs)/nV_T) - 1\right] \qquad (28)$$

Dwg. 6435A40



(b) — Top View of the TO5 Header

Figure 9 Schematic diagram of the sample arrangement used for DLTS measurements.

where V_T is the thermal voltage. The fit gives the parameters I_o', Rs and n. The peak power point (I_p) was determined by solution of the following condition:

$$dP/dI = I(dV/dI) + V = 0 \qquad (29)$$

V_p is obtained from Eq. (28) and the cell efficiency was then determined by:

$$Eff = (V_p x I_p x 100)/(91.6 x A_o) \qquad (30)$$

where A_o is the total area of the cell. The curve fill factor, (FF), is given by:

$$FF = EFF/(V_{oc} I_{sc}) \qquad (31)$$

4.0 ANALYSIS OF IMPURITY EFFECTS IN SILICON AND SILICON SOLAR CELLS

4.1 Ingot Characteristics

4.1.1 Resistivity

No problems were encountered in meeting resistivity requirements called for in the impurity matrix except in a few instances where relatively large resistivities (6-9 ohm cm) were observed. We attributed this to interaction between the boron dopant and transition metal dopants. Ingots W-080, W092, W*-116 and W-118 were p-type material compensated with deliberate phosphorus additions. This produced significantly higher resistivities than normally observed for the boron concentrations present. Yield of this material was limited due to the differences in segregation coefficients of boron and phosphorus. Resistivity data for all ingots grown during Phases I and II are compiled in Appendix 2.

4.1.2 Microstructural Features and Impurity Characteristics

Structural breakdown due to constitutional supercooling is a characteristic of all ingots grown from heavily doped melts. This breakdown, evidenced by the appearance of a feathered pattern on the crystal surface and impurity inclusions in the interior of the ingot,[1] occurs at melt impurity concentration in the range of $2x10^{20}$ atoms cm^{-3} to $5x10^{20}$ atoms cm^{-3} for ingot diameters of approximately 4 cm and growth rates of from 7 cm hr^{-1} to 9 cm hr^{-1}. At higher growth rates the onset of breakdown occurred at lower impurity concentrations as would be expected from theory.[7] In addition to the phenomena of breakdown, below are listed by element other problems encountered during Czochralski pulling.

Aluminum	Maximum concentration limited due to acceptor characteristic
Boron	No problem

Calcium	Volatile-nearly complete loss from melt when elemental form used
Carbon	No problem - maximum concentration limited by solid solubility of approximately 10 ppma
Chromium	At high melt concentrations (3x10^{20} atoms cm^{-3}) particles form on the melt resulting in ingot twinning
Copper	No problem - maximum concentration limited by solid solubility
Iron	No problem
Magnesium	Volatile - significant loss of material from melt. Mg vapor highly flammable presenting exhaust handling problem
Manganese	No problem
Molybdenum	No problem-small segreagation coefficient limits ingot impurity concentration
Nickel	No problem - fraction of nickel found to be lost from early melts using Ni powder dopant
Oxygen	Level established by dissolution of quartz crucible
Phosphorus	No problem-concentration in p-type ingots limited by compensation effect
Sodium	Highly volatile-impossible to retain in melt to achieve measurable quantity in ingot
Titanium	No problem-small segregation coefficient limits ingot concentration
Tantalum	No problem-small segregation coefficient limits ingot concentration
Vanadium	No problem-small segregation coefficient limits ingot concentration
Zinc	Highly volatile-toxic zinc vapor evolved from melt poses health hazard
Zirconium	No problem-small segregation coefficient limits ingot concentration

In Appendix 2 are the etch pit densities obtained on seed and tang end slices. In many instances, structural breakdown occurred near the end of the ingot; this was reflected by the presence of lineage in the tang slices. Solar cell blanks had etch pit densities comparable to seed end values. No particular emphasis was placed on growing dislocation free ingots; however, approximately 30 percent of the ingots prepared were dislocation free in the seed region. We have found no affect on solar cell characteristics attributable to variations in defect structure over the range of etch pit densities encountered.

Polycrystalline structure was purposely induced in three ingots by seeding the crystal from a polycrystalline seed. The structure of this material is considered along with other analytical results in section 4.3.

4.1.3 Carbon and Oxygen Content

Normal carbon and oxygen concentrations found in Czochralski grown material are in the range of $2.5\text{x}10^{16}$ atoms cm^{-3} to $5\text{x}10^{17}$ atoms cm^{-3} for carbon and $50\text{x}10^{16}$ atoms cm^{-3} to $150\text{x}10^{16}$ atoms cm^{-3} for oxygen. No significant variations from these values were observed except for the higher carbon values in purposely doped ingots. Carbon and oxygen in the float zone ingots were below the limits of detection. Carbon and oxygen contents for all odd-numbered ingots are tabulated in Appendix 3.

4.1.4 Metal Impurity Content of Silicon Ingots

Fundamental to the success of the program was the reasonably accurate determination of the impurity concentration in each ingot. Samples from all ingots were analyzed by spark source mass spectroscopy and selected samples were subjected to neutron activation analysis.* The results have been reported on a regular basis in quarterly progress reports and only new data or data considered to be of particular interest is discussed here.

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* Neutron activation analysis was performed at General Activation Analysis, San Diego CA, and Kraffwerk Union A.G., Erlangen, FDR

The measured concentrations of the intentionally added impurities are compiled in Appendix 4. The target concentration is derived by multiplying the melt concentration (based on atoms of melt and atoms of impurity element added) times the effective segregation coefficient (Appendix 1). The target values shown in Appendix 4 have been updated to reflect the best available values of K_{eff}. The calculated concentrations represent the product of measured melt concentration corrected for the amount of melt solidified and the effective segregation coefficient. Measured concentrations are averaged SSMS data; the figures in parenthesis are NAA data. The N/A entries indicate that no impurity, save the desired donor or acceptor, was added to the ingot.

4.1.4.1 Data Evaluation

In general, good agreement exists between target and calculated concentrations. Target differences occur for the impurities calcium, magnesium, sodium, and zinc which are volatilized from the melt. The discrepancy in nickel concentration for ingot W-006 was caused by a loss of nickel powder used as a dopant during furnace evacuation.

A calculated value within ± 60 percent of the targeted value was considered sufficient to insure that the melt was properly doped. Usually the agreement was considerably better than this.

The measured values in Appendix 4 are either single measurements or the average of several determinations. Some effort also was expended to provide assurance that unintentionally added impurities were not present in doped and undoped ingots. The sensitivity of the SSMS measurements is inadequate to detect the majority of potential contaminants below the concentration of approximately 1.5×10^{14} atoms cm^{-3}, so NAA, was used to examine 18 selected samples. Typical concentrations of unintentionally-added impurities are given in Table 5. All detected impurity concentrations are well below concentrations which would have any impact on solar cell performance.

It may be noted from the Appendix that the concentration of impurities in a number of the ingots is below the limit of detection of the measurement method. In these instances, the measured concentration

Table 5 Concentrations of Unintentionally-Added Impurities

Impurity	Concentration Atoms/cm^3	(ppba)
Antimony	1.3×10^{11}	(0.0026)
Arsenic	7×10^{12}	(0.14)
Cr	2×10^{12}	(0.04)
Cu	5×10^{12}	(0.1)
Gold	$\sim 1 \times 10^{9}$	(.00002)
Iron	$<5 \times 10^{13}$ *	(<1)
Nickel	$<5 \times 10^{12}$	(<0.1)
Titanium	$<8 \times 10^{13}$	(<1.6)
Zirconium	$<3 \times 10^{13}$	(<0.6)

*Iron was detected at concentrations of 1×10^{14} - 1.7×10^{14} atoms/cm^3 in ingots heavily doped with nickel.

is shown to be less than the limit of detection. Two of the impurities, tantalum and zirconium, have not yet been detected; molybdenum was detected in only one ingot. For the above reasons, it is difficult to establish the accuracy of the primary measurement techniques for each impurity element. Where sufficient data exists an assessment has been made of both SSMS and NAA as a measurement tool. The SSMS data are analyzed in Table 6, which shows the mean value, the number of measurements made as well as the standard deviation. For certain impurities, the highest achievable concentration is near the detection limit; this produces a large standard deviation, e.g magnesium and vanadium. Results obtained by NAA exhibit much less variability although data for fewer elements are available, Table 7. NAA data has been found to consistently provide an accuracy of ± 30 percent.

As noted zirconium has not yet been detected so all target and calculated zirconium concentrations shown in Appendix 4 represent upper limits. Neither zinc, sodium, nor calcium have been detected since they evaporated from the melt. Aluminum is found by both SSMS and resistivity measurements since it is electrically active at room temperature. A higher aluminum concentration by as much as ten times, is measured by SSMS than by electrical measurements.[1] Since molybdenum was detected in one ingot all calculated concentration values are based on this analysis.

A limited number of tang end slices also were analyzed. If the samples were taken from a region of good crystal structure, i.e, well in advance of apparent structural breakdown, agreement with seed end measurements was excellent. Tang end concentrations were always greater by from 25 percent to approximately 45 percent depending on the exact location of the sample and the melt volume consumed. However the closer the slices lie to the region where structural breakdown occurs, the nearer is the impurity concentration to that of the melt. Changes in concentration of 4 to 5 orders of magnitude within a few centimeters are common. Thus great care must be taken when employing data gathered from tang end material.

Table 6 Analysis of Spark Source Mass Spectrographic Data

Impurity	SSMS Mean/# of Measurements (ppba)	SSMS Standard Deviation (ppba)
Cr	26/13	10
Cu	32/19	19
Fe	ND	--
Mg	11/3	7.8
Mn	29/6	16
Ni	64/10	19
Ti	8.5/6	1.6
V	8.8/5	6.2
Zr	ND	--
M/e = 90	11.6/∿100	6.3

Table 7 Analysis of NAA Data

Ingot #	Impurity	Target Conc. x 10^{15} atoms/cm^3	Measured Conc. x 10^{15} atoms/cm^3
W-016	Fe	1.0	1.0
W-018	Fe	2.0	2.0
W-045	Fe	0.66	0.64
	Cr	0.5	0.26
N-061	Cr	1.1	1.1
W-064	Mn	1.0	0.61
W-067	Cr	0.44	0.25
	Mn	0.50	0.66
W-068	Cr	1.0	0.44
W-069	Fe	0.98	1.1
W-083	Fe	1.0	1.0
W-089	Cu	2.3	2.5
W-090	Mn	0.7	0.69
W-093	Mn	0.66	0.77
W-094	Mn	0.9	1.07
W-096	Mn	0.63	0.62
W-100	Cu	1.0	1.31

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* Neutron Activation Analysis performed at Kraftwerk Union A.G. and General Activation Analysis

4.1.4.2 Best Estimates of Impurity Concentrations

Table 8 contains our best estimate of the impurity concentration characteristic of each ingot supplied. The estimated value is based on the current total data available for each ingot. Also incorporated into the estimate is the degree of reliability in the effective segregation coefficients. It is this best estimated value which is used in all analyses drawn throughout the rest of the report. For many ingots the impurity concentrations were sufficiently low that no direct measurement was possible. In these cases either no value is shown in the table or the upper limit is quoted. Bearing in mind the stated cautions relating to the detectability of some elements and that our data base will be improved as more measurements are made, we have attempted to ascertain the degree of uncertainty in the concentration values compiled in Table 8. We also assume that k_{eff} is concentration independent (which appears reasonable in view of the solar cell data described later). The estimated percentage uncertainties are as follows:

Al ± 30 ;
B ± 15
C ± 50
Ca + 50, -100
Cu ± 40
Cr ± 40
Fe ± 40
Mg + 50,-100
Mn ± 30
Mo ± 90
Ni ± 50
Ph ± 15
Ta + 50,-100
Ti ± 50
V ± 50
Zn + 50,-100
Zr + 50,-100

For some cases the uncertainty is larger than desireable but still probably within the bounds needed to identify the utility of a solar grade silicon. Extensive use of NAA would considerably improve the situation for impurities like Mo, Ta, Ti, V, Zr and Ni.

Table 8 Best Estimate of Impurity Concentrations

Ingot Identification	Best Estimate of Impurity Conc. (10^{15} atoms/cm^3)
W-001-00-000	--
W-002-00-000	--
W-003-00-000	--
W-004-Cr-001	1.0
W-005-Mn-001	1.3
W-006-Ni-001	0.5
W-007-Cu-001	1.7
W-008-Ti-001	0.20
W-009-V-001	0.4
W-010-Ni-002	4.0
W-011-Zr-001	<0.0007
W-012-Cr-002	0.2
W-013-Mn-002	0.25
W-014-00-000	--
W-015-Zn-001	<0.001
W-016-Fe-001	0.9
W-017-Cu-002	19
W-018-Fe-002	1.7
W-019-Cu-003	0.4
W-020-00-000	--
W-021-Mg-001	0.003
W-022-00-000	--
W-023-00-000	--
W-024-Mg-002	0.032
W-025-00-000	--
W-026 Mn-003	0.012
W-027-Mn/Cu-001	1.3/1.7
W-028-Al-001	26
W-029-Cr-003	0.012
W-030 Cr/Cu-001	1/1.7

TABLE 8 (cont.)

Ingot Identification	Best Estimate of Impurity Conc. (10^{15} atoms/cm^3)
W-031-Cr/Mn-001	1.0/1.3
W-032-Mg-003	0.32
W-033-Ti-002	0.0020
W-034-00-000	--
W-035-V-002	0.004
W-036-Zr-002	<0.0014
W-037-Zr/Ti-001	<0.0007/0.22
W-038-Al-002	60
W-039-Ni-003	8
W-040-Cr/Ni-001	0.8/2.4
W-041-Ni/Cr/Cu-001	2.1/0.8/1.7
W-042-Ti-003	0.04
W-043-Fe/Ti-001	0.56/0.033
W-044-Fe-003	0.017
W-045-Cr/Fe/Ti-001	0.65/0.43/0.039
W-046-Fe/V-001	0.57/0.07
W-047-Cu/Ni/Zr-001	1.7/1.0/<0.00021
W-048-Ti-004	0.0002
W-049-V-003	0.0004
W-050-Ti/V-001	0.0002 /0.0004
W-051-Cu/Ti-001	1.7 / 0.20
W-052-Ni-004	4.5
W-053-Poly	--
W-054-00-000	--
W-055-Cu-004	0.05
W-056-Cu-005	65
W-057-00-000	--
W-058-00-000	--
W-059-00-000	--
W-060 00-000	--
W-061-Cr/Ti-001	1.0/0.011
W-062-N/Cu-001	2.5
W-063-N/Cr-001	0.8
W-064-N/Mn-001	1.0

TABLE 8 (Cont.)

Ingot Identification	Best Estimate of Impurity Conc. (10^{15} atoms/cm^3)
W-065-N/Ti-001	0.20
W-066-Ti-005	0.033
W-067-Cr/Mn/Ti-001	0.4 0.5 0.0033
W-068-Cr-004	1.0
W-069-Fe-004	1.0
W-070-Al-003	50
W-071-00-000	--
W-072-Cr-005	0.4
W-073-Cr/Mn/Ni/Ti/V-001	0.4 0.4 2.0 0.0024 0.004
W-074-Cr/Mn/Ni/Ti/V-002	0.08 0.08 0.5 0.00033 0.0006
W-075-Ti/V-002	0.056 0.1
W-076-Poly-2	--
W-077-Mo-001	0.0042
W-078-00-000	--
W-079-00-000	--
W-080-Ph-001	0.7
W-081-N/Ni-001	1.7
W-082-N/V-001	0.4
W-083-N/Fe-001	1
W-084-N/Al-001	50
W-085-N/Zr-001	< 0.0007
W-086-C-001	200-400
W-087-Ca-001	?
W*-088-Cr-001	0.5
W*-089-Cu-001	2.0

TABLE 8 (Cont.)

Ingot Identification	Best Estimate of Impurity Conc. (10^{15} atoms/cm^3)
W*090-Mn-001	0.7
W-091-Cr/Mn-002	0.5/0.3
W-092-Ph-002	28
W-093-Mn-004	0.66
W-094-Mn-005/Poly	0.9
W-095-Mn-006(F)	1.0
W-096-Mn-007(S)	0.63
W-097-00-000	--
W-098-Mo-002	0.00092
W-099-FZ-001	--
W-100-Cu/Ti-002	1.0/0.033
W-101-FZ-002	--
W-102-Ti-006/Poly	0.11
W*-103-Ti-001	0.167
W-104-Cu/Ti-003	2.0/0.14
W*105-V-001	0.4
W-106-N/Al-002	10
W-107-FZ/Al-001	30
W-108-N/V-002	0.08
W-109-C-002	<20-140
W*-110-Fe-001	0.8
W-111-Cu/V-001	2.5/0.3
W-112-Ta-001	<0.004
W-113-FZ/Cr-001	0.8
W-114-00-200	--
W-115-N/Cu-002	10
W*-116-Ph-001	100
W-117-00-000	--
W-118-Ph-003	140
W-119-N/Fe-002	0.3
W-120-N/Cr-002	0.3
W-121-N/Ti-002	0.039

TABLE 8 (Cont.)

Ingot Identification	Best Estimate of Impurity Conc. (10^{15} atoms/cm^3)
W-122-Ti-007 (F)	0.084
W-123-Ti-008 (S)	0.105
W-124-Mo-003	0.000018
W-125-Mo-004	0.0003
W-126-Multi-001	See Data Sheet
W-127-FZ/Ti-001	0.039
W-128-Ta-002	< 0.0008

* Low resistivity p-type ingot identification.

4.2 Processing Studies

The degree of electrical activity of impurities in silicon-and hence device properties-is a function of the thermal history of the material. The purpose of the studies described here was to examine the effect of sequences of heat treatment and gettering cycles as well as growth history on the properties of silicon infused with controlled amounts of impurities. In this context we used recombination lifetime measurements to track the effects of processing. This information can then be used to design process sequences which minimize the harmful aspects of these contaminants on solar cell performance.

4.2.1 Thermal Treatment

Mitigation of impurity effects requires removal of the impurities themselves or a reduction of their electrical activity. In either case some motion of the impurity atoms is necessary with practical rates being acheivable only at elevated temperatures. Studies such as these are complicated by the potential presence of surface contamination. Such impurities can diffuse from the surface into the silicon lattice during high temperature cycles may diminish or mask any expected improvement in lifetime due to the treatment. The magnitude of the effect would increase as the wafer thickness decreased. For this reason some discussion of the problem is warranted here.

4.2.1.1 Cleaning Studies

Bulk impurity levels as low as $1x10^{12}$ cm^{-3} can severely reduce recombination lifetime.[1] The number of impurity atoms, N_i necessary to effect a wafer of thickness, h can be expressed.

$$N_i = 1x10^{12}\ h\ \ cm^{-2} \tag{32}$$

Silicon contains $5x10^{22}$ atoms/cm^3, or $1.37x10^{15}$ atoms/cm^2 per monolayer. Assuming a similar packing density for contaminants; the number of impurity monolayers, N_m necessary to effect lifetime would be

$$N_m = \frac{1x10^{12}\ h}{2(1.37x10^{15})} = 3.65x10^{-4}\ h \tag{33}$$

The factor 2 being necessary to account for both surfaces of a wafer. A silicon wafer 0.0254 cm (10 mils) thick thus requires only 9.3×10^{-6} of a monolayer of contamination prior to heat treatment to provide the potential for reduced lifetime. Fortunately, most contamination is organic in nature and is either evaporated or is ashed during thermal processing.

Practical experience (e.g,reference 22) indicates that there is difficulty in preserving recombination lifetime during high temperature diffusions, and control of this degradation is requisite prior to studying methods for mitigating bulk impurity effects. Thus we initiated a study similar to that performed by Yang et. al.[23] except that recombination lifetime was used as the evaluation method. Thick silicon specimens were used to minimize contamination (viz, Equation 32) and to maximize the accuracy of lifetime measurements.[12,13] The lifetime of each sample was measured before and after the short anneal cycle. An updated summary of the results of these experiments is provided in Table 9. The specimens were sawn extra thick and etched to 0.115 ± .001 cm (45-46 mils) to minimize higher mode errors in PCD measurements.[13] Samples A and B were from a second boron doped ingot with 4 Ω cm resistivity. These samples were sawn following the heat treatment to determine whether the lifetime was adversely effected by propagation of saw damage during the annealing cycle. The initial lifetimes listed for these samples is that typical of 4 Ω cm ingots we have studied previously since PCD measurements cannot be performed without saw preparation. Comparing the data for samples A and B, with that from samples 19 and 20, we concluded that some saw damage does propagate during the anneal cycle but that this is a lesser factor contributing to lifetime degradation. A significant increase in sample lifetime was noted whenever HCℓ was added to the furnace atmosphere. Sample 21a was processed in oxygen, but the furnace was precleaned with HCℓ to determine whether the lifetime improvement stemmed from furnace decontamination or silicon surface cleaning. The data indicated that most of the improvement was obtained for HCℓ etching/cleaning of the silicon surface not furnace cleanup. The results of the experiments on sample 21b corroborated the initial postulate that sample contamination, not thermal damage, is responsible for the degradation of lifetime.

TABLE 9

Retention of Recombination Lifetime
Anneal 15 Min. at 1000°C
Cooling Rate, dT/dt = 1°C/Min.

SAMPLE	WAFER CLEANING PROCEDURE (1)	FURNACE ATMOSPHERE	τ_r (μsec) INITIAL	τ_f (μsec) FINAL	τ_f / τ_i	COMMENTS
14	Clean 1	N_2	52.8	0.45	0.009	
17	Clean 2	N_2	52.1	1.7	0.033	
18	Clean 3	O_2	52.6	2.6	0.049	
19	Clean 3	95% O_2 + 5% HCL	52.6	6.9	0.131	Note 2
20(3)	Clean 3	95% O_2 + 5% HCL	52.3	9.0	0.172	Note 2
A	Clean 3	95% O_2 + 5% HCL	62.7(7)	4.9	0.078	
B	Clean 3	95% O_2 + 5% HCL	62.7(7)	10.4	0.166	
21a	Clean 3	O_2	52.1	5.9	0.113	Note 4
21b	-	See Note 5	52.1	13.5	0.259	
22	Clean 3	95% O_2 + 5% HCL	52.1	18.8	0.361	Notes 2 and 6
23	Clean 4	95% O_2 + 5% HCL	52.0	9.3	0.179	Note 2
24	Clean 5	95% O_2 + 5% HCL	51.5	6.6	0.128	Note 2
25	Clean 6	95% O_2 + 5% HCL	58.4	6.7	0.115	Note 2
26	Clean 3	95% O_2 + 5% HCL	52.3	8.35	0.160	Notes 2, 8, and 11
27	Clean 3	95% O_2 + 5% HCL	52.3	8.19	0.157	Notes 2, 9, and 11
1B	Clean 3	95% O_2 + 5% HCL	52.8	5.14	0.097	Notes 2, 10, and 11

1. Procedure details in Appendix 5.
2. Furnace precleaned 3 hrs. with 95% O_2 + 5% HCL.
3. Edge of specimen etched 2-3 mils to remove saw damage.
4. Furnace precleaned 3 hours @ 1200°C with 95% O_2 + 5% HCL.
5. 21 a gettered 45 min. $POCl_3$ @ 950°C.
6. DI Rinse = 2 min., Final rinse = 5 min., H_2O resistivity = 18 Megohm.
7. Average initial value.
8. All DI rinses = 5 min.
9. Intermediate DI rinses = 3 min, final rinse = 10 min.
10. Intermediate DI rinses = 3 min, final rinse = 15 min.
11. Anneal time = 3 1/2 hr. (controller malfunction).

The results for sample 22 clearly show that cleaning procedures which minimize contamination strongly effect lifetime. Moreover, controlled final rinsing in DI water is more effective for cleaning than complicated and expensive acid techniques. The effect of varying the final DI rinse cycle time can be observed by noting that Clean 3 specifies a standard 30 second final rinse (Appendix 5). Samples 19, 20, A and B were all rinsed for 30 seconds, annealed with 5% $HC\ell$, and the average value of final lifetime was 7.80 μsec ($\sigma = 2.1$).

Due to a malfunction in the programmed furnace ramp controller samples 26, 27 and 1B were annealed for 3 1/2 hours (normal = 15 min.) and the final lifetimes must be viewed with consideration that, as a group, they may be lower than normal. We ignore this variance for the moment. Note that samples 22 and 26 were rinsed ultimately in DI water for 5 minutes producing an average post anneal lifetime of 13.6 μsec ($\sigma = 5.23$). (The large value of standard deviation is, evidence that sample 26 **was** adversely effected by the longer anneal cycle). Samples 27 and 1B utilized final rinse times of 10 and 15 minutes respectively, and the post anneal lifetimes were 8.19 and 5.14 μsec. These results suggest that an optimum final DI rinse time exists which will maximize the post anneal lifetime and that the time is in the vicinity of 5 minutes. This result can be plausibly explained if we assume that the maximum lifetime is associated with minimum surface contamination. A minimum of two time dependent competing mechanisms are necessary to describe such a functional relation between lifetime and final rinse time. We consider two probable mechanisms in our model. The first mechanism involves those contaminants which are soluable, C_s in deionized water according to the reversible reaction

$$C_s(H_2O)_\ell \rightleftarrows C_s\ (Si)_{surface}$$

The reaction toward Si can be reduced to insignificance by lowering the contamination level in the deionized water, for example by the use of high resistivity deionized water (intrinsic) at high flow rates. The decontamination reaction rate(to the left side in the equation is according to the law of mass action.

$$\frac{dC_{Si}}{dt} = - r_s C_{Si} \tag{34}$$

where r_s is the reaction rate constant. The minus sign denotes that soluble contaminants are being removed from the surface into the flowing water. The other mechanism to be considered in this model is that due to insoluable (particulate) contamination in the water being deposited on the silicon surface. Examples of this form of contamination include bacteria, pathogens, yeast, mold, viruses, and etc. These contaminates are present even in sub-micron (0.22 μm) filtered water since they are either too small to be filtered or they multiply by division downstream from the submicron filter. Particulate contamination cannot readily be dissolved and is the reason why the semiconductor industry has embraced the concept of spin scrubing. The localized nature of particulate contamination would be obliterated during annealing or diffusion. The rate of particulate contamination also follows a mass action equation according to

$$\frac{dC_{Si}}{dt} = r_p C_{pw} \tag{35}$$

where r_p is the contamination rate constant for particulate contamination. The total contamination rate is the sum of Equations 34 and 35.

$$\left.\frac{dC_{Si}}{dt}\right|_{\text{Total}} = - \left.\frac{dC_{Si}}{dt}\right|_{\text{Soluable}} + \left.\frac{dC_{Si}}{dt}\right|_{\text{Particulate}} \tag{36}$$

$$\frac{dC_{Si}}{dt} = - r_s C_{Si} + r_p C_{pw} \tag{37}$$

The solution to Equation 37 with appropriate boundary values is

$$C_{Si}(t) = C_{Si}(o)\ e^{-r_s t} + r_p\ C_{pw}\ t \quad cm^{-2} \tag{38}$$

where $C_{Si}(o)$ is the surface contamination on the wafer prior to the start of the deionized water rinse cycle. The optimum rinse time is obtained by differentiating Equation 38 and solving for t.

$$\frac{dC_{Si}}{dt} = - C_{Si}(o)\ r_s\ e^{-r_s t} + r_p\ C_{pw} = 0 \tag{39}$$

$$t_{opt} = \frac{1}{r_s} \left\{ \ell n \left[\frac{r_s\ C_{Si}(o)}{r_p\ C_{pw}} \right] \right\} \tag{40}$$

Equation 40 implies that the optimum rinse time increases as the particulate contamination, C_{pw}, decreases (higher purity water). The optimum rinse time becomes "negative" (no rinse suggested) when $r_p\ C_{pw} \geq r_s\ C_{Si}(o)$. Equation 40 describes our experimental observations obtained for variable rinse times. Additional work will be done in modeling this phenomenon, to develop experimental verification of the model.

4.2.1.2 Gettering Studies

With some confidence in maintaining adequate bulk lifetime during heat treatment we undertook a series of gettering studies. $POC\ell_3$ gettering was the prime approach adopted for these experiments. Table 10 illustrates the results obtained for an experimental matrix of variable time and temperature. The impurities Ti, Cr, Fe and Al were selected for this study based on their controlability, absence of shallow trapping, and pronounced effect on lifetime.[1] Each of the

TABLE 10

EFFECT OF $POCL_3$ GETTERING TIME AND TEMPERATURE ON RECOMBINATION LIFETIME

T = 900°C

Impurity (conc./cm^3)	Gettering Time (Min)				
	0	25	100	400	1600
W066 Ti 005 3.3x10^{13}	0.49	0.67	0.42	0.39	0.18
W068 Cr 004 1x10^{15}	0.03	0.41	0.29	0.59	1.04
W069 Fe 004 1x10^{15}	0.04	2.61	0.94	1.99	0.11
W070 Al 003 5x10^{16}	1.75	0.77	0.94	0.73	0.50

T = 1000°C

Impurity (Conc./cm^3)	Gettering Time (Min)				
	0	15	60	240	960
W066 Ti 005 3.3x10^{13}	0.49	0.59	0.50	0.34	0.63
W058 Cr 004 1.0x10^{15}	0.03	1.13	2.95	0.89	0.30
W069 Fe 004 1x10^{15}	0.04	2.37	2.61	2.12	1.98
W070 Al 003 5x10^{16}	1.75	0.90	0.76	0.74	0.27

impurities exhibits a characteristic maximum in lifetime as a function of gettering time, at fixed temperature, Table 10. This result was not anticipated from simple gettering theory. The time required to reach maximum lifetime decreases with increasing temperature. The data suggest that two competing mechanisms are active, but experimental data is too scarce yet to model the process. The decrease in lifetime beyond the maximum or peak value is most probably due to an increase in the number of electrically active sites for a given impurity or a shift in the trap level toward the center of the band gap, which increases the capture cross section. DLTS measurements will be used in the future to determine the detailed nature of the lifetime variation.

One possible explanation for the decay in lifetime after the maximum was that the phosphorus surface concentration falls with increased diffusion time. This would diminish the number of active gettering sites available.

To test this simple idea and to increase the size of the gettering matrix we examined the effects of multiple gettering cycles. Gettered impurities tend to be concentrated mainly in the thin diffused n+ layer of silicon, (see e.g reference 1) and smaller amounts in the phospho- silicate glass. This suggests that the concentrated impurities can be physically removed from the wafer by etching off the glass and the thin n+ layer. The wafer could then be gettered a second time to further remove impurities, and the cycle repeated as many times as necessary to achieve the required silicon purity. The results of this type of study are given in Table 11. The lifetime reaches a maximum value after one gettering cycle, and further cycles only degrade the lifetime. This data contradicts the postulate of the simple theory- that saturation of the gettering sites is occuring. The decay in lifetime beyond the peak value is apparently unrelated to the effectiveness of the n+ layer. Wafer contamination is also ruled out by the fact that the lifetime of the simultaneously processed baseline specimens fluctuated somewhat but did not decay monotonically.

TABLE 11

EFFECT OF MULTIPLE GETTERING CYCLES* ON RECOMBINATION LIFETIME

Ingot Identification	As Grown (μsec)	1 Getter Cycle (μsec)	2 Getter Cycle (μsec)	3 Getter Cycle (μsec)	4 Getter Cycle (μsec)	5 Getter Cycle (μsec)	6 Getter Cycle (μsec)
W068 Cr 004	0.03	2.92	0.77	0.95	0.17	0.11	0.19
W069 Fe 004	0.04	1.97	0.29	0.14	0.09	0.10	0.10
W097 Baseline	4.78	11.47	10.72	9.84	8.85	12.42	3.27
W117 Baseline	-	12.40	10.50	11.89	3.39	14.48	8.39

* Gettering cycle consists of cleaning samples in $NH_4OH + H_2O_2$ followed by DI rinsing for 5 minutes gettering in $POCl_3$ for 1 hour at 1000°C, slow cool (1°C/min) to 200°C, Etch phosphorsilicate glass, and etch silicon to remove contaminated n+ layer (note: N+ layers in baseline samples were not removed).

Taken together data from $POC\ell_3$ gettering time temperature experiments and the multiple gettering sequences suggest that maximum bulk lifetime develops within a finite time period. The peak lifetimes we observed here for ∿ 10^{15} impurity doping are considerably larger than in the as-grown ingots, but still less than that necessary for highly efficient solar cell performance. The maximum gettered lifetime is apparently controlled by the "degradation mechanism" and not by the effectiveness of the phosphorus n+ layer.

The nature of this degradation phenomenon must be better understood before fully effective gettering can be achieved. Experiments designed to this end are in progress.

4.2.2 Evaluation of Bulk Recombination Lifetimes for As-Grown and Diffused Silicon

As an adjunct of the processing studies and to monitor the electrical properties of wafers before and after the standard solar cell diffusion cycles we have measured the bulk recombination lifetimes of all ingots by the PCD method. All measurements beyond ingot W056 were made using the laser excited PCD equipment which is capable of measuring lifetime in low lifetime, low resistivity silicon. The lifetimes of only two ingots, W059 and W110, could not be determined due to insufficient signal. A compilation of this data base is presented in Table 12.

4.3 Modeling Impurity Effects in Silicon

The impurity effects model described in the following section was derived to provide a means of predicting the performance behavior of solar cells made from silicon containing known concentrations of various impurities associated with silicon refining and processing.

Several key assumptions underlie the model formulation.

(a) Cell performance is primarily controlled by the properties of its largest region, its base, and the dominant effect of impurities is the reduction of the base diffusion length through recombination processes.

TABLE 12

Bulk Lifetimes (Photoconductive Decay) for Silicon Ingots Before and After Phosphorus Diffusion

(LED EXCITATION)

Ingot Identification	Lifetime $\tau(\mu sec)$	(As-Grown) σ(Note 1)	Lifetime $\tau(\mu sec)$	(Diffused) σ(Note 1)
W001-00000	7.1	1.1(5)	6.9	0.5(3)
W002-00000	6.3	0.6(2)	8.6	1.6(2)
W003-00000	11.6	2.3(2)	8.4	0.7(2)
W004-Cr001	0.35	0.2(3)	1.1	0.2(4)
W005-Mn001	1.8(2)	--	0.3	0.0(5)
W006-Ni001	11.3	2.7(2)	7.7	0.2(2)
W007-Cu001	6.9	0.9(4)	6.6	3.2(3)
W008-Ti001	2.0	0.5(3)	0.4	0.2(3)
W009-V001	0.4	0.1(3)	<2.2(2)	1.8(5)
W010-Ni002	6.8	2.6(3)	3.4	3.3(4)
W011-Zr001	2.6	0.2(2)	2.4	0.7(4)
W012-Cr002	<0.4	0.1(2)	4.9	1.0(5)
W013-Mn002	1.2(2)	1.0(3)	10.5(2)	4.7(5)
W014-00000	7.5	0.4(2)	8.3	0.1(2)
W015-Zn001	7.2	0.6(2)	5.3	0.4(4)
W016-Fe001	0.5	0.0(2)	3.8	1.5(4)
W017-Cu002	8.8	0.1(2)	7.1	0.7(2)
W018-Fe002	8.1	5.5(2)	0.6	0.3(4)
W019-Cu003	4.3	3.3(2)	5.7	0.5(2)
W020-00000	7.0	1.7(2)	7.3	1.2(2)
W021-Mg001	8.2	0.8(2)	7.7	0.1(2)
W022-00000	7.8	1.0(2)	9.1	0.2(2)
W023-00000	1.93	--	Note 4	
W024-Mg002	7.5	0.9(2)	10.2	0.9(2)
W025-00000	7.6	0.0(2)	12.7	1.0(2)
W026-Mn003	5.1	0.2(2)	9.3	0.0(2)
W027-Mn/Cu001	22.3(2)	2.3(2)	0.5	0.2(3)

TABLE 12 (Continued)

Bulk Lifetimes (Photoconductive Decay) for Silicon Ingots Before and After Phosphorus Diffusion

(LED EXCITATION)

Ingot Identification	Lifetime τ(μsec)	(As-Grown) σ(Note 1)	Lifetime τ(μsec)	(Diffused) σ(Note 1)
W028-Al001	2.9	0.2(2)	1.9	0.0(2)
W029-Cr003	1.1	0.6(2)	6.2	0.4(4)
W030-Cr/Cu001	<0.3	0.0(2)	0.4	0.1(2)
W031-Cr/Mn001	Note 5	--	<0.3	0.0(2)
W032-Mg003	7.2	1.1(2)	7.1	1.1(2)
W033-Ti002	3.1	0.0(2)	2.9	0.1(2)
W034-0000	21.8	4.2(2)	1.7	0.1(2)
W034-V002	1.2	0.0	1.5	0.2(2)
W036-Zr002	1.2	0.0(2)	1.0	0.0(2)
W037-Zr/Ti001	0.5	0.1(2)	0.4	0.1(2)
W038-Al002	0.7	0.2(2)	<0.1	0.0(2)
W039-Ni002	2.0	0.1(2)	6.5	1.5(2)
W040-Cr/Ni001	<0.2	0.0(2)	1.4	0.4(2)
W041-Ni/Cr/Cu001	<0.2	0.0(2)	0.4	0.3(2)
W042-Ti003	0.8	0.1(2)	0.7	0.1(2)
W043-Fe/Ti001	0.9	0.0(2)	0.5	0.0(2)
W044-Fe003	1.3	0.2(2)	6.6	0.1(2)
W045-Cr/Fe/Ti001	0.1	0.0(2)	1.0	0.8(4)
W046-Fe/V001	<0.1	0.0(2)	<0.1	0.0(2)
W047-Cu/Ni/Zr001	3.4	0.1(2)	2.6	0.1(2)
W048-Ti004	4.30	0.2(2)	5.1	0.4(2)
W049-V003	3.7	0.2(2)	4.3	0.1(2)
W050-Ti/V001	1.1	0.1(2)	1.1	0.1(2)
W051-Cu/Ti001	0.5	0.0(2)	1.6	0.3(2)
W052-Ni004	0.1	0.0(2)	Note 3	--

Note 1. Sample size shown in parentheses.

Note 2. Lifetime measurements subject to large errors due to extreme shallow trap density.

Note 3. Polycrystalline ingot -- no evaluation performed.

Note 4. Lifetime measurements not practical due to low resistivity.

Note 5. Lifetime measurements not possible due to very low lifetime (Δv too small).

TABLE 12 (Cont.)

RECOMBINATION LIFETIME MEASURED BY PHOTOCONDUCTIVE-DECAY METHOD (Q-SWITCHED Nd:YAG Laser Excitation)

Ingot Identification	Lifetime τ(μsec)	(As-Grown) σ(Note 1)	Lifetime τ(μsec)	(Diffused) σ(Note 1)
W053-00-00	*6.6	0.1 (2)	--	--
W054-0000	*6.3	0.4 (2)	--	--
W055-Cu004	*6.2	0.1 (2)	*7.8	0.6 (2)
W056-Cu005	*6.7	0.3 (2)	*5.6	1.7 (4)
W057-0000	1.84	- (1)	*4.6	0.7 (2)
W058-0000	1.76	0.94(2)	1.78	0.01(2)
W059-0000	Note 2	-	Note 2	--
W060-N/000	11.45	0.24(3)	15.67	1.79(4)
W061-Cr/Ti001	-	-	0.60	0.09(2)
W062-N/Cu001	13.62	0.58(2)	12.11	2.01(2)
W063-N/Cr001	1.67	0.11(2)	0.77	0.09(4)
W064-N/Mn001	0.26	0.04(2)	7.64	1.63(5)
W065-N/Ti001	0.16	0.01(2)	0.34	0.21(4)
W066-Ti005	0.49	0.0 (2)	0.73	0.0 (2)
W067-Cr-Mn/Ti	-	-	0.75	0.2 (2)
W068-Cr004	0.03	0.00(2)	0.85	0.1 (2)
W069-Fe004	0.04	0.01(2)	1.80	0.3 (2)
W070-Al003	1.75	0.07(2)	0.88	0.0 (2)
W071-00-000	3.75	0.31(2)	6.43	1.2 (2)
W072-Cr-005	0.06	0.01(2)	1.75	0.04(2)
W073-Cr/Mn/Ni/Ti/V-001	-	-	0.09	0.02(2)
W074-Cr/Mn/Ni/Ti/V-002	0.10	0.01(2)	1.68	0.28(2)
W075-Ti/V-002	0.06	0.01(2)	0.10	0.04(2)
W076-Poly-002	0.48	0.00(2)	2.51	0.37(2)
W077-Mo-001	0.36	0.13(2)	0.31	0.00(2)

Note 1. Sample size shown in parenthesis
Note 2. Insufficient electrical signal for measurement
Note 3. Lifetime measurements subject to large errors due to extreme shallow trap density
* Measured by LED excitation source

TABLE 12 (Cont.)

RECOMBINATION LIFETIME MEASURED BY PHOTOCONDUCTIVE-DECAY METHOD
(Q-Switched Nd: YAG Laser Excitation)

Ingot Identification	Lifetime τ(μsec)	(As-Grown) σ(Note 1)	Lifetime τ(μsec)	(Diffused) σ(Note 1)
W078-00-000	8.32	4.49 (3)	---	---
W079-N/00-000	86	34 (2)	---	---
W080-Ph-001	4.39	0.41 (2)	2.48	0.10 (2)
W081-N/Ni-001	5.62	1.18 (2)	10.36	1.63 (2)
W082-N/V-001	0.25	0.01 (2)	0.25	0.01 (2)
W083-N/Fe-001	1.56	0.41 (2)	---	---
W084-N/Al-001	0.97	--- (1)	---	---
W085-N/Zr-001	140	--- (1)	---	---
W086-C-001	3.06	0.52 (2)	2.30	0.05 (2)
W087-Ca-001	2.81	0.63 (2)	2.08	0.54 (2)
W088-Cr-001	0.01	--- (1)	2.23	0.92 (2)
W089-Cu-001	2.37	0.05 (2)	3.06	0.02 (2)
W090-Mn-001	0.06	0.01 (2)		
W091-Cr/Mn-002	0.09	0.02 (2)	0.20	0.09 (2)
W092-Ph-002	7.83	0.24 (2)	5.49	1.49 (2)
W093-Mn-004	0.19[3]	0.04 (2)	0.70	0.13 (2)
W094-Mn-005	0.38[3]	0.07 (2)	2.58	0.33 (2)
W095-Mn-006	0.15	0.00 (2)	0.38	0.03 (2)
W096-Mn-007	0.34[3]	0.19 (2)	2.32	0.43 (2)
W097-00-000	4.78	0.52 (2)	2.66	0.04 (2)
W098-Mo-002	1.40	0.01 (2)	0.89	0.16 (2)
W099-Fz-001	4.34	0.40 (2)	3.12	0.35 (2)
W100-Cu/Ti-002	0.30	0.02 (2)	0.37	0.05 (2)
W101-Fz-002	4.30	0.12 (2)	9.58	0.34 (2)
W102-Ti-006	0.21	0.02 (2)	0.41	--- (1)
W103-Ti-001	0.12	0.00 (2)	0.07	0.00 (2)
W104-Cu/Ti-003	0.16	0.02 (2)	0.45	0.05 (2)

Note 1. Sample size shown in parenthesis
Note 2. Insufficient electrical signal for measurement
Note 3. Lifetime measurements subject to large errors due to extreme shallow trap density.

TABLE 12 (Cont.)

RECOMBINATION LIFETIME MEASURED BY PHOTOCONDUCTIVE-DECAY METHOD
(Q-Switched Nd: YAG Laser Excitation)

Ingot Identification	Lifetime τ(μsec)	(As-Grown) σ(Note 1)	Lifetime τ(μsec)	(Diffused) σ(Note 1)
W*105-V-001	0.07	0.01 (2)	0.07	0.00 (2)
W106-N/Al-002	16.56	0.86 (2)	---	---
W107-Fz/Al-001	2.61	0.00 (2)	2.29	0.29
W108-N/V-002	0.72	0.09 (2)	---	---
W109-C-002	3.05	0.98 (2)	---	---
W*110-Fe-001	Note 2	---		
W111-Cu/V-001	0.15	0.00		
W112-Ta-001	1.06	0.07		
W113-Fz/Cr-001	0.13	0.04		
W114-00-000	6.75	1.58 (2)		
W115-N/Cu-002	8.39	0.01 (2)		
W116-Ph-001	1.61	0.06 (2)		
W117-00-000	3.65	0.67 (2)		
W118-Ph-003	4.16	---- (1)		
W119-N/Fe-002	5.21	---- (1)		
W120-N/Cr-002				
W121-N/Ti-002				
W122-Ti-007	0.68	0.00 (2)		
W123-Ti-008	0.59	0.01 (2)		

Note 1. Sample size shown in parenthesis
Note 2. Insufficient electrical signal for measurement
Note 3. Lifetime measurements subject to large errors due to extreme shallow trap density.
* Low resistivity p-type ingot identification.

(b) The impurity induced diffusion length reduction results either by carrier recombination via deep centers associated with the impurities or by carrier mobility loss due to ionized impurity scattering.

(c) The number of electrically active centers is a species dependent linear function of the total metallurgical concentration of that impurity.

The hypotheses suggest that the base diffusion length, L_n, is a characterizing parameter for the impurity effects. Experience has shown that the diffusion length or equivalently the lifetime is difficult and time consuming to measure accurately. The large number of samples and data necessitated a simpler measurement. Solar cell processing effects make it necessary to obtain a statistically meaningful data base. We have therefore chosen to model the impurity effect as a function of the short circuit current, a more easily measured quantity and directly related to the diffusion length.

4.3.1 Short Circuit Current as a Function of Diffusion Length

The relationship between I_{sc} and L_n can be obtained by solving the carrier transport equations in the base with appropriate boundary conditions. A one-dimensional computer solution is shown as the solid curve in Fig. 10. The basic equation in this solution is:

$$dI_\lambda = qA(N_\lambda/L_\lambda)\ (1-R_\lambda)\cdot\exp(-x(1/L+1/L_n))dx \tag{41}$$

where N_λ = the number of photons with wavelength λ

L_λ = the absorption length, $1/a_\lambda$

R_λ = the reflection coefficient

x = distance from the cell surface. The solution at a single wavelength is then:

$$I_\lambda = qA(N_\lambda/L_\lambda)\ (1 - R_\lambda)\ \cdot\ (1-\exp(-x(1/L_\lambda+1/Ln))) \tag{42}$$

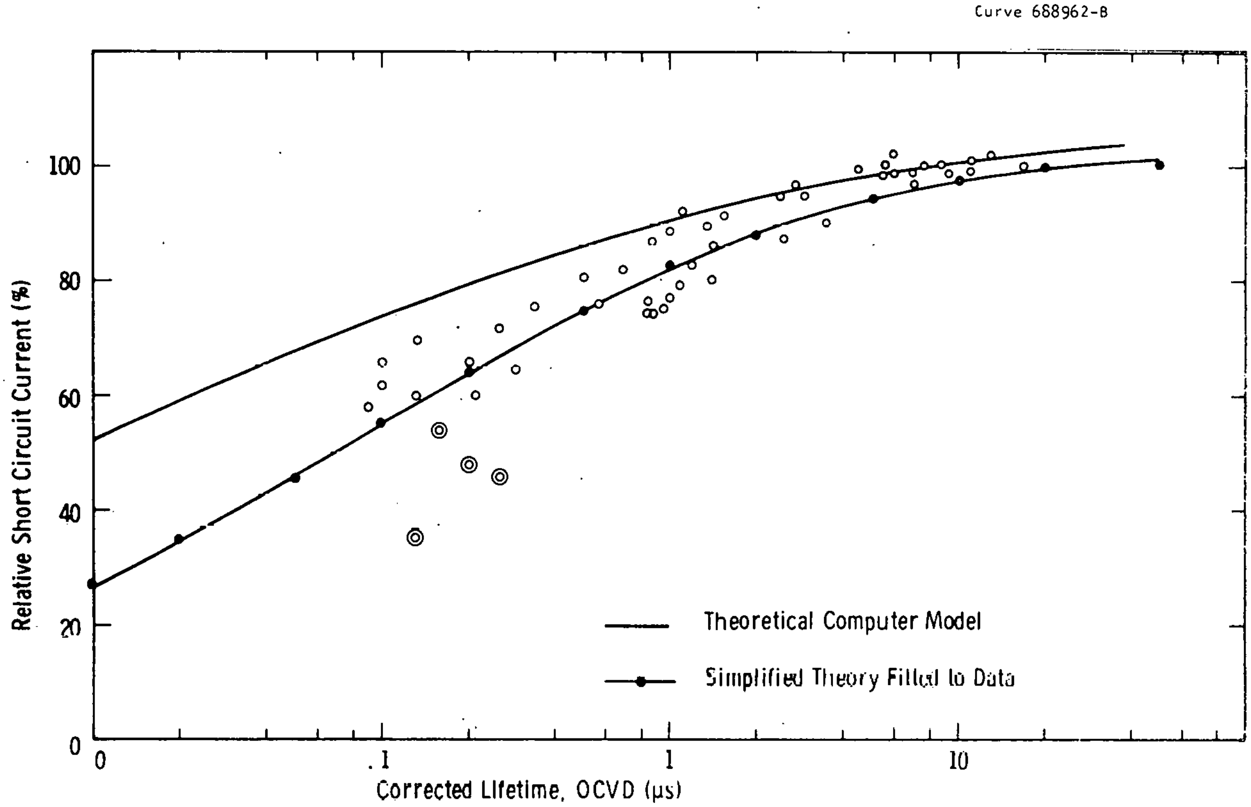

FIGURE 10 Photocurrent as a function of lifetime

The active base thickness, x, for a diffusion length limited cell, without a back surface field, is on the order of two or three diffusion lengths.

If we choose a wavelength near the middle of the solar spectrum we find $L_\lambda \doteq 20$ µm and we obtain:

$$I_\lambda = qAN_\lambda(1 - R_\lambda)/(L_\lambda/L_n + 1) \cdot (1 - \exp(-2L_n/20 - 1) \qquad (43)$$

Over the range of values of L_n appropriate to our experiments, the second term is essentially unity, and we have:

$$I_\lambda = (qAN_\lambda(1-R_\lambda)/(L_\lambda/L_n+1) \qquad (44)$$

A more convenient form is:

$$I_{sc}(L_n) = I_{sc}(L_n = \infty)(1/(L_\lambda/L_n + 1) \qquad (45)$$

Using a normalized short circuit current, $I_n = I_{sc}$ (impurity sample)/$I_{sc\,(baseline)}$ we can obtain from the experimental data, a least-squares set of values for $I_{n\infty}$ and L_λ.

The resulting values for the data in Figure 10 are $I_{n\infty} = 1.08$ and $L \doteq 17$ µm. An absorption length of 17 µm corresponds to a wavelength of 850 nm which is plausibly near the center of the solar spectrum.

4.3.2 Impurity Dependent Diffusion Length

The diffusion length in the base of the cells depends on the density of recombination centers. We assume no concentration dependent effects and thus expect the density of centers, N_T, to be proportional to the concentration of the metal impurity atoms, N_x. Note that N_T need not equal N_x since many metal atoms may be in electrically inactive sites.

The lifetime as a function of N_T is given by:

$$\tau = 1/(\sigma_x v_{th} N_T) \tag{46}$$

where σ_x is the recombination cross-section for metal-x and v_{th} is the thermal velocity of the carriers. If $N_T = a_x N_x$ we have:

$$\tau = 1/(\sigma_x v_{th} a_x N_x) \tag{47}$$

With several lifetime mechanisms, the effective lifetime is obtained from the reciprocal sum:

$$\frac{1}{\tau} = \frac{1}{\tau_o} + \frac{1}{\tau_x} + \cdot \cdot \cdot \frac{1}{\tau_z} \tag{48}$$

where τ_o is lifetime observed in uncontaminated baseline samples and τ_x, τ_y, and τ_z are associated with the metals x, y, . . . and z. Using the relationship, $L_n^2 = D\tau$ with Eq. (47) gives:

$$1/L_n^2 = 1/L_{no}^2 + k_x N_x + k_y N_y + \ldots + k_z N_z \tag{49}$$

Eq. 45 then takes the following convenient form:

$$(I_{n\infty}/I_n - 1)^2 = L_\lambda^2 [1/L_{no}^2 + k_x N_x + k_y N_y + \ldots + k_z N_z] \tag{50}$$

For the samples containing single metal impurites, we can express Eq. 50 as:

$$(I_{n\infty}/I_n - 1)^2 = C_{2x}(N_{ox} + N_x) \tag{51}$$

where N_{ox} is a threshold concentration of impurity x above which degradation is observed. Table 13 gives the least-squares values obtained from the single metal data using Eq. 51.

4.3.3. Open Circuit Voltage Behavior

The open circuit voltage using the base controlled model is:

$$V_{oc} = nV_T Ln(I_{sc}/I_o) \tag{52}$$

where n is the ideality factor

$V_T = kT/q$ the thermal voltage

I_{sc} is the short circuit current and

I_o is the saturation current.

I_o, based on our assumptions, is proportional to $1/L_n$ and from Eq. 45:

$$1/L_n = (1/L_\lambda)(I_{n\infty}/I_n - 1) \tag{53}$$

Using $V_n = V_{oc}/V_{oco}$ and $I_n = I_{sc}/I_{sco}$ we can write:

$$V_n = E\log(I_n(1/I_n + 1/I_{n\infty})) + F \tag{54}$$

where E and F are determined by fitting Eq. 54 to experimental data. The result is shown in Figure 11. Note: $V_{oco} = 0.556$ volts and $I_{sco} = 22.5\ mA/cm^2$.

TABLE 13 MODEL COEFFICIENTS FOR SINGLY DOPED, P-BASE SOLAR CELLS

IMPURITY	C_1	C_{2X}	N_{OX}
ALUMINIUM	1.288E-02	2.919E-18	4.412E+15
CHROMIUM	9.278E-03	6.702E-17	1.384E+14
COPPER	1.286E-02	3.095E-20	4.155E+17
IRON	1.192E-02	4.928E-17	2.419E+14
MANGANESE	9.800E-03	5.322E-17	1.841E+14
MOLYBDENUM	1.413E-02	1.996E-14	7.079E+11
NICKEL	1.444E-02	2.549E-18	5.665E+15
PHOSPHORUS	1.175E-02	6.822E-21	1.722E+18
TANTALUM	1.229E-02	1.163E-14	1.057E+12
TITANIUM	1.328E-02	5.410E-15	2.455E+12
VANADIUM	1.383E-02	5.408E-15	2.557E+12
ZIRCONIUM	1.032E-02	2.796E-14	3.691E+11

$$\left(\frac{In^{\infty}}{In} = 1\right)^2 = C_1 + C_{2x}N_x \equiv C_{2x}\,(N_{ox}+N_x)$$

4.3.4. Efficiency Behavior

We obtain the efficiency behavior from the I-V equation. Using normalized variables, $i = I/I_{sco}$ and $v = V/V_{oco}$ with Eq. 53:

$$i = I_n - C(1/I_n - 1/I_{n\infty})\exp(v(V_{oco}/nV_T)) \tag{55}$$

where C is a constant found from the boundary requirement that if $I_n = 1$ and $i = 0$ then $v = 1$. From the data in Figure 11 $C = 9.71\text{x}10^{-9}$.

The normalized peak power results when:

$$dp/dv = i + v(di/dv) = 0 \tag{56}$$

$$I_n - (C(1/I_n - 1/_{n\infty})\ \exp(v(V_{oco}/nV_T))\ (v(V_{oco}/nV_T)+1) = 0 \tag{57}$$

Numerically solving 57 gives v_p as a function of I_n and i_p is obtained from Eq. 55. The normalized efficiency is then:

$$\eta/\eta_o = (i_p v_p)/(i_{po} v_{po}) \tag{58}$$

where the zero subscripts again denote baseline quantities. The efficiency as a function of I_n is shown in Figure 12. As Eq. 57 has no closed form solution, an empirical approximation was made:

$$\eta/\eta_o = 0.964 I_n^{1.239} + 0.036 I_n^{12} \tag{59}$$

We now can calculate the efficiency as a function of metal concentration for either p or n-base devices by use of Eqs. 59 and 51 coupled with data like that in Table 13. The results of such calculations are described in section 4.4 and 4.5.

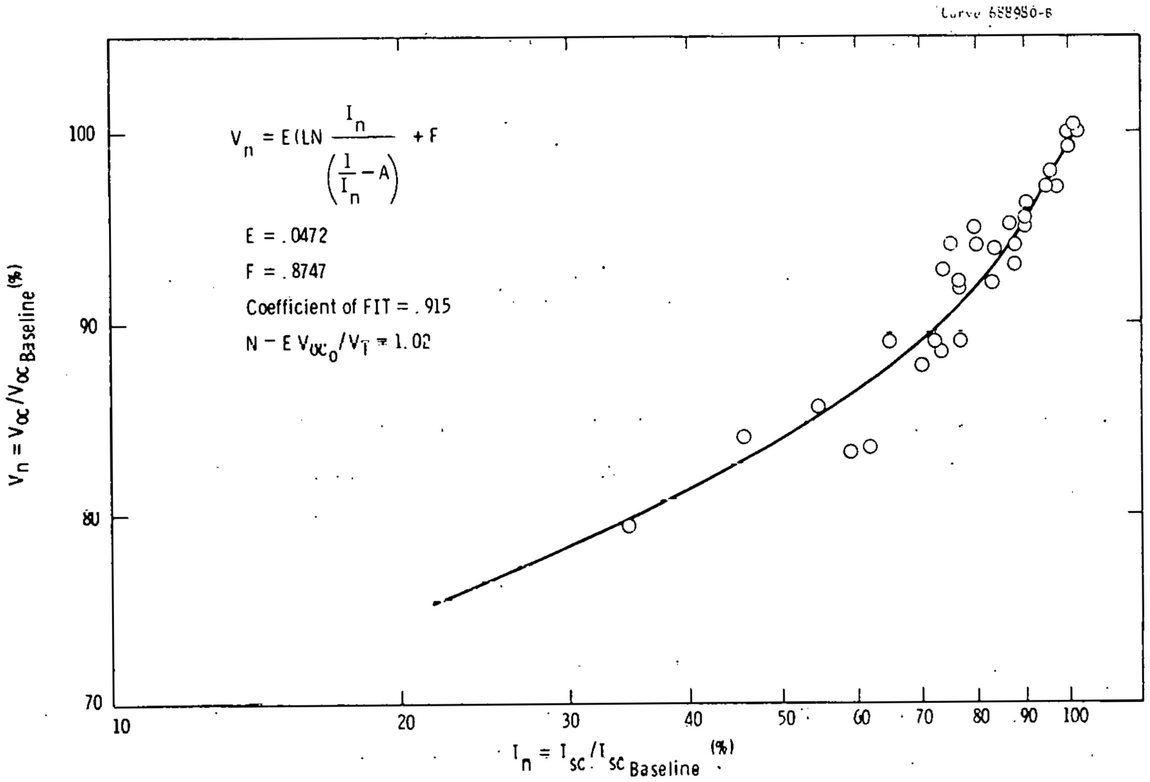

Figure 11 V_{oc} as a function of I_{sc} for metal-doped solar cells.

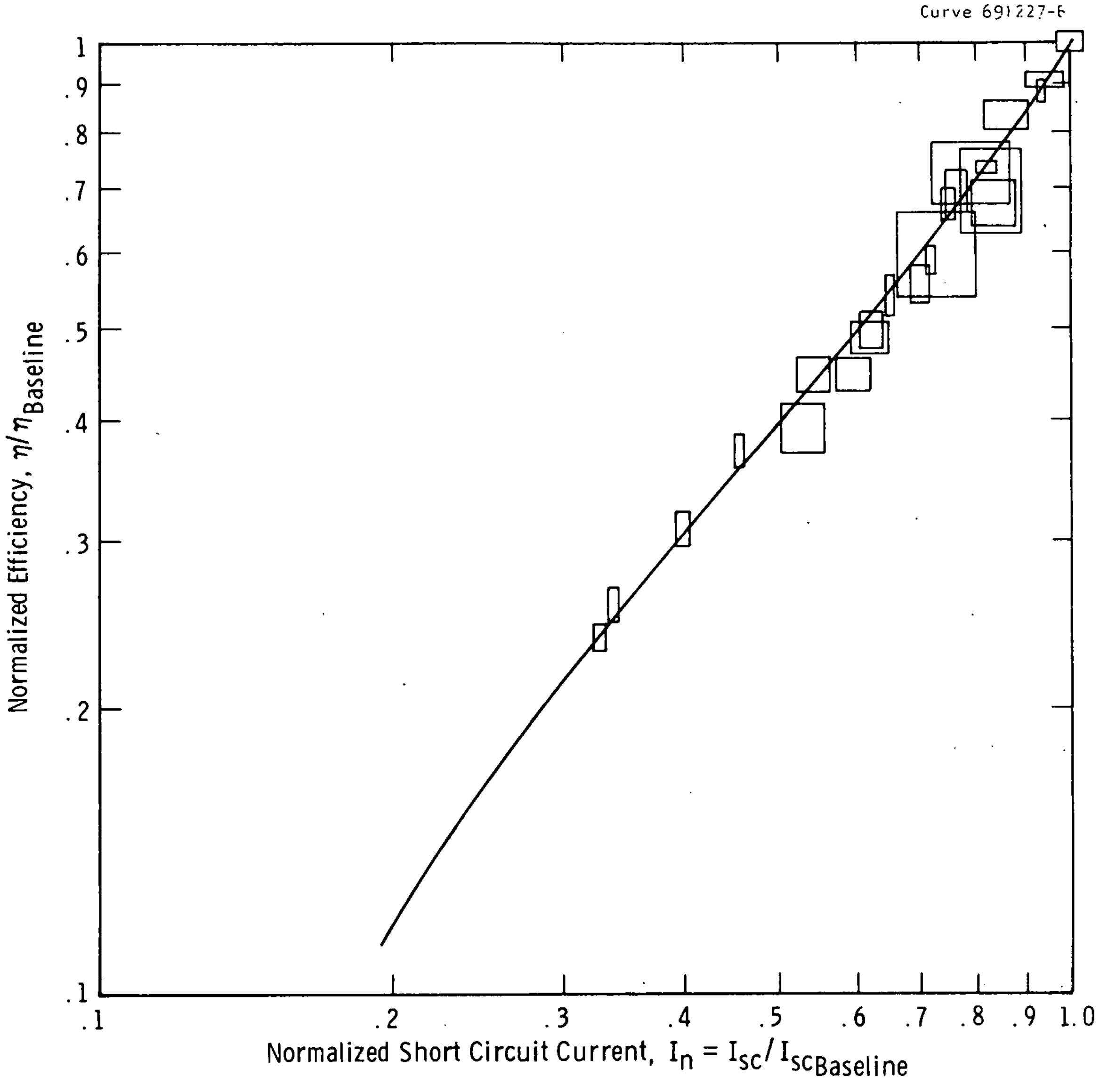

Figure 12 Efficiency versus short circuit current.

4.4 Analysis of p-base Solar Cells

4.4.1 Model Predictions

Figure 13 depicts the calculated efficiency of 4 Ω-cm p-base solar cells as a function of the base material impurity content for a variety of added single impurities. With Eq. 50 the efficiency of devices bearing multiple contaminants also can be calculated. These results are compiled in Table 14 and displayed in Figure 14. The model curves for most impurities are generally in good agreement with the data. The data points have been deleted from the curves for clarity). A notable exception to this result is iron and to a lesser degree copper and nickel. We ascribe these disparities to degradation mechanisms beyond the scope of the base controlled model. This point is clarified in the I-V analyses to follow.

4.4.2 Detailed I-V Analysis

Generally detailed I-V analysis showed that impurities do not alter the shunt or the series resistance appreciably to account for observed cell degradation. In all cases, the shunt resistance was above 20 kΩ and the series resistance was less than 1Ω, thus in most cases where relative shift in the bulk and junction component was of interest, correction for resistive components was not made in the detailed I-V analysis. However, when absolute value of I_o was needed, corrections were made for R_s and R_{sh}.

Dominantly impurities lowered the bulk lifetime to degrade the device performance as assumed in our model. In those cases which did not conform to the model properly, junction recombination played an appreciable role. Some specific examples of these are discussed below. The bulk current component (I_b) obtained from the transformed I-V plots was quite reproducible from sample to sample in each run. However, the junction excess current (I_j) showed some scatter and only the average behavior is indicated on the transformed I-V plots. It is important to recognize that the operating point of the solar cell lies around 0.5 volts and a slight shift in the bulk current segment on the log I-V plot can

Curve 696864-B

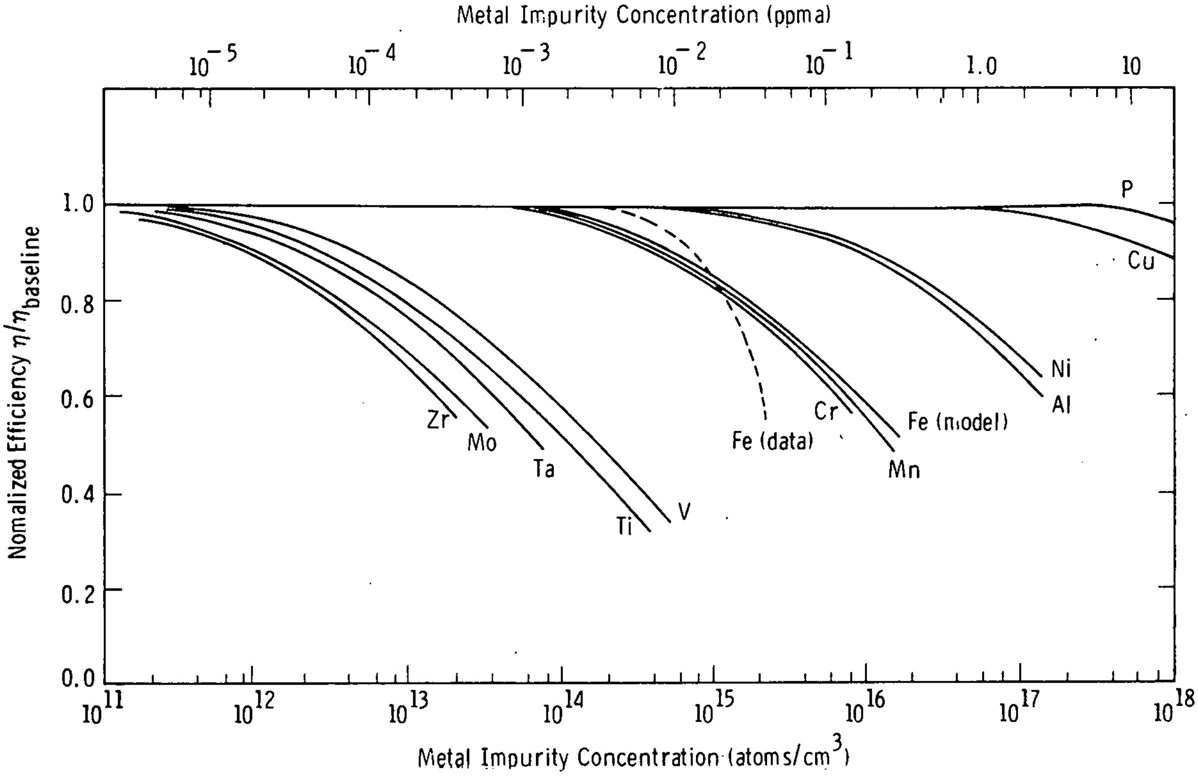

Figure 13 Efficiency versus metal content; p-base devices. Model derived curves.

TABLE 14a Calculated and Measured Normalized Short Circuit Currents and Efficiencies for Multiple Metal Additions

Ingot No.	Calculated In	Measured In	Calculated η/η baseline	Measured η/η baseline
027	0.86 ± 0.02	0.74 ± 0.03	0.81 ± 0.03	0.70 ± 0.04
030	0.87 ± 0.03	0.76 ± 0.03	0.81 ± 0.04	0.69 ± 0.04
031	0.80 ± 0.03	0.54 ± 0.03	0.74 ± 0.04	0.45 ± 0.03
037	0.53 ± 0.05	0.59 ± 0.02	0.44 ± 0.06	0.45 ± 0.02
041	0.88 ± 0.03	0.83 ± 0.06	0.83 ± 0.03	0.72 ± 0.08
043	0.76 ± 0.05	0.70 ± 0.01	0.68 ± 0.05	0.60 ± 0.03
045	0.72 ± 0.05	0.73 ± 0.07	0.65 ± 0.05	0.62 ± 0.07
046	0.67 ± 0.05	0.77 ±	0.59 ± 0.06	0.66 ± 0.03
047	0.97 ± 0.01	0.94 ± 0.01	0.96 ± 0.02	0.90 ± 0.01
050	0.99 ± 0.01	0.87 ± 0.01	0.98 ± 0.01	0.80 ± 0.01
051	0.54 ± 0.05	0.62 ± 0.03	0.45 ± 0.06	0.49 ± 0.03
061	0.81 ± 0.04	0.73 ± 0.04	0.74 ± 0.05	0.62 ± 0.04
067	0.86 ± 0.03	0.84 ± 0.02	0.81 ± 0.03	0.74 ± 0.05
073	0.84 ± 0.03	0.77 ± 0.02	0.79 ± 0.04	0.63 ± 0.03
074	0.95 ± 0.01	0.93 ± 0.02	0.93 ± 0.02	0.89 ± 0.03
091	0.89 ± 0.02	0.75 ± 0.04	0.84 ± 0.03	0.63 ± 0.06
100	0.77 ± 0.05	0.67 + 0.01	0.70 ± 0.05	0.59 ± 0.06
111	0.49 ± 0.05	0.69 ± 0.03	0.40 + 0.05	0.55 ± 0.04
126	0.93 ± 0.03	0.91 ± 0.02	0.89 ± 0.03	0.83 ± 0.03

TABLE 14b. Impurity Concentrations for Ingots Tabulated in Table 14a.
(10^{15} atoms cm^{-3})

Ingot No.	Ti	Cu	V	Cr	Fe	Zr	Ni	Mn
027		1.7						1.3
030		1.7		1.0				
031				1.0				1.3
037	0.22					0.0007		
041		1.7		0.8			2.1	
043	0.033				0.56			
045	0.039			0.65	0.43			
046			0.07		0.57			
047		1.7				0.0002	1.0	
050	0.0002		0.0004					
051	0.20	1.7						
061	0.011			1.0				
067	0.0033			0.4				0.5
073	0.0024		0.004	0.4			2.0	0.4
074	0.0003		0.0006	0.08			0.5	0.08
091				0.5				0.3
100	0.033	1.0						
111	0.14	2.0						
126	Ten elements; See Table 33							

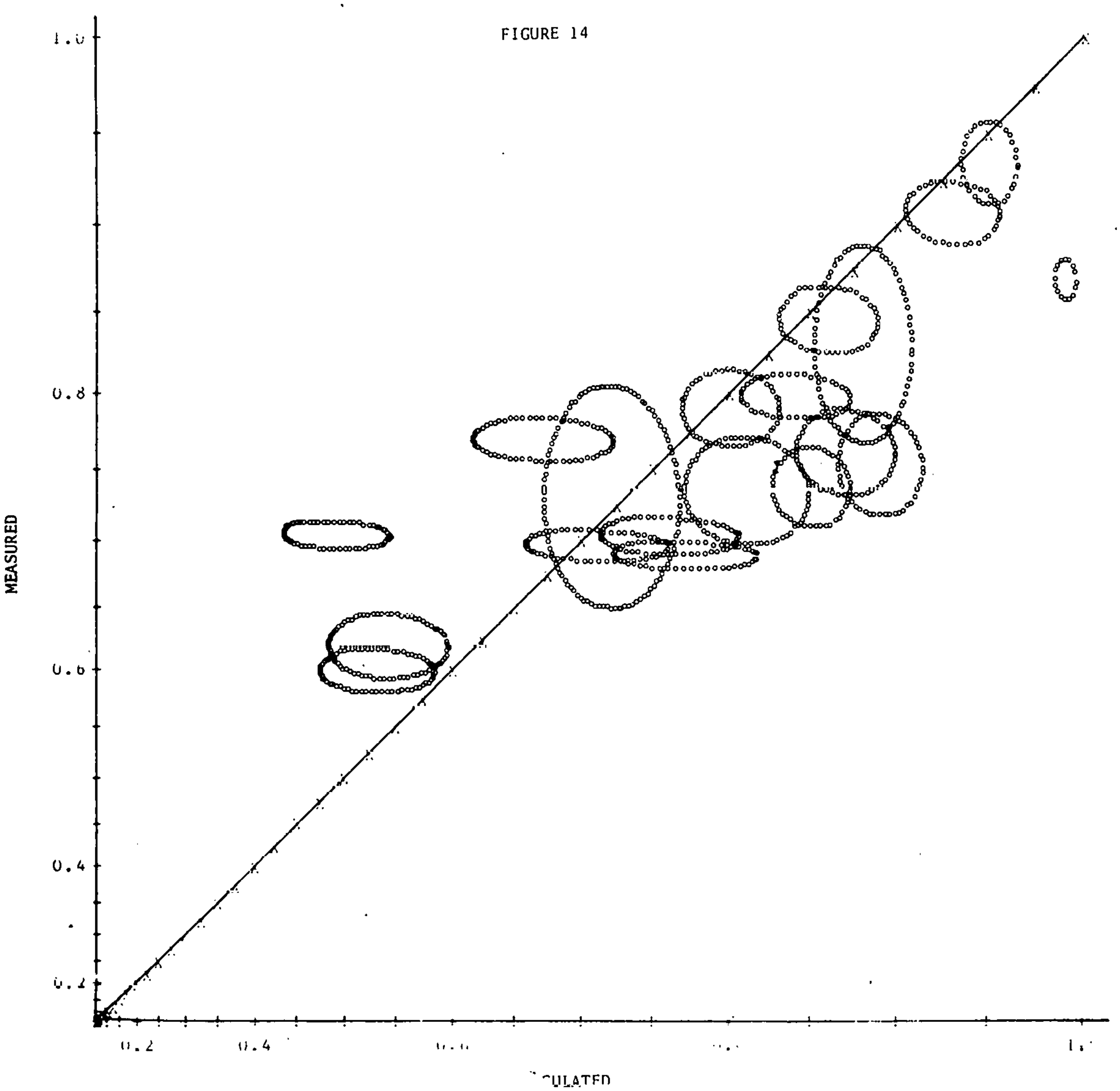

Figure 14 Calculated versus measured efficiency for multiply doped devices.

result in considerable change in the cell performance. On the other hand, junction excess current will have to change quite a bit on the log I-V plot to affect the operating point at all. In the following sections transformed I-V plots are used extensively to describe the detailed impurity effects on the cell performance.

4.4.2.1 I-V Analysis of p base Solar Cells with Single Impurities

The impurity-effects model predicts very well the influence of impurities, like Mn, Cr, Ti and V, on the cell performance. Figure 15 shows the transformed I-V plots for Ti doped cells. It is quite clear that the addition of Ti results in a systematic increase in the reverse saturation current or a decrease in the bulk lifetime. Only at very high Ti concentrations there seems to be a small increase in the junction excess current. Ti does not alter R_s, R_{sh} and I_j appreciably to account for any cell degradation. This behavior is typical of impurities which satisfy the model assumptions.

Unlike Ti, impurities like Cu and Ni have large threshold concentration beyond which they degrade the cell performance very slowly. The transformed I-V plot, (Figure 16), of Cu-doped cell indicates that Cu induced cell degradation can be largely attributed to the increased junction excess current. Precipitates occur frequently in the heavily Cu-doped ingots, e.g Figure 17, and their presence in the high field space charge region can result in excess currents. The increase in I_j will depend on the quantity and location of the precipitates in the space charge region which could vary from sample to sample. Consequently, a much larger scatter is observed in the junction excess current of Cu doped cells. Figure 16 also demonstrates that Cu incorporated into Si in this manner has very little effect on the bulk lifetime which implies that if recombination centers are present, they are either very few in number or have a very small capture cross sections.

At high iron concentrations, iron doped cells conform poorly to the model, viz Figure 13. The transformed I-V plot for iron doped cells, Figure 18, indicates that at higher concentrations Fe degrades the cell performance both by lowering the bulk lifetime and by increasing the

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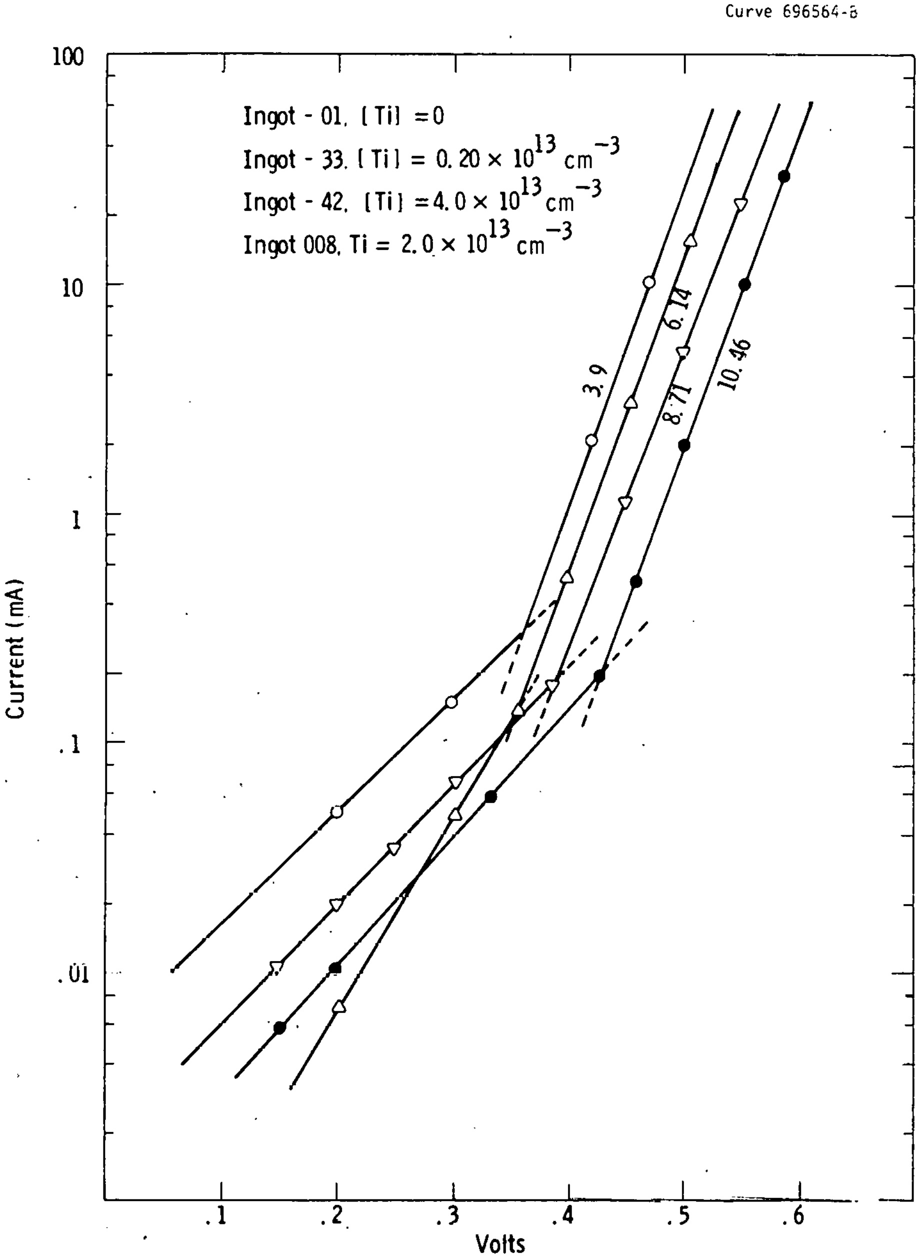


Figure 15 Transformed dark I-V curves for Ti-doped 4 Ωcm silicon solar cells.

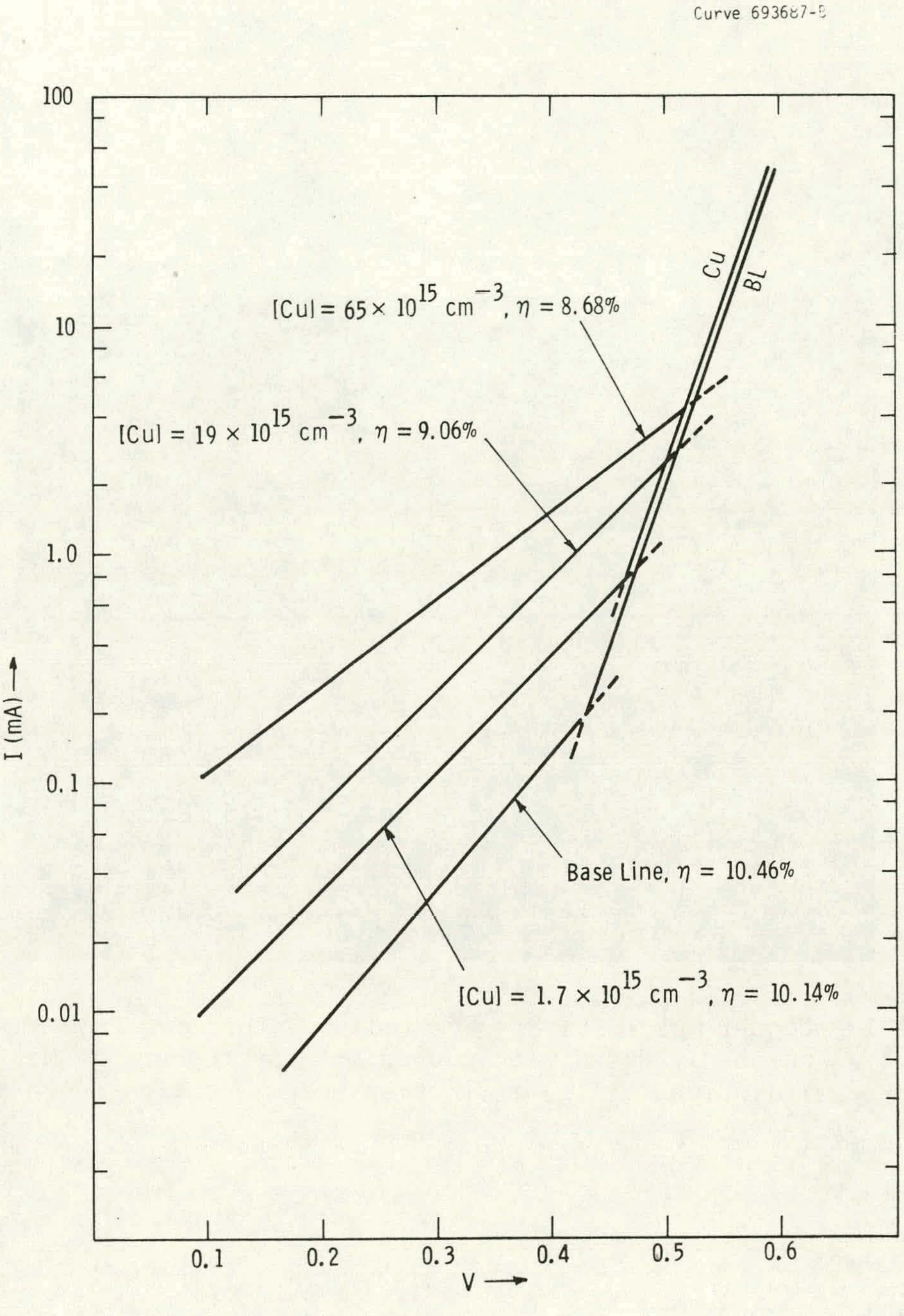


Figure 16 Transformed dark I-V curves for Cu-doped 4 Ωcm silicon solar cells.

Figure 17 Copper precipitates revealed in wafers cut from ingots purposely doped with copper. X-ray topograph, MoK radiation, (111) reflection, magnification approximately 20X.

Curve 693689-B

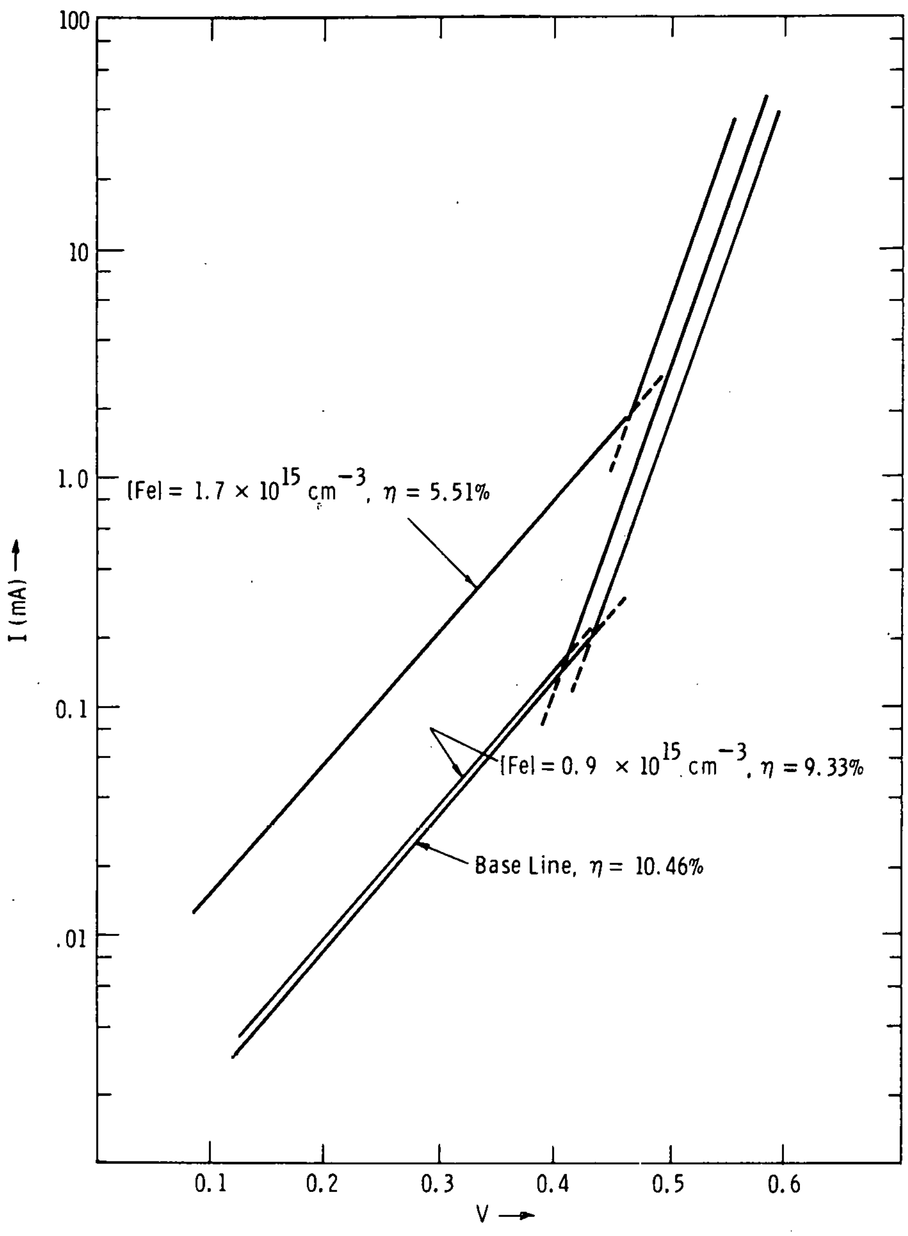


Figure 18 Transformed dark I V curves for Fe-doped 4 Ωcm silicon solar cells.

junction excess current. Since the first order model does not account for the degradation due to enhanced junction recombination, therefore, iron as expected, shows much more rapid degradation than predicted by the model. Considerable scatter was observed in the junction excess current of Fe doped cells. In fact, some cells which showed fairly low I_j were in good agreement with the model.

4.4.2.2 I-V Analysis of Multiply-Doped Solar Cells

Based on the assumption that impurities do not ineract, the calculated efficiencies from the model are in fair agreement with the experimental data for the multiply doped solar cells. Figure 19 shows the transformed I-V curve for Mn plus Cu doped cell. Transformed I-V plots for Mn and Cu singly-doped cells with the same concentrations are also shown in the figure. It is quite clear that the lifetime of Cu + Mn doped cells is determined by the Mn content, but the junction excess current is governed by the Cu content. Thus, Cu and Mn do not show any evidence of interaction. Figure 20 shows that Cr + Mn doped cells (Ingot 31) have much smaller lifetime compared to Mn or Cr doped cells containing the same metal concentration separately. Again no compelling evidence of interaction is present.

However in the case of Cu + Ti doping, Cu appears to mitigate the effect of Ti somewhat (e.g ingots 51 and 104) but only when the impurity concentrations are large. Transformed I-V curves in Figure 21 indicate that when the Ti concentration is about $4x10^{13}$ cm^{-3}, addition of $1x10^{15}$ cm^{-3} Cu (Ingot-100) actually lowers the cell efficiency from 6.1% to 5.5% suggesting no interaction. On the other hand, Figure 22 shows that when Ti concentration is large ($\sim$ $2x10^{14}cm^{-3}$) then addition of $2x10^{15}cm^{-3}$ Cu improves the cell efficiency from 3.9% to 4.85%, approximately 20% improvement in the cell performance. Figure 22 also shows that the improvement results from the lifetime enhancement as though Cu gettered some of the electrically active Ti. Similar beneficial effects of Cu were also observed on samples containing large amounts of V. For example Figure 23 shows that addition of $2.5x10^{15}$ cm^{-3} Cu in samples containing $\sim$ $4x10^{14}$ cm^{-3} V improves the cell performance from 3.9% to 5.2%.

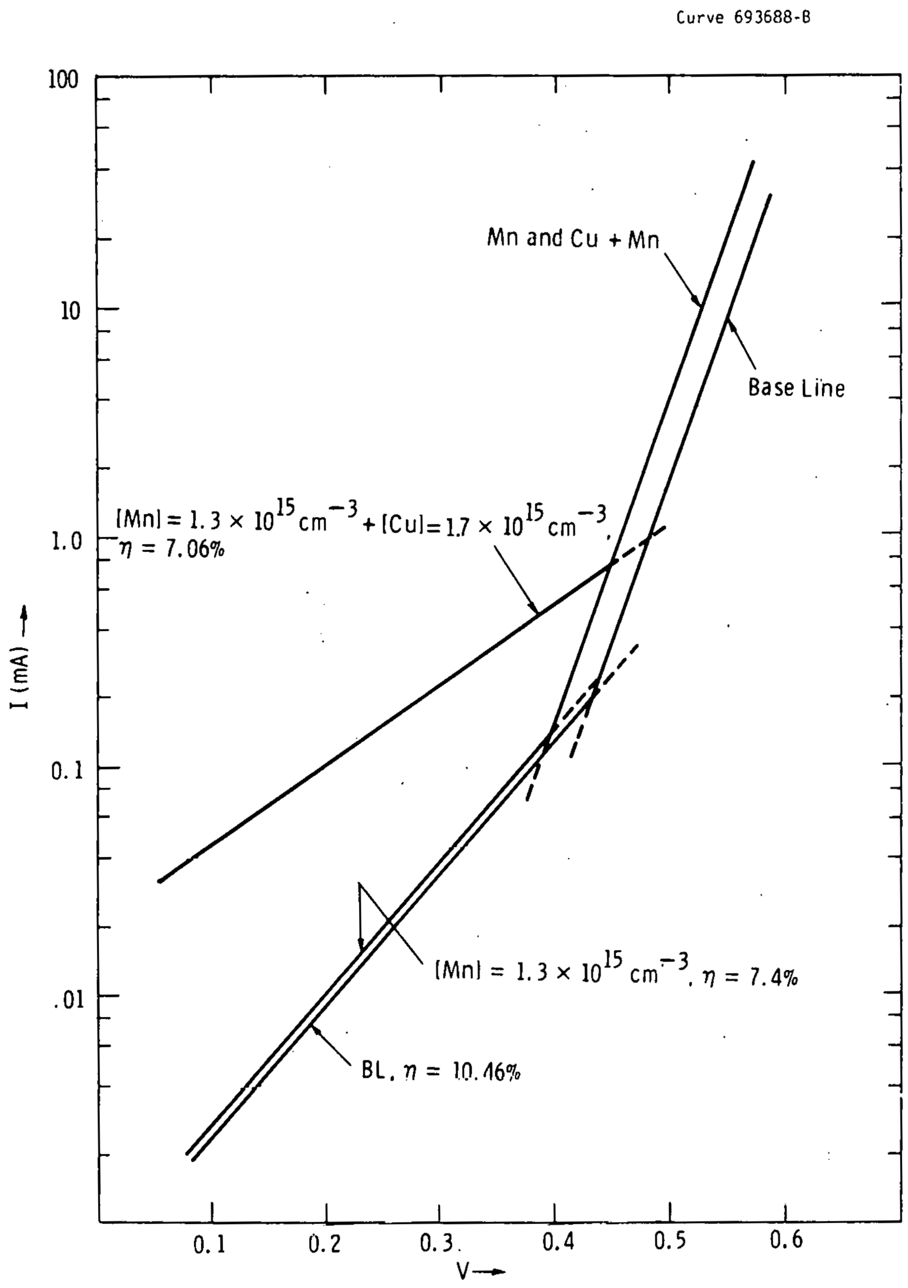


Figure 19 Transformed dark I-V curves for Mn/Cu-doped 4Ωcm silicon solar cells

Curve 695081-A

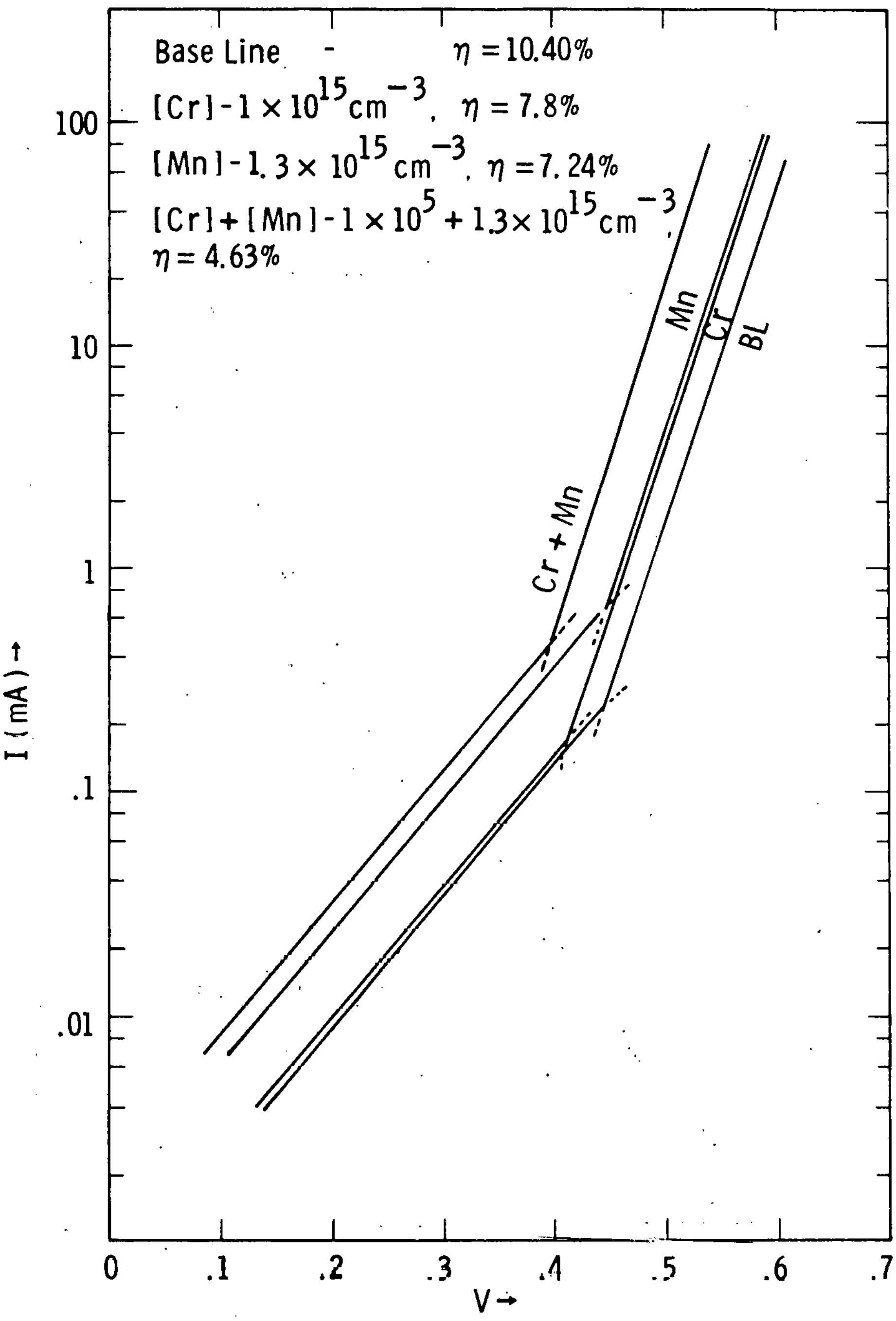


Figure 20 Transformed dark I-V curves for Mn/Cr-doped 4 Ωcm silicon solar cells

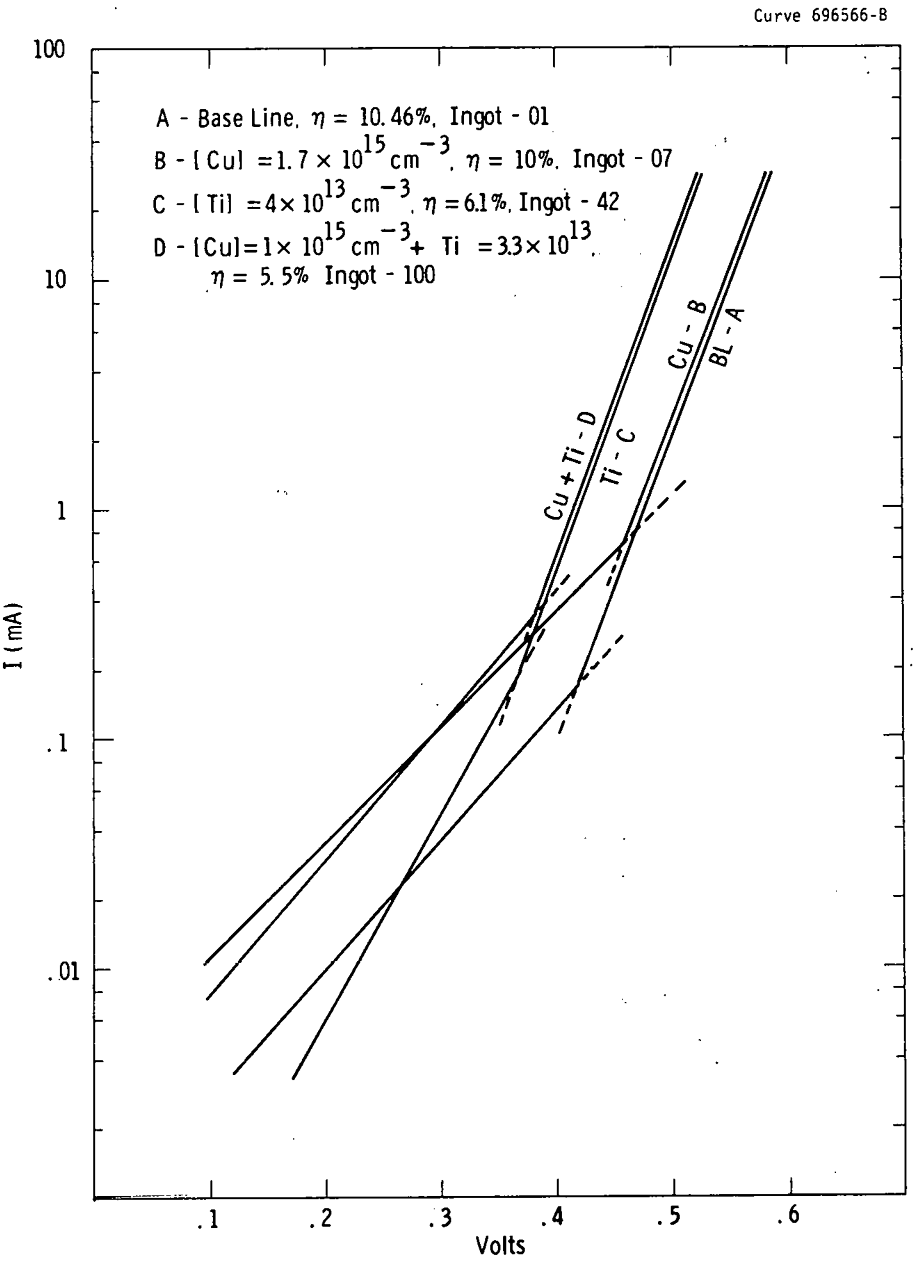


Figure 21 Transformed dark I-V curves for Cu/Ti doped 4 Ωcm silicon solar cells

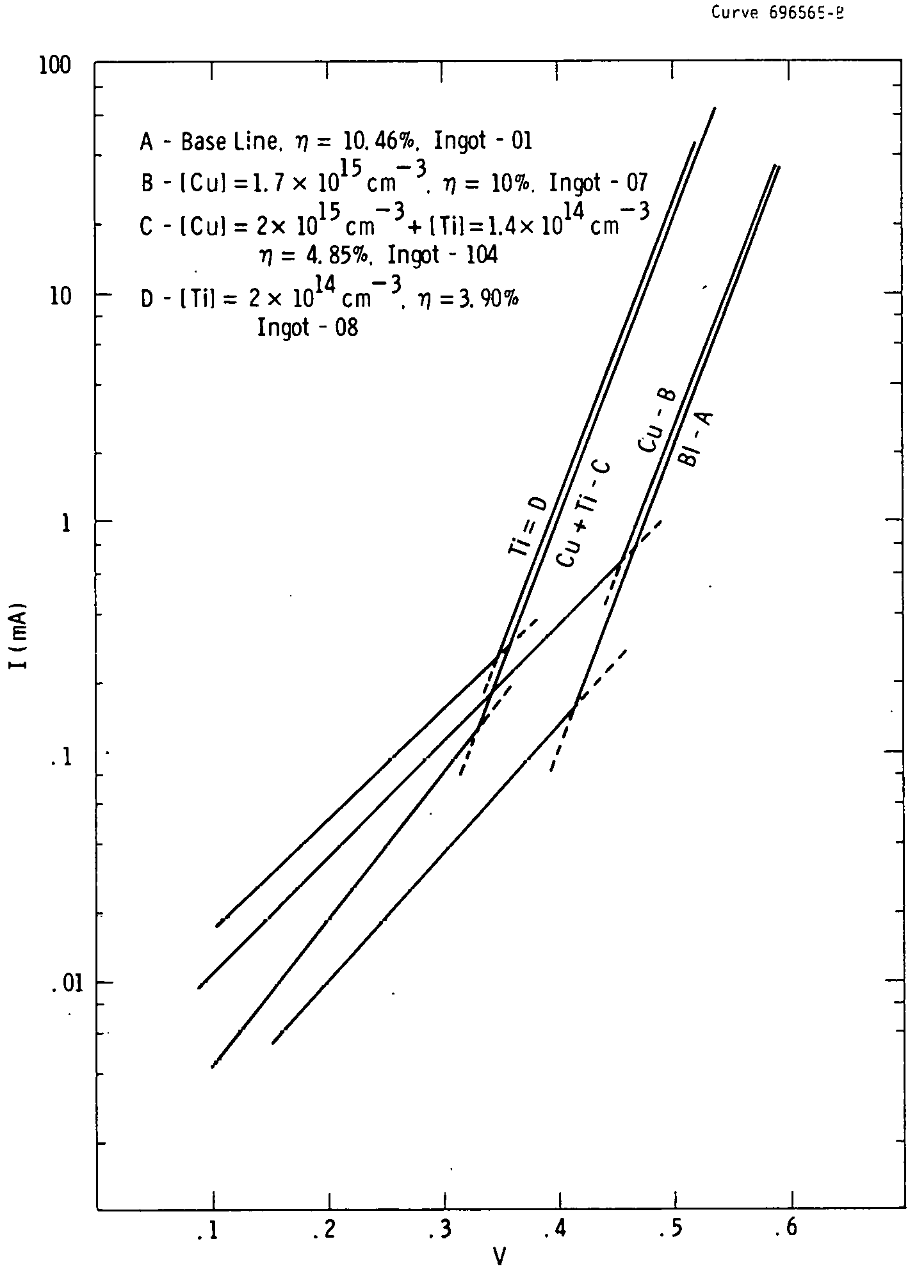


Figure 22 Transformed dark I-V curves for Cu/Ti-doped 4 Ω cm silicon solar cells

Curve 696568-E

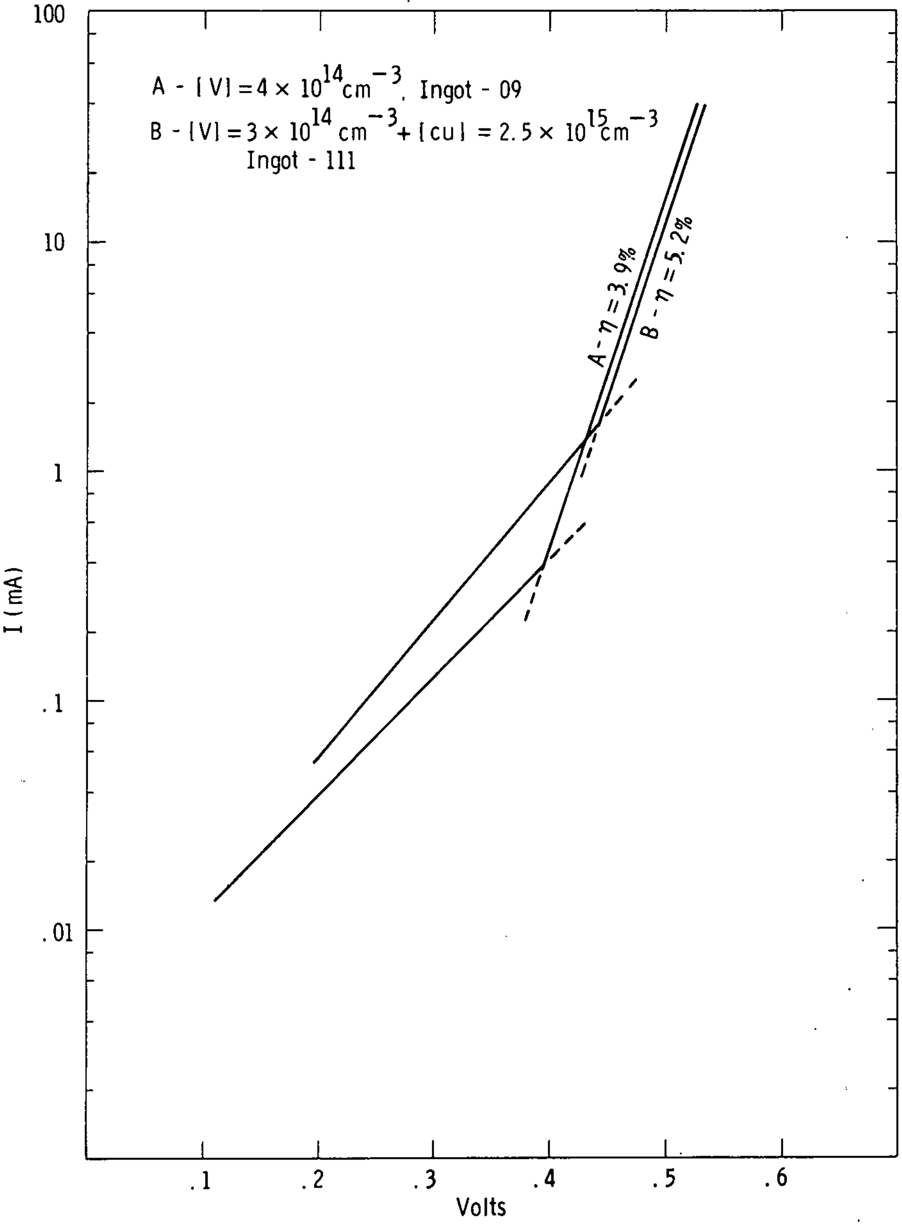


Figure 23 Transformed dark I-V curves for V/Cu-doped 4 Ω cm silicon solar cells

It is important to realize that the favorable synergic effect of Cu additions is apparently small and shows up only at large impurity concentrations.

In general the results of the I-V analyses are consistent with DLTS data (Section 4.6); interactions between impurities if present are weak.

4.4.3 Polycrystalline Material

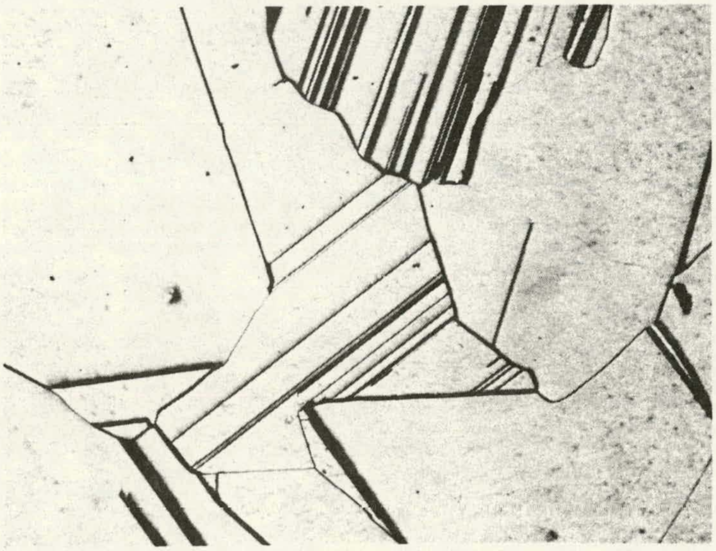
Polycrystalline ingots or forms of silicon sheet containing grain boundaries are potential low cost substrates for terrestrial solar cells. Thus a part of this program is directed at elucidating the response of solar cells made on polycrystalline silicon to controlled additions of metal contaminants. The experiments were limited, comprising two metal-doped (Ti and Mn) and one baseline ingot, and directed primarily towards developing techniques to analyze such materials.

Polycrystalline structure was induced by initiating growth from a large-grained seed. No attempt was made to control the grain size of the ingots which varied somewhat from seed to tang end, e.g Figure 24. The ingot microstructure contained a variety of twins, low angle and high angle grain boundaries, and cell performance improved slightly in the larger grained areas. All comparisons were thus made on wafers from similar regions of the ingots.

Analysis of the Mn-doped ingot (W094-Mn005) proved extremely difficult. Cell data, Appendix 6, scatter considerably with some cells exhibiting efficiency comparable to the poly baseline (∿ 7% uncoated) and others only 1-2%. Large variations in V_{oc} and the n factor were apparent from cell to cell while I_{sc} was relatively constant. The result was replicated in a second solar cell run. Detailed I-V analysis proved fruitless but overall the effect of Mn on cell performance appeared to be through junction degradation.

In contrast the Ti-doped cells fabricated on poly ingot W102-Ti-006 were considerably better behaved. Average cell efficiency, Appendix 6, was 3.9 ± 0.4% (without coatings) at an estimated Ti concentration of 10^{14} cm^{-3}. Figure 25 shows the transformed I-V plots

(a) Seed end



(b) Tang end

Figure 24 Sirtl Etched Wafers from Polycrystalline Baseline Ingot W076. Reflected Light 32X

Curve 696567-B

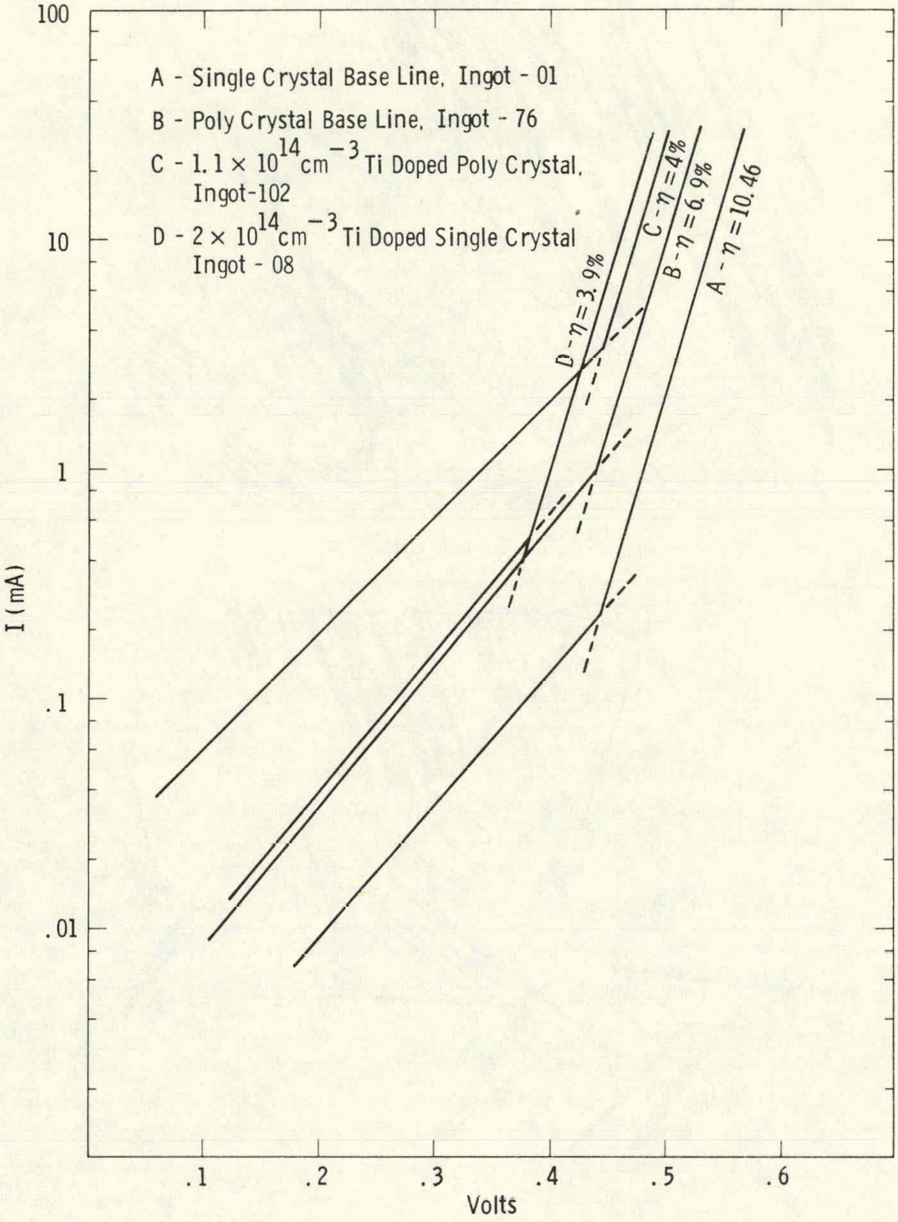


Figure 25 Transformed dark I-V curves for Ti-doped 4 Ω cm poly and single crystal silicon solar cells

for base line single crystal and polycrystalline solar cells along with cells containing Ti. The poly base line gives a smaller efficiency than the single crystal base line both because of reduced bulk lifetime and somewhat larger leakage current. This is expected since grain boundaries act as recombination sites and their presence in the space charge region can result in junction excess current. Although Ti-doped single crystal and Ti-doped poly cells both exhibit about 4% cell efficiency, it is noteworthy that poly material has a better bulk lifetime and a higher leakage current. This suggests that of a given total concentration there is less electrically active Ti within the bulk of the poly grains and more at the grain boundaries. An approximate calculation can be made from the reverse saturation currents (I_o) to determine the ratio of electrically active Ti concentrations in the bulk of the single crystal and the grains in the poly ingot:

$$I_o \, \alpha \, \frac{1}{\sqrt{\tau}} \, \alpha \, \sqrt{N_T} \quad (\because \; \tau = \frac{1}{V_{th} N_T \sigma})$$

where N_T is the concentration of electrical active centers

I_o for single crystal baseline = 1×10^{-11} amps

I_o for polycrystalline baseline = 4.64×10^{-11} amps

I_o for Ti doped single crystal = 2.2×10^{-10} amps

I_o for Ti doped poly = 1.2×10^{-10} amps

All I_o's were determined from the transformed I-V plots of Figure 25 and not from the measured I-V data.

The effective carrier lifetime of a cell containing Ti impurity can be separated into two components:

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_{BL}} + \frac{1}{\tau_{Ti}}$$

or

$$I_o^2)_{eff} = I_o^2)_{BL} + I_o^2)_{Ti}$$

where BL denotes baseline data and Ti denotes the contribution due to titanium alone. The reverse saturation current due to Ti only for the

single crystal is : $I_o^2)_{Ti} = (2.2\times10^{-10})^2-(1\times10^{-11})^2 = 4.83\times10^{-20}$,

and for poly is : $I_o^2)_{Ti} = (1.2\times10^{-10})^2-(4.64\times10^{-11})^2 = 1.225\times10^{-20}$

$$\text{Thus}\quad \frac{N_T)\text{single x tal}}{N_T)\text{ Poly}} = \frac{I_o^2)\text{Ti-single x tal}}{I_o^2)\text{ Ti-Poly}} = \frac{4.83\times10^{-20}}{1.225\times10^{-20}} = 3.95$$

If the electrically active concentration is a fixed fraction of total concentration in the bulk then there is approximately 4 times less Ti in the bulk of poly, the rest apparently being segregated at the grain boundaries. This fraction may be different for different grain size poly because : 1) difference in grain boundary area will result in different segregated amount of Ti, 2) $I_o)_{BL-Poly}$ may change with grain size and, 3) the recombination character of grain boundary may change with the presence of titanium thus invalidating the assumption that τ_{BL} and I_{oBL} remain the same.

4.4.4 Low Resistivity Material

The effect of impurities in high and low resistivity silicon appears suprisingly the same. Baseline cells on 0.2 ohm-cm and 4.0 ohm-cm silicon have approximately the same relative efficiencies e.g Table 15 , and the two types of devices experience nearly identical degradation in the presence of an impurity.

One might presume from this comparison that the mechanisms of degradation were identical. However, a careful examination of the physics reveals significant differences and an important conclusion. The low resistivity cells apparently are more severely affected than are the high resistivity devices.

TABLE 15

COMPARISON OF LOW AND HIGH RESISTIVITY P-BASE SOLAR CELLS DOPED WITH SIMILAR CONCENTRATIONS OF METAL CONTAMINANTS

Contaminant	Concentration (10^{14} cm^{-3})	Resistivity	Relative Cell Efficiency ($\eta/\eta o$)
Mn	7	0.2	84
	6.6	4.0	86
Ti	1.7	0.2	47
	2.0	4.0	43
V	4	0.2	54
	4	4.0	49
Fe	8	0.2	84
	9	4.0	86
Cr	5	0.2	89
	4	4.0	83
Cu	2	0.2	102
	1.7	4.0	100

* ηo is the efficiency of uncontaminated baseline devices, about 10% without AR coatings.

This is shown by examining the relative change in the impurity dependent component of the saturation current and including the effect of bandgap narrowing. For example, Figure 26 shows the transformed I-V data for titanium-doped and baseline devices in both high and low resistivity material. Note that while the efficiencies are similar in like cells, that the I_B components for the low and high resistivity cases differ considerably. This is not entirely due to the differences in base lifetimes because of the dependence of I_o on the base acceptor concentration and on the intrinsic carrier concentration ($I_{01} \alpha n_i^2/N_A$).

From these data we obtain the four base dependent saturation currents:

I_o for high resistivity baseline Si = $1\text{x}10^{-11}$ amps
I_o for Ti doped high resistivity Si = $2.2\text{x}10^{-10}$ amps
I_o for low resistivity baseline Si = $2.15\text{x}10^{-12}$ amps
I_o for Ti doped low resistivity Si = $1.468\text{x}10^{-11}$ amps

all I_o's were determined from the transformed I-V plots.

$$\text{Since} \quad \frac{1}{\tau_{eff}} = \frac{1}{\tau_{BL}} + \frac{1}{\tau_{Ti}} \tag{60}$$

$$I_o^2)_{eff} = I_o^2)_{BL} + I_o^2)_{Ti} \tag{61}$$

$$\text{Thus } I_o^2)_{Ti\text{-}HR} = (2.2\text{x}10^{-10})^2 - (1\text{x}10^{-11})^2 = 4.83\text{x}10^{-20}$$

$$I_o^2)_{Ti\text{-}LR} = (1.468\text{x}10^{-11})^2 - (2.15\text{x}10^{-12})^2 = 2.109\text{x}10^{-22}$$

where subscripts Ti-HR and Ti-LR refer to the contribution due to Ti alone in high resistivity and low resistivity Si.

$$I_o^2 \;\alpha\; \frac{\eta i^4 D}{N_A^2 \tau} \;\alpha\; \frac{\eta i^4}{N_A^2} \; D\, N_T \sigma \tag{62}$$

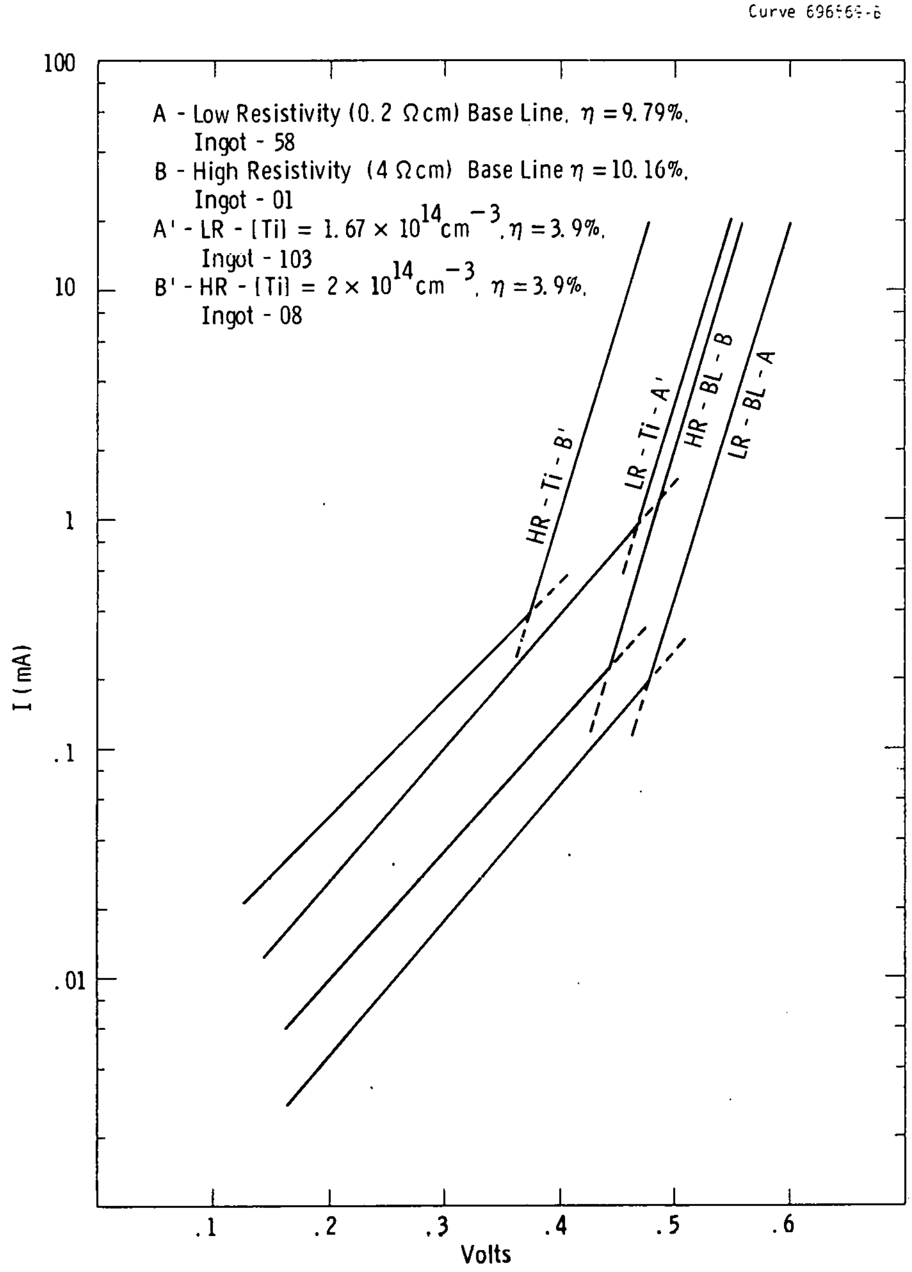


Figure 26 Transformed dark I-V curves for Ti doped 4 Ω cm and 0.2 Ω cm silicon solar cells

where ηi is the intrinsic carrier concentration, D is the diffusivity, N_A is the doping, N_T is the electrically active trap concentration and σ is the capture cross section of the trap.

If we assume that the capture cross section is the same in the two cases, Eq. 62 reduces to :

$$\frac{Io^2)_{Ti-HR}}{Io^2)_{Ti-LR}} = \frac{\eta_i{}^4)_{HR}}{\eta_i{}^4)_{LR}} \; \frac{D_{HR}}{D_{LR}} \; \frac{N_A{}^2{}_{LR}}{N_A{}^2{}_{HR}} \; \frac{N_{THR}}{N_{TLR}} \tag{63}$$

or

$$\frac{\eta_i{}^4{}_{LR}}{\eta_i{}^4{}_{HR}} \; \frac{N_{TLR}}{N_{THR}} = \frac{Io^2)Ti\text{-}LR}{Io^2)Ti\text{-}HR} \cdot \frac{D_{HR}}{D_{LR}} \cdot \frac{N_A{}^2{}_{LR}}{N_A{}^2{}_{HR}} \tag{64}$$

Since $\eta_i^2 \; \alpha \; e^{-Eg/kT}$ then

$$e^{2\Delta Eg/kT} \cdot \frac{N_{TLR}}{N_{THR}} = \frac{2.109\text{x}10^{-22}}{4.83\text{x}10^{-20}} \text{ x } 2 \text{ x } (43)^2$$

$$e^{2\Delta Eg/kT} \cdot \frac{N_{TLR}}{N_{THR}} = 16.1 \tag{65}$$

where ΔEg is the band gap narrowing.If we assume that in 0.2 Ωcm Si ($N_A \sim 1.5\text{x}10^{17}\text{cm}^{-3}$) no band gap narrowing takes place then equation 65 implies that the same amount of Ti produces 16 times more electrically active centers in low resistivity Si. On the other extreme if we assume no interaction between the electrically active dopant and Ti and that there are equal number of traps, in high and low resistivity material then equation 65 gives ΔEg = 36 meV .

If we use the following emperical relationship for bandgap narrowing from reference 24

$$\Delta V g \ (N) = 9 \left| \ln \frac{N}{10^{17}} + \sqrt{((\ln^2 N/_{10}17) + 0.5)} \right|$$

$$\Delta V g = 9.63 \text{ mV for } N = 1.5\text{x}10^{17} \text{ cm}^{-3}$$

$$\Delta Eg = 9.63 \text{ meV}$$

Substituting this value of ΔEg, equation 65 gives

$$\frac{N_{TLR}}{N_{THR}} = 7.7 \text{ or more}$$

correctly $\frac{N_{TLR} \ \sigma_{LR}}{N_{THR} \ \sigma_{HR}} = 7.7$ because band gap shrinkage may effect capture cross section.

The foregoing analysis indicates that the cell efficiencies are nearly same for low and high resistivity Si containing ∿ $2\text{x}10^{14}$ Ti, but for different reasons. Low resistivity Si suffers from bandgap shrinkage and excess recombination centers which mitigate or annul the beneficial effect of a large built-in field. DLTS experiments are being carried out to determine the ratio N_{TLR}/N_{THR} in an attempt to verify the above analysis.

4.4.5 Float Zone Material

Previous studies[25] have suggested that solar cells fabricated on purposely-contaminated float zone material exhibited higher efficiencies than their Czochralski-grown counterparts. This could be attributed to the reduction in carbon and oxygen in the material per se or to the elimination of metal-oxygen or metal-carbon complexing in the low C, low o floatzone crystals. We conducted a limited series of experiments in an attempt to clarify the origin of the performance difference for Czochralski float zone materials. The impurities Ti, Al and Cr were chosen for study on the basis they would be among the most likely elements in our matrix to exhibit chemical interaction with oxygen or carbon. Ti is a strong oxide and carbide former, Al is known to complex with oxygen in silicon and Cr also forms highly stable oxides.

The results of the experiments, Table 16, indicate no dramatic differences between the float zone and Czochralski cells with the exception of Al. The efficiencies of the Ti and Cr float zone cells are close to those of the Czochralski devices, small differences being attributable to experimental error or to slight variations in the actual impurity content of the ingots. In both float zone and Czochralski material device performance reduction is due to a lowering of the bulk lifetime as illustrated by the transformed I-V plots, Figure 27a. Unlike Cr or Ti however, the effect of Al is very different in the two base materials. The I-V plots, Figure 27b, show that Al at the nominal 3×10^{16} cm^{-3} concentration has little effect on the float zone cells but degrades efficiency to about 80% of baseline in the Czochralski cells. In the latter case Al appreciably reduces bulk lifetime and also promotes an increase in junction excess current. Since the carbon and oxygen content of the Czochralski ingot considerably exceeds that of the float zone crystal one might indeed postulate complexing of Al with C or O as a mechanism for the formation of recombination centers in the former.

4.5 Analysis of N-base Solar Cells

The behavior of n-base devices was modeled in the same manner as for the p-base cells. The least squares parameters derived from the single impurity data,(Appendix 6)by means of Eq. 51 are compiled in Table 17. With these parameters and Eqs. 59 we calculate the variation in cell efficiency with impurity content which are compared in Figure 28 with similar curves for p-type silicon.

TABLE 16

RELATIVE CELL EFFICIENCY FOR SOLAR CELLS ON 4 Ωcm FLOAT ZONE AND CZOCHRALSKI SILICON

Impurity	Concentration (10^{15} cm^{-3})	Growth Technique	Relative Efficiency (η/η_0) *
Cr	1.0	Cz	76
Cr	0.8	Fz	82
Al	26	Cz	80
Al	30	Fz	101
Ti	0.04	Cz	63
Ti	0.04	Fz	60

*η_0 is the efficiency of uncontaminated baseline devices, about 10% without AR coatings.

Curve 696563-B

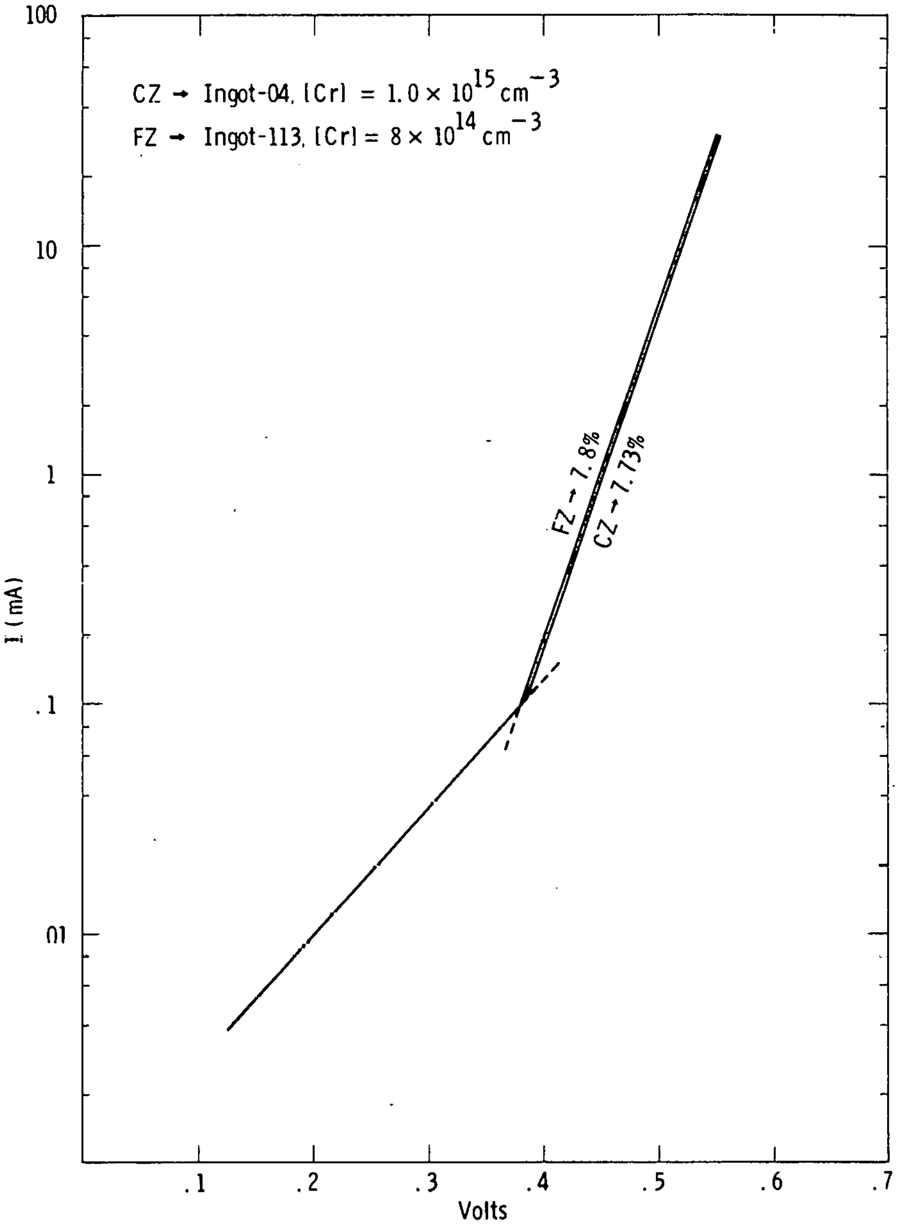


Figure 27a Transformed Dark I-V Curves for Cr-doped 4 Ωcm Silicon Solar Cells

Curve 696562-B

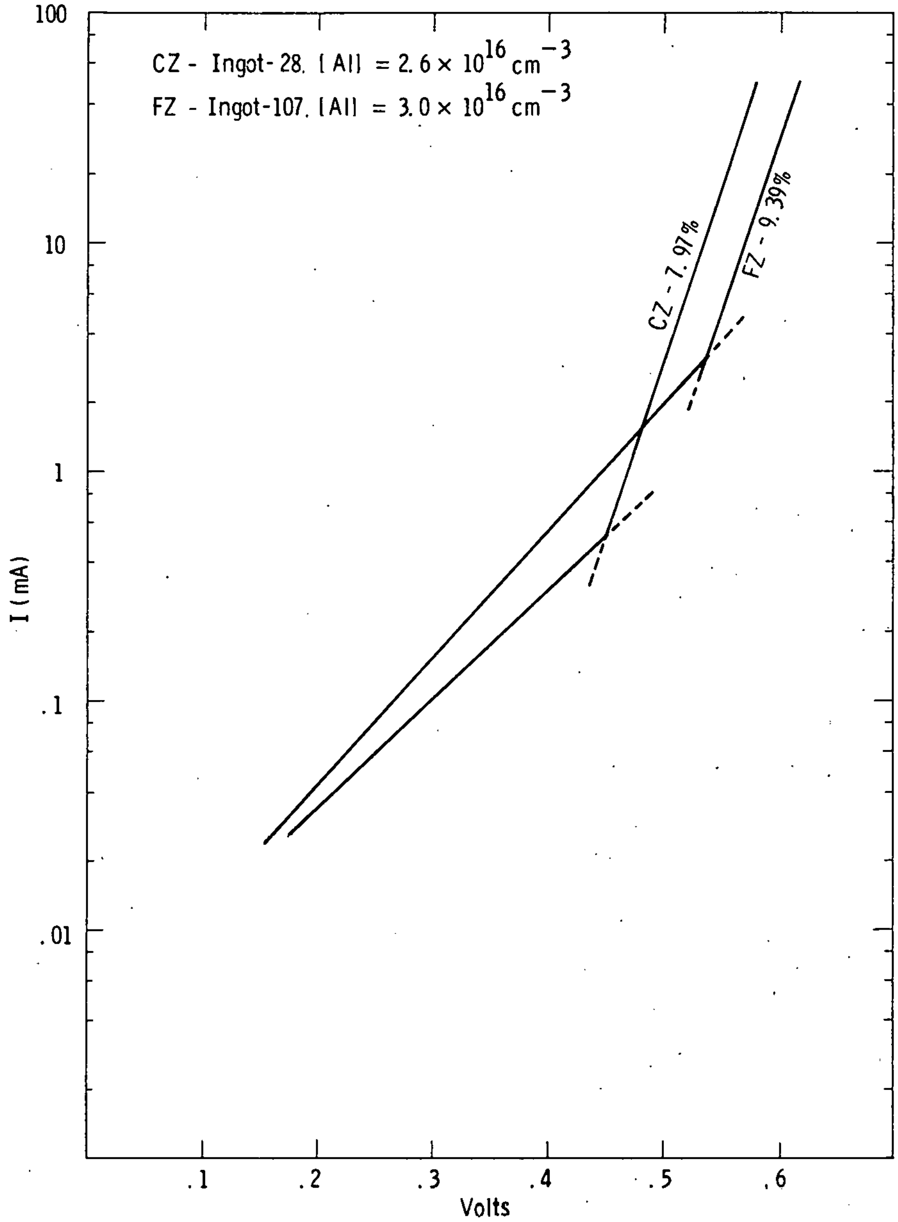


Figure 27b Transformed Dark I-V Curves for Al-Doped 4 Ωcm Cz and Fz Silicon Solar Cells

In the p-base studies most impurity induced cell degradation was found to be a result of increased carrier recombination in the cell base-region. When impurity atoms are incorporated in the silicon lattice they induce discrete energy states in the forbidden gap which are characteristic of each specific impurity. The degree to which these energy states act as recombination centers depends on their energy position in the band and on their relative position with respect to the Fermi level which depends on doping type and concentration. Thus while the states associated with a given impurity should be the same in p and n-type material, the degree of recombination activity should in general be different because the relative position of the Fermi level will be different as the deep level measurements, Section 4.6, indicate. The curves of Figure 28 illustrate clearly this expected differences in behavior for n and p-devices.

Of particular interest is the fact that the performance degradation in n-base devices is less than in the corresponding p-base devices but in both cases is the result of diffusion length loss. For example, the transformed I-V plots of n and p base devices containing Ti, Figure 29, illustrate this point nicely. In both cases Ti lowers the lifetime to degrade the cell performance; however, it reduces the electron lifetime more than the hole lifetime. Again, exceptions to this general pattern are the elements copper and nickel. Copper appears to have little effect in either n or p silicon except at very high concentrations. Nickel*, however, exhibits an entirely different behavior. The efficiency of the nickel doped n-base cells was severely reduced while the short circuit currents were only slightly diminished. This indicates that the base diffusion length is not the controlling parameter but rather the effect of excessive junction dark current or contact degradation. (This effect was confirmed by repeating the experiment). It is apparent, however, that nickel does not produce large recombination effects in either n or p-base material.

* Not illustrated in Figure 28, see Appendix 6.

TABLE 17 MODEL COEFFICIENTS FOR SINGLY DOPED,N-BASE SOLAR CELLS

IMPURITY	C_1	C_{2X}	N_{0X}
ALUMINIUM	1.250E-02	1.147E-18	1.090E+16
CHROMIUM	1.076E-02	7.068E-17	1.522E+14
COPPER	1.127E-02	1.396E-19	8.073E+16
IRON	1.103E-02	7.122E-17	1.549E+14
MANGANESE	1.187E-02	1.247E-17	9.519E+14
TITANIUM	1.355E-02	3.642E-16	3.720E+13
VANADIUM	1.398E-02	3.348E-16	4.176E+13

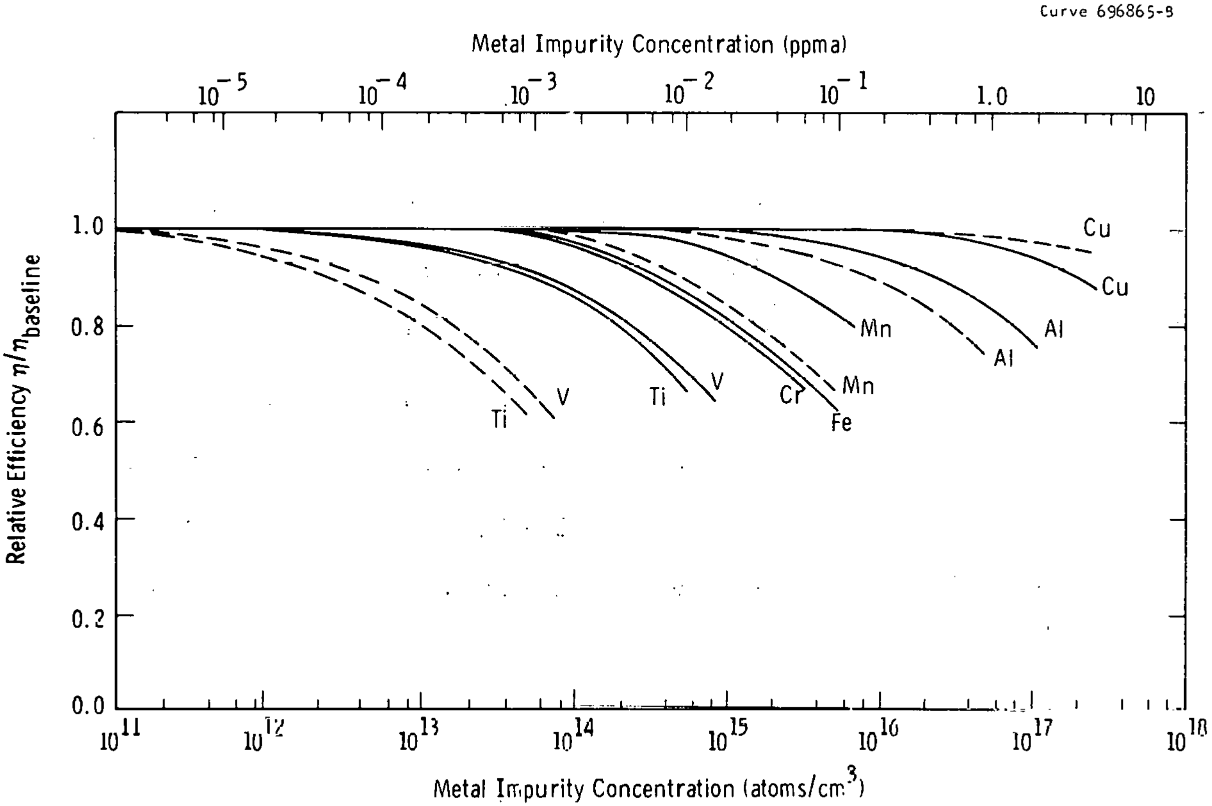


Figure 28 Efficiency versus metal content. Solid curves are n-base; dashed curves are comparable p-base data

Curve 693686-B

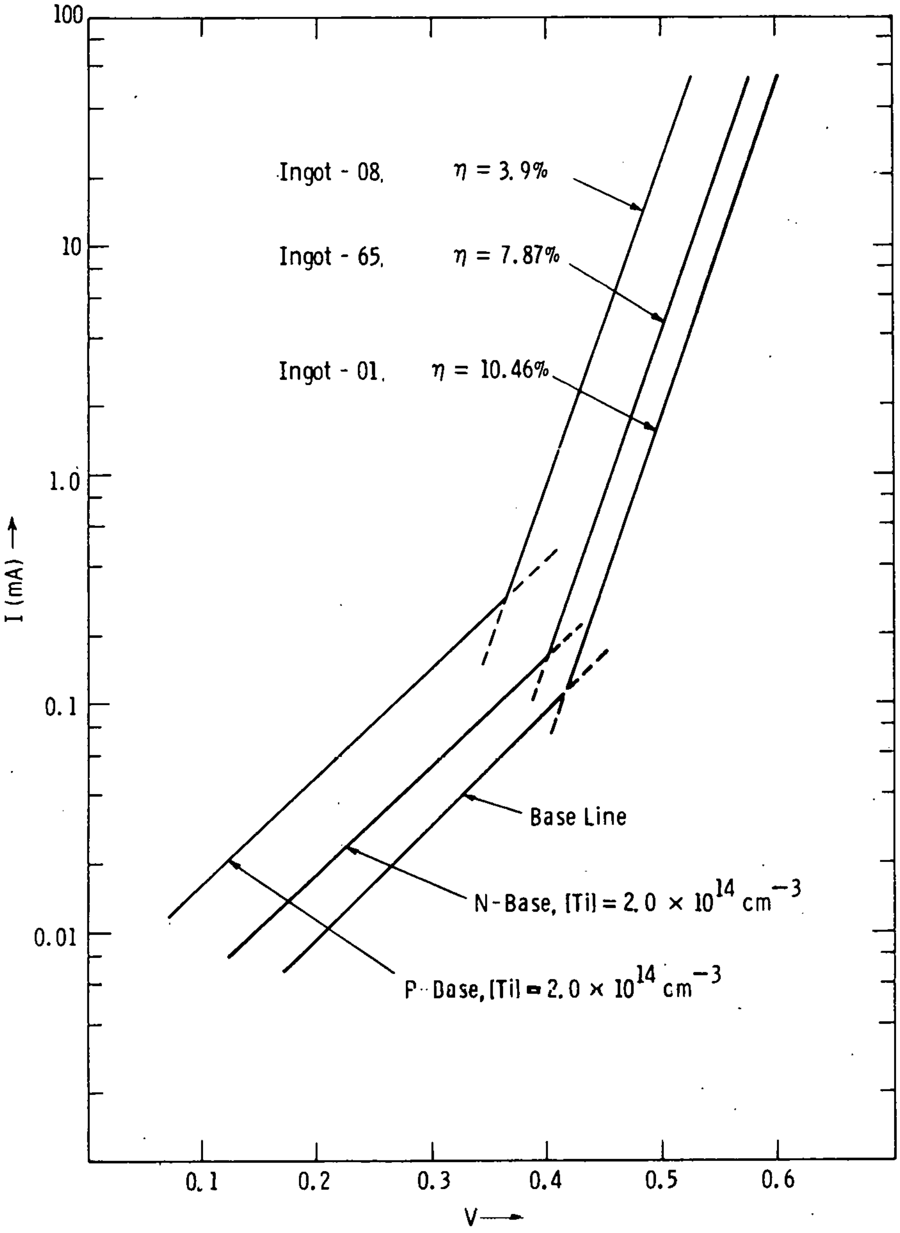


Figure 29 Transformed dark I-V curves for Ti-doped n and p base 4 Ωcm silicon solar cells.

4.6 Spectroscopic Characteristics of Impurities in Silicon

Impurity-induced hole and electron trap levels, their densities and capture cross sections obtained from DLTS measurements are tabulated in Table 18. The spectrum of the energy levels obtained for various impurities, e.g. Ti, V, Mo, Ni, Mn, Fe, Cr, and Al in Si, is shown in Figure 30. The last column in Table 18 gives the correlation factor for the best linear fit to the data. Some of the energy levels for these impurities in Si reported by other investigators[26,27,28,29,30] agree with our data while others do not. For example three electron traps (Ec-.28, Ec-.35 and Ec-.41) and two hole traps (E_V + .22 and E_V - .35) have been reported for Ni while we see only a hole trap at EV + .31 and an electron trap at Ec-.31. In other cases like V, Fe, and Mn, we see some trap levels which have not been reported earlier but other levels which are in agreement with the literature. Perhaps this should not be surprising since the energy levels depend on the method of impurity incorporation and also the heat treatment used to process the device. For example P-Ti-008 showed two majority traps when a Schottkey barrier diode was fabricated but only one majority trap when p-n junction was used. This suggests that one majority trap disappeared during phosphorous diffusion, a gettering step. This result is preliminary and needs further clarification as nonuniformity on the wafer doping could also explain the observation.

The P-Ti-008 sample which had 2.6×10^{14} cm^{-3} Ti showed one majority trap (E_V + 0.29) and one minority trap (E_c - 0.264) but P-Ti-033 which contained $3.6 x 10^{12}$ cm^{-3} Ti showed only one minority trap (E_c -.267). The disappearance of the majority trap in sample P-Ti-033 is not clearly understood. It could result from impurity anisotropy or the low Ti concentration may fail to reveal that trap. Similar results were observed in Mn-doped samples. This point will be investigated further.

The listed capture cross sections, Table 18, should be used with some caution because they are estimated by assuming temperature independence of the cross section. This may not necessarily be true and can result in as much as one or two orders of magnitude difference. The DLTS technique can be used to determine the cross sections more accurately[21] and this will be one of the tasks of future DLTS measurements.

Curve 695417-B

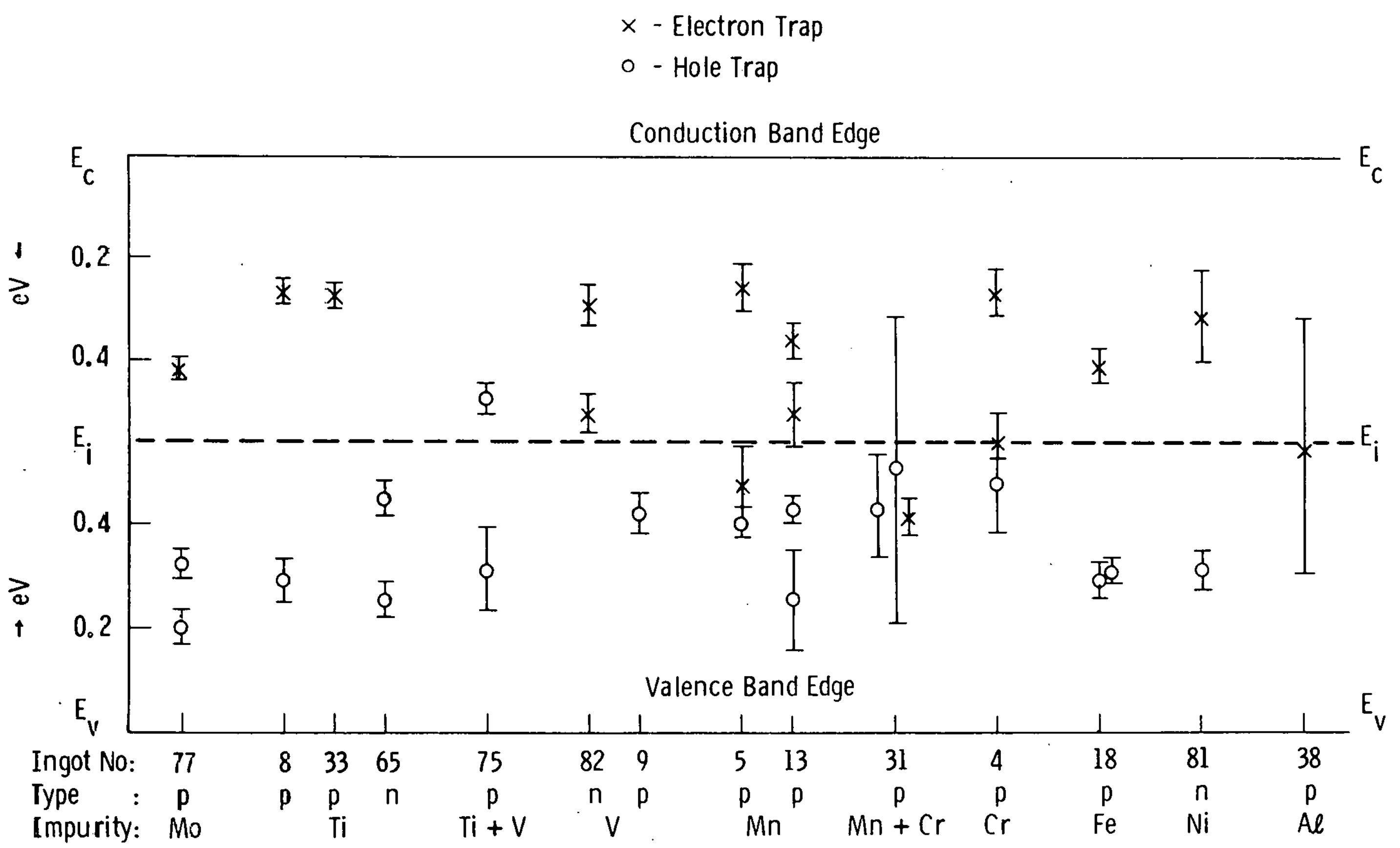


Figure 30 Trap levels determined by DLTS in impurity-doped solar cells.

TABLE 18

TRAP LEVEL, CONCENTRATIONS AND CAPTURE CROSSECTIONS
FOR IMPURITY-DOPED SOLAR CELLS

Sample ID	Metallurgical Conc. cm-3	Trap Level	Trap Conc. cm^{-3}	Approximate Capture Cross section $(\sigma_O) cm^{-2}$	Correlation Coefficient
P-Mo-077	4.2×10^{12}	EV + 0.32	4.90×10^{13}	1.5×10^{-15}	0.990
		EV + 0.20	3.96×10^{13}	1.6×10^{-19}	0.998
		EC - 0.41	3.30×10^{13}	2.6×10^{-17}	0.997
P-Ti-008 (Schottky barrier)	2.0×10^{14}	EV - 0.29	7.0×10^{13}	4.7×10^{-14}	0.996
		EV = 0.34	3.0×10^{14}	4.0×10^{-16}	0.999
P-Ti-008 (p-n junction)	2.0×10^{14}	EV + 0.29	2.6×10^{13}		
		EC - 0.26	1.5×10^{13}		
P-Ti-033	2.0×10^{12}	EC - 0.27	4×10^{12}	4.5×10^{-17}	0.999
N-Ti-065	2.0×10^{14}	EV + 0.25	3.0×10^{13}	1.2×10^{-15}	0.999
		EV + 0.45	3.6×10^{13}	3.6×10^{-16}	0.999
N-V-082	4.0×10^{14}	EC - 0.29	2.87×10^{13}	8.1×10^{-13}	0.994
		EC - 0.50	2.87×10^{13}	1.4×10^{-13}	0.999
P-V-009	4×10^{14}	EV + 0.42	-	-	-
P-V + Ti-075	$5.6 \times 10^{13} + 1 \times 10^{14}$	EV + 0.54	1.13×10^{13}	4.1×10^{-13}	0.999
		EV + 0.31	2.26×10^{13}	8.2×10^{-17}	0.997
P-Mn-005	1.3×10^{15}	EV + 0.40	1.6×10^{13}	5.5×10^{-16}	1.0
		EC - 0.25	2.1×10^{13}	3.9×10^{-18}	0.999
		EC - 0.64	2.7×10^{13}	2.9×10^{-12}	0.999
P-Mn-013	2.5×10^{14}	EV + 0.25	5.67×10^{13}	8.8×10^{-14}	0.987
		EV + 0.43	1.28×10^{14}	1.4×10^{-15}	0.999
		EC - 0.35	5.3×10^{13}	2.7×10^{-15}	1.0
		EC - 0.50	9.3×10^{12}	3.9×10^{-16}	0.999
P-Cr-004	1.0×10^{15}	EV + 0.53	5.0×10^{13}	1×10^{-16}	0.999
		EC - 0.26	4.4×10^{13}	5.9×10^{-18}	0.993
		EC - 0.55	1.47×10^{13}	9.8×10^{-14}	0.998
P-Cr + Mn-031	$1 \times 10^{15} + 1.3 \times 10^{15}$	EV + 0.44	2.4×10^{13}	3.1×10^{-15}	0.992
		EV + 0.51	2.6×10^{13}	2.8×10^{-17}	0.836
		EC - 0.69	6.4×10^{12}	2.3×10^{-12}	0.978
P-Fe-018	1.7×10^{15}	EV + 0.29	3.1×10^{13}	4.7×10^{-16}	0.999
		EV + 0.31	1.9×10^{13}	1.2×10^{-17}	0.999
		EC - 0.40	1.1×10^{13}	3.4×10^{-17}	1.0
N-Ni-081	1.5×10^{15}	EV + 0.31	6.7×10^{13}	5.3×10^{-18}	0.997
		EC - 0.31	1.38×10^{13}	2.9×10^{-18}	0.999
P-Al-038	6.0×10^{16}	EC - 0.57	4.5×10^{13}	6.5×10^{-13}	0.99

The trap concentrations listed in Table 18 should also be applied with care. This is because the analysis of minority trap concentration and its cross section is very poorly understood. The minority trap concentration is determined by increasing the width of the injecting pulse to saturate the traps. However, one may receive a false indication of saturation for the following reasons: 1) the resulting population of states reflects the competition for capture of both carrier types during the injection, (The relative ratio of concentrations of minority to majority carriers may be varied from zero to unity by varying the magnitude of the injected current.) 2) If the minority and the majority peaks are quite close then the overlap may affect the peak amplitude. The above ambiguities can be removed for the majority trap by using reverse bias pulse instead of the injecting pulse. Most of the data quoted in this report were taken by the injecting pulse because the main purpose of these first experiments with the DLTS technique was to identify levels in the processed solar cells. Thus the absolute trap concentrations and the cross sections, Table 18, may be questionable but the energy levels are quite reliable.

It is clear from the above discussion that some disparity exists between DLTS and cell performance data. It is important to recognize that the DLTS samples are only a 30 mil dot while the cell performance represents the whole 1 cm^2 cell area. Lifetimes ($\tau_o = \frac{1}{N_T \sigma V_{th}}$) calculated from the trap density (N_T) and the capture cross section (σ) in Table 18 are not consistent with the OCD lifetime and this is probably because of a) error in the estimated cross section or b) the assumption that $\tau = \tau_o$ which is true only for low level injection with $E_T \sim E_i$ and σ_{maj} [Maj] $>>$ σ_{min} [Min]. We expect to resolve the apparent discrepancies in the near future and to improve our understanding of impurity effects on cell performance.

We have successfully demonstrated that shallow solar cell junctions can be used for the DLTS measurements. Our preliminary data indicate that the DLTS technique can be a powerful method for exploring a number of interesting areas related to the impurity affects in silicon and silicon solar cells. More careful and accurate determination of the trap concentration and the cross section will help us answer the several important questions: 1) Is electrically active concentration a fixed fraction of the metallurgical concentration of the impurity in the Si and if yes, how different is this fraction for different impurities? 2) Why do some impurities degrade n-base devices more than the p-base devices or vice versa? 3) Do the impurities interact in a multiply-doped cell? 4) How uniform is the impurity distribution in the silicon? 5) What is the nature of process and impurity interaction, e.g. during gettering and annealing etc.

5.0 SOLAR GRADE SILICON: SOME CONSIDERATIONS FOR ITS USE

To reach the 1986 JPL silicon solar cell cost guidelines silicon considerably cheaper than now available must be provided for crystal growth and subsequent cell fabrication. This material, Solar Grade silicon, will probably contain contaminants at levels higher than is usual, or acceptable in current semiconductor grade stock. We pointed out in earlier discussions[1,31,32] the major impacts of such material on cell manufacture: (1) loss of structure during crystal growth and (2) reduced efficiency in the final device, viz Figures 13 and 28. The result is that some of the lower silicon material cost may be recovered at later processing stages in the form of reduced growth throughput, diminished crystal yield, and degradation in device performance. Moreover, we found that the extent to which these consequences ensue depends on the species of impurity and detailed steps-from growth to cell fabrication -- which make up the overall process sequence. Thus specific tradeoffs can be identified between feedstock purity and the approaches used to transform the silicon into the end product, cells and modules.[1,31] We review here some of these conclusions in light of our most recent information and suggest a method to evaluate the tradeoffs for various low-purity silicon feedstocks as they are developed.

The data in Table 19 (derived from updated cell performance and analytic results) illustrate both the species dependence of efficiency degradation and also that feedstock impurity levels depend on the acceptable solar cell efficiency. As noted previously, when a relative efficiency $\eta = 0.9\ \eta_0$ is acceptable the feedstock impurity concentration C_0 ranges from about 10^{17} to mid 10^{19} cm^{-3} (2 to 1000 ppm) for a single charge Czochralski growth operation in which about 90% of the melt is converted to crystal. Elements like Ti, V, and Mo fall at the low end of the

TABLE 19 Tolerable Feedstock Impurity Concentration to Achieve Specific Solar Cell Performance Levels

(Assumes one Czochralski pull; fraction frozen 90%)

	$\eta = 0.9\ \eta_o$*		$\eta = 0.95\ \eta_o$*	
Impurity	(atoms cm^{-3})	(ppma)	(atoms cm^{-3})	(ppma)
Cu	$7.5\ (10^{19})$	1500	$2.5\ (10^{19})$	500
Ni	$4.7\ (10^{19})$	940	$1.3\ (10^{19})$	250
Al	$3.\ (10^{16})$	0.6	$1.\ (10^{16})$	0.2
Fe	$9.4\ (10^{18})$	188	$3.1\ (10^{18})$	62
Mn	$3.8\ (10^{18})$	76	$1\ (10^{18})$	20
Cr	$3.5\ (10^{18})$	70	$8.7\ (10^{17})$	17
V	$1\ (10^{17})$	2	$5\ (10^{16})$	1
Ti	$1.5\ (10^{17})$	3	$7.5\ (10^{16})$	1.5
Mo	$2\ (10^{18})$	40	$1.2\ (10^{18})$	24

η_o is the efficiency of a typical baseline device, about 10% without AR coatings.

tolerable, range Cu at the upper end, and Cr, Fe and Mn of an intermediate position.

Structural breakdown is governed more by the total impurity content of the feedstock than by the particular species. For Czochralski growth the critical liquid impurity Content C_ℓ^* at which breakdown occurs is given by an equation of the form[1]

$$C_\ell^* = - \frac{D}{m} \left[\frac{A}{r^{1/2} V} - B \right]$$

where D is the liquid diffusion coefficient, m the liquidus slope, r the crystal radius (cm) and V the growth velocity (cm/sec). Curves calculated with data from reference 1, Figure 31, indicate that critical melt concentrations for single pass pulling generally will be above 10^{19} cm^{-3} (200 ppm), so that cell efficiency usually is impacted before structural breakdown occurs. Recent studies[33] suggest that the total module cost for photovoltaic systems is heavily leveraged by cell efficiency, reinforcing the conclusion that this should be a major concern in the cost effective use of Solar Grade feedstock.

It now seems unlikely that one pass crystal growth operations can meet the long-run cost objectives of the JPL program. Both continuous and sequential melt replenishment systems are under development. We pointed out earlier[1,31] that replenishment reduces the tolerable level of feedstock contaminants since the melt and solid impurity concentration tends to rise as more material is crystallized, an outcome illustrated in Figure 32. For example, after five replenishments (n = 5) in which 90% of the melt is frozen each time, the liquid impurity level would be about 46 times larger than its initial feedstock value C_o. With continuous replenishment the impurity level would grow to 4.5 times C_o for an equivalent amount of crystal product. The implication of this result is that the tolerable feedstock levels for each impurity in Table 19 would have to be reduced by a factor of 2.4 to 4.6 if cell efficiency for the last crystal grown is not to fall below $\eta = 0.9\ \eta_o$. The ultimate value of C_o of course depends on what efficiency can be accepted, what

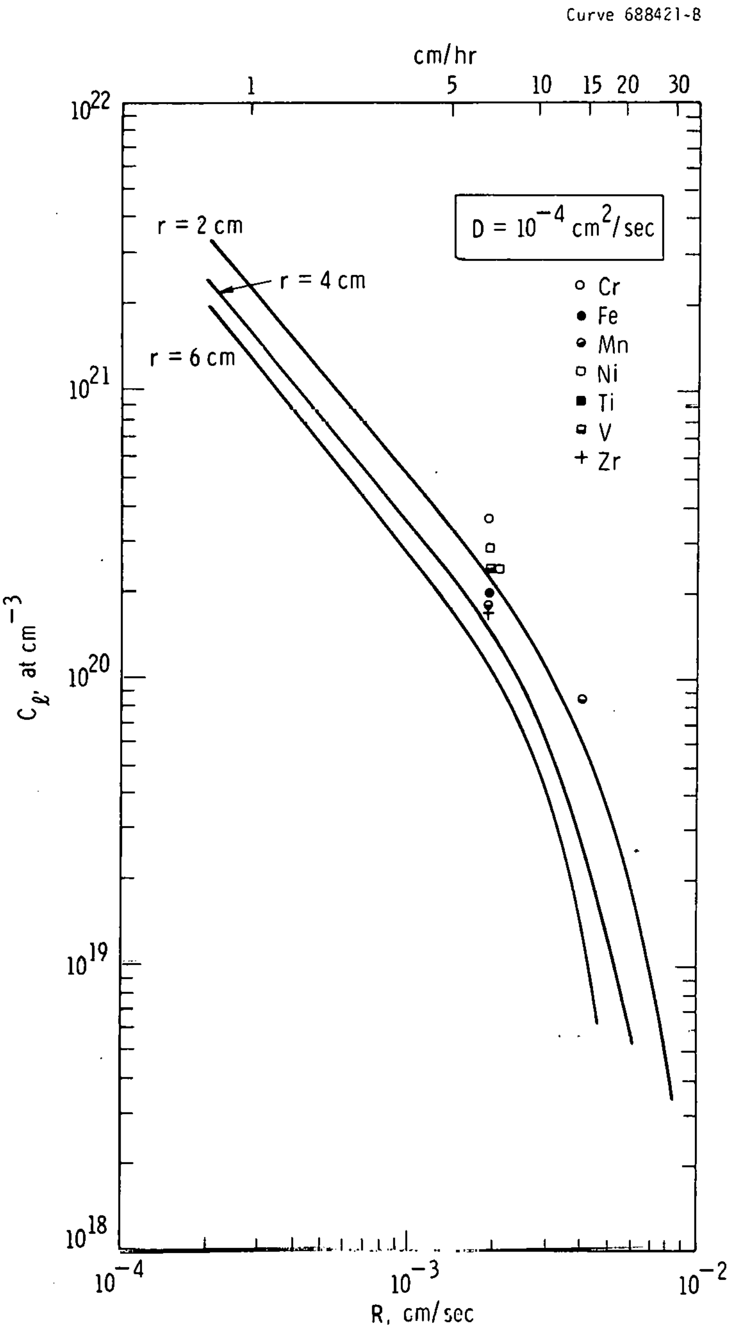


Figure 31 Predicted variation of critical liquid impurity concentration for crystal breakdown with crystal growth velocity during Czochralski pulling of silicon. Metal concentrations for which breakdown actually occurred are indicated by the data points (Assumes heatloss by radiation to 0°1C environment).

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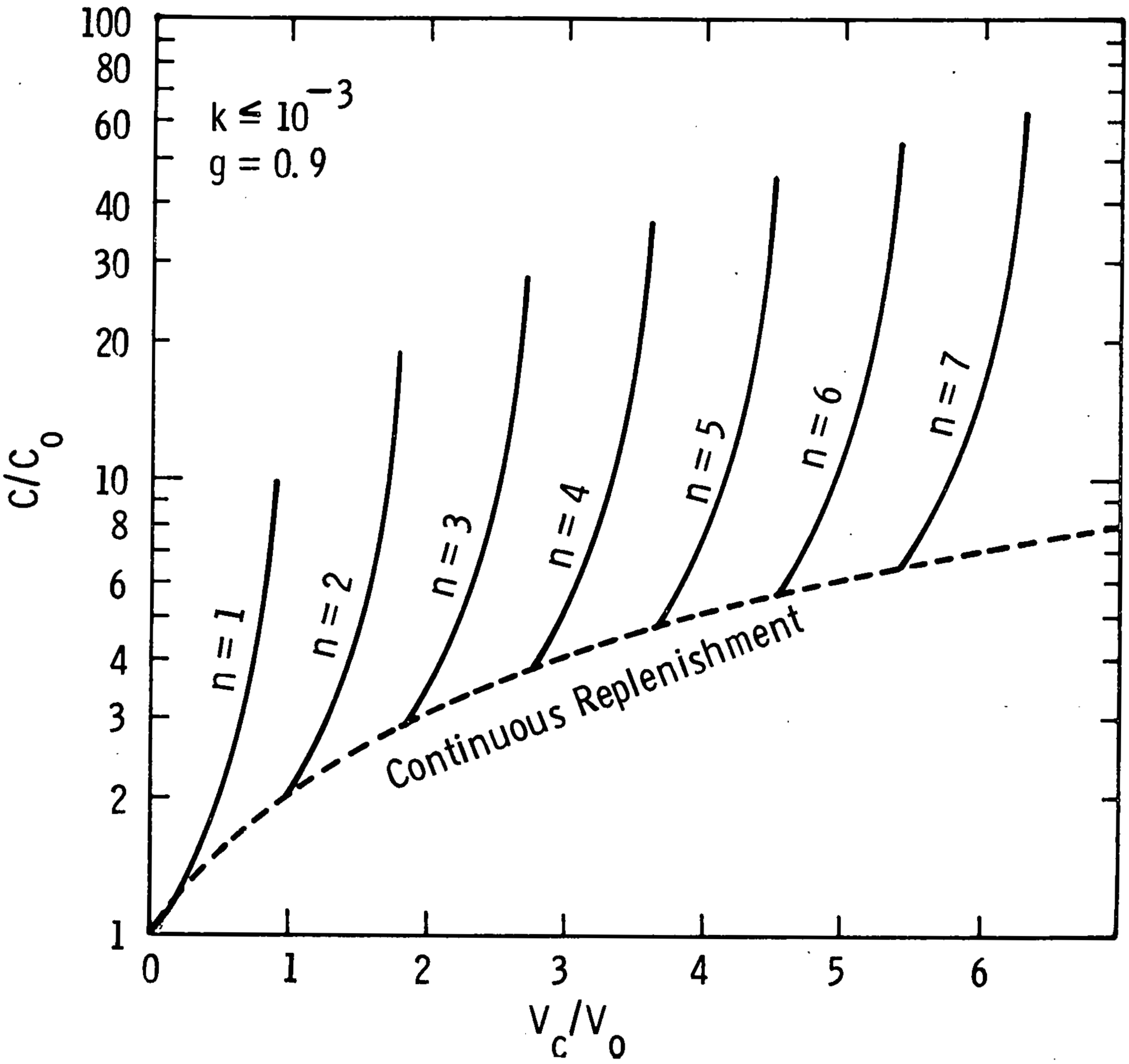

Fig. 20 — Impurity build up

Figure 32 Solute build-up in the liquid (or crystal) as a function of the volume of crystal grown for sequential (solid) or continuous (dashed) melt replenishment.

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TABLE 20

FEEDSTOCK IMPURITY CONCENTRATIONS FOR WEB GROWTH

Impurity	C_ℓ (struct) 10^{18}cm^{-3}	ppma*	C_ℓ (cell), $n/n_B \approx 1.0$ 10^{18} cm^{-3}	ppma	C_o^* 10^{18}cm^{-3}	ppma
Cu	$> 1.4^+$	28	1.1 (est)	22	.06 (est)	1.2 (est)
Ni	> 1.0	> 20	≥1.1	≥22	≥.06	≥1.2
Cr	6	120	≥1.6	≥32	≥.09	≥1.5
Mn	> 2.6	52	≥2.6	≥52	≥.14	≥2.8
Fe	3	60	≥1.3	≥26	≥.07	≥1.4
Ti	4	80	0.05 (est)	1	.003 (est)	.06 (est)
V	4	80	0.04 (est)	0.8	.002 (est)	.04 (est)
Mo	2.5	50	0.8 (est)	16	.04 (est)	.8 (est)

+ > indicates no breakdown observed at this concentration

≥ indicates no apparent cell degradation

* assumes continuous growth for 65 hours

rather than p-base device, viz Figure 28. This advantage may be outweighed by the difficulty in controlling base resistivity with phosphorus as the electrically active dopant, $k_{eff} = 0.35$.

The methodologies we have developed to identify tradeoffs and impurity target ranges can also be employed in another way: to project the efficiency of solar cells when the feedstock purity, and process history are specified. A model of this kind might provide several benefits. For example, it could be used to estimate the impact of specific species (in a feedstock containing several impurities) on cell efficiency, thus providing a "figure of merit" for the product of a given refining scheme. The manufacturer could then evaluate alternative refining and design strategies, or raw material specifications in a cost effective manner. Comparison of crystal growth and replenishment strategies could also be evaluated for different types of solar grade silicon without recourse to expensive experimental reduction to practice. Finally when sufficient data on thermal treatment effects become available, the role of such processes as gettering could be factored into the analysis.

5.1 Feedstock Purity/Device Performance Modeling

The basic components of the model suggested above are outlined in Figure 33. The input parameters are: (1) Feedstock impurity concentration $C_o(X)$ where $X = 1, 2, \ldots n$ are the concentrations of each impurity species 1 to n. (2) The replenishment strategy and the amount of crystal transformed compared to the melt volume, viz Figure 32. (3) The appropriate segregation coefficients (Appendix I for Czochralski). (4) The critical liquid concentration C_ℓ^* for which structural breakdown occurs.

The model calculation would be performed in the following sequence. Specify C_o, the replenishment strategy (either continuous or sequential), the ratio V_c/V_o, and the effective segregation coefficients for the growth technique and conditions to be employed. The model first calculates $C_\ell(X)$, the liquid concentration of each impurity

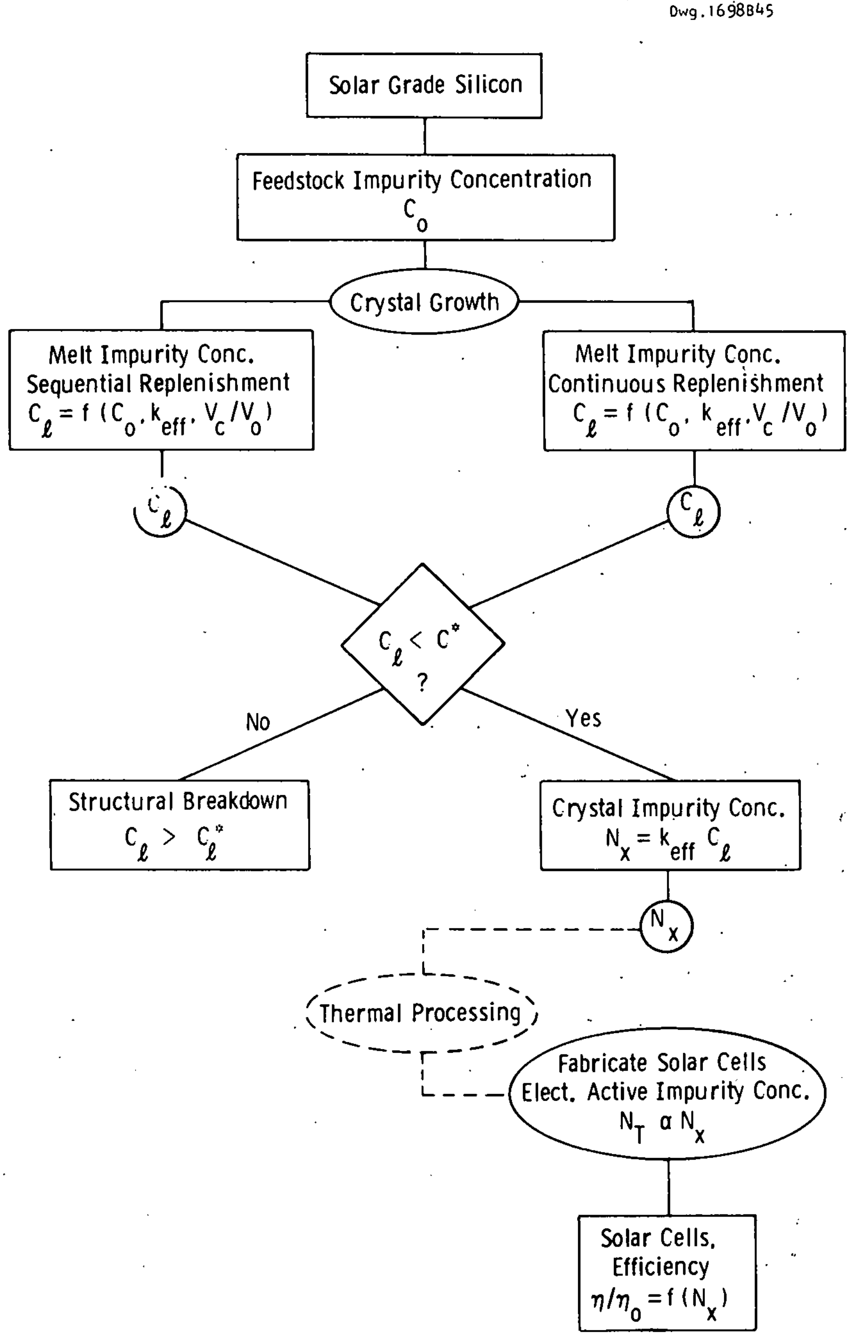

Figure 33 Schematic diagram of model for estimating performance tradeoffs of impurity bearing silicon feedstocks.

following the growth of V_c/V_o silicon crystal. For typical metal impurities k << 1 and the liquid concentrations are given approximately by[1]

$$C_\ell(x) = Co\ (1 + V_c/V_o) \text{ for continuous replenishment}$$

or $$C_\ell(x) = Co\ \left(1 + \frac{ng}{1-g}\right) \text{ where n is the number of}$$

sequential replenishments and g the fraction of the melt frozen each time.

Once $C_\ell(x)$ is obtained it may be compared to C_ℓ^*, the critical impurity level at which constitutional supercooling occurs. Values of C_ℓ^* may be determined experimentally or derived from relations of the type given above. If $C_\ell(x)>C_\ell^*$ structural breakdown is expected at the specified feedstock purity level. If $C_\ell(x)<C_\ell^*$ then the impurity content of the crystal N_x is calculated from $N_x = k_{eff}(x)C_\ell(x)$ where $k_{eff}(x)$ is the appropriate partition coefficient for impurity x. The final step employs equations 51 and 59 to project the efficiency of devices made on base material whose impurity concentration is N_x.

The results in Table 21 indicate model calculations for two multiply-doped Czochralski ingots one containing five impurity species, the second eleven. The total feedstock impurity concentration for the first ingot was $3\text{x}10^{19}$ (about 600 ppm); that for the second was about $4\text{x}10^{19}$ (800 ppma). No melt replenishment was employed in either case and only between one quarter and one third of the melt was consumed so structural breakdown was not present in the wafers from which the cells were made. The agreement between the predicted and measured values of short circuit current and cell efficiency for each ingot are quite good.

The method is not specific to the growth technique involved so long as the segregation coefficients are known or can be calculated. For example Table 22 illustrates the feedstock concentration, calculated and measured cell efficiencies for silicon web crystals. Agreement is good except for copper, a result discussed elsewhere.[31] Unfortunately,

TABLE 21 Calculated and Measured Performance for Ingots Used to Model "Solar Grade" Feedstock

INGOT	IMPURITY	C_o		C_s	
		10^{19} cm^{-3}	ppma	10^{14} cm^{-3}	ppma
W074	Cr	0.73	146	0.8	.0016
	Mn	0.62	124	0.8	.0016
	Ni	1.60	320	5.0	.01
	Ti	0.017	3.4	0.0033	.-
	V	0.015	3.0	0.06	.-
Total		2.97	596	6.6	.0132

η/η_o (calc) = 0.93 ± 0.02 η/η_o (meas) = 0.89 ± .03

INGOT	IMPURITY	10^{19} cm^{-3}	ppma	10^{14} cm^{-3}	ppma
W126	Al	0.0033	0.66	10	.02
	Cr	.18	36	0.2	.0004
	Cu	.10	20	8	.016
	Fe	.31	62	0.2	.0004
	Mn	.15	30	0.2	.0004
	Mo	.33	66	0.0015	-
	Ni	2.50	500	8	.016
	P	.0003	.06	9	.018
	Ti	.02	4	0.004	-
	V	.01	2	0.004	-
	Zr	.46	92	0.004	-
Total		4.0	804	35.6	.071

η/η_o (calc) = 0.89 ± 0.03 η/η_o (meas) = 0.83 ± 0.03

TABLE 22

SOLAR CELL PERFORMANCE OF CONTAMINATED SILICON WEB

(updated from Ref. 31)

Impurity	$C_o (10^{18} cm^{-3})$	$C_s (10^{13} cm^{-3})$	η/η_o^+ (calc)	η/η_o^+ (meas)
Cu	1.4	250	.99	0.87
Mo	2.5	.03	.93	0.85
Ni	1.0	9.5	.99	1.03
Ni	1.1	8.8	.99	1.01
Cr	1.6	4.4	.99	1.03
Mn	2.6	8.5	.99	1.07
Fe	1.3	2.1	.99	1.01
Ti	2.2	1.2	.75	.73
V	1.5	1.5	.82	.80

+ η_o is the efficiency of an uncontaminated device, about 12.5% with AR coatings in these studies.

no data are yet available on silicon web specimens doped with multiple contaminants but on the basis of the Czochralski results we would expect good agreement with the model here also.

5.2 Growth Rate Effects

Modeling of the kind described above depends on the availability of accurate segregation coefficient data for those impurities which are liable to be encountered in the feedstock. The effective segregation is known to depend on freezing velocity during Czochralski pulling[7] and web growth.[34] To examine the regimes where such rate dependences might be important for Czochralski pulling we conducted two sets of experiments, one with Mn as dopant the second with Ti. The results are outlined below in Table 23.

TABLE 23

EFFECT OF CZOCHRALSKI GROWTH RATE ON IMPURITY CONTENT AND CELL PERFORMANCE

INGOT	IMPURITY	PULL RATE (cm/hr)	IMPURITY CONC. (10^{15} cm^{-3})	η/η_o
096	Mn	1.9	0.63*	.96
093	Mn	8.3	0.66	.91
095	Mn	15	1.0	.83
122	Ti	3	0.84	.49
123	Ti	14	1.05	.52

* Target concentrations the same

For Mn when the growth rate was raised to 15cm/hr rather than the 7-8 cm/hr typical of most of our experiments, impurity incorporation increased by 30 to 40%. This is reflected in the cell performance data as well. The results for Ti are somewhat equivocal because the actual ingot concentrations were below detection limits. However cell efficiency is below what has generally been measured for the expected concentration value. We conclude that at growth rates in excess of 8-10 cm/hr corrections must be applied to the Czochralski segregation data to reflect the impact of pull speed on k_{eff}. The limited data available suggest factors of 1.3 to 1.4 are appropriate.

6. CONCLUSIONS AND RECOMMENDATIONS

The objective of this program has been the investigation of the effects of impurities and processing on terrestrial silicon solar cells. Phase II of the program has now been successfully finished. The conclusions derived so far encompass a number of topics including thermal treatment, crystal growth rate, base doping level (low vs high resistivity), base doping type (n vs. p), grain boundary structure, and complexing phenomena in silicon solar cells.

We have studied the effects of various metallic impurities, both singly and in combinations, on the performance of silicon solar cells. Czochralski, float zone, and polycrystal ingots, as well as silicon web crystals were grown with controlled additions of secondary impurities. The primary dopants were boron and phosphorous. The metal elements were selected on the basis of their occurrence in silicon raw material or possible introduction during subsequent processing. The metals included Al, C, Ca, Cr, Cu, Fe, Mg, Mn, Mo, Ta, Ti, V, Zn and Zr. Impurity concentrations were in the range of 10^{11} to 10^{17} cm^{-3}.

All crystals were grown under carefully monitored conditions and with high purity charge and dopant material to minimize unintentional contamination. This was verified by the periodic growth and analysis of special audit ingots. Following growth each crystal was characterized by chemical, microstructural, electrical and solar cell tests to provide a detailed and internally consistent description of the relationships between silicon impurity concentration and solar cell performance. Whenever possible, multiple techniques were employed for analysis to improve the quality of the data and eliminate spurious experimental results. For example, analysis of vacuum cast melt samples provided accurate data regarding melt impurity concentration at the completion of crystal growth. This value used with a reliable effective segregation coefficient permits accurate calculation of ingot impurity concentration. Both spark source mass spectrographic and neutron activation analyses provided direct data on ingot impurity concentrations. (SSMS is limited to concentrations above 1×10^{14} atoms cm^{3} for all elements investigated in this program. Neutron activation coupled with radiochemical analysis can reduce the detection limit below this value depending on the specific impurity) Both photoconductive decay and open circuit decay lifetime measurements were used to evaluate wafer properties. Conventional and detailed I-V analyses were used to assess cell performance characteristics.

Solar cells were made using a conventional diffusion process and were characterized by computer reduction of I-V data. The collected data indicated that impurity-induced performance loss was primarily due to reduction of the base diffusion length. Based on this assumption, an analytical model was developed which predicts cell performance as a function of secondary impurity concentration. The calculated performance parameters are in good agreement with measured values except for the impurities Cu, Ni and Fe, which at high concentrations degrade the cell performance substantially by means of junction mechanisms. This behaviour has been distinguished from base diffusion length effects by careful analysis of IV data. Deep levels have been identified by transient spectroscopy for most impurities which degrade the cell performance by reducing the lifetime.

The effects of impurities in n-base and p-base devices differ in degree but submit to the same modelling analysis. It is notable that Ti and V, two of the more deleterious impurities in p-base devices, produce significantly less performance reduction in n-base silicon. For example, nearly ten times more Ti may be tolerated in n-type silicon to produce the same cell efficiency as in similarly doped p-base device.

A comparison of calculated and measured performance for multiple impurities indicates that there is, at most, a limited interaction between impurities, e.g. copper appears to improve titanium-doped cells somewhat. Most of the introduced impurities appear both as precipitates and as distributed centers in the silicon host. Precipitated impurities have little or no effect on carrier transport properties in the low field base region of the solar cell and affect cell performance primarily when they occur in or near the high field junction region.

Of the three impurities studied at similar doping levels in float zone and Czochralski ingots, Ti and Cr produced essentially the same reduction in cell performance (due to diminished bulk lifetime) in both materials. Aluminum on the other hand degrades the Czochralski material more than the floatzone (by about 20%), suggesting some interaction between oxygen or carbon normally present in the Czochralski ingots.

Modeling of the behavior of the impurity doped cells provides a basis for silicon feedstock producers, sheet manufacturers and solar cell fabricators to perform tradeoff analyses on the costs and benefits in utilizing solar grade material. The major negative impacts of solar grade material (assuming its purity will be lower than semiconductor grade stock) are reduced device performance and crystal growth yield. Thus the degree of acceptability of solar grade feedstock depends on the growth technique, growth strategy, and solar cell processes involved. As we noted before both Czochralski and silicon web techniques are somewhat "tolerant" of feedstock impurities since most of the contaminants are rejected to the melt during growth. The degree of tolerance is species sensitive since elements like Ti impair cell efficiency considerably more than say Ni. For example, in a one pass Czochralski operation, only about 3 ppma Ti would be acceptable to produce cells 90% as efficient as baseline devices while nearly 1000 ppm Ni could be present in the feedstock. The greater the efficiency required the lower must the feedstock level be. Moreover because of the buildup of impurities during growth feedstock levels must be several times lower than suggested above if melt replenishment is to be employed. Here continuous replenishment has the advantage over the sequential recharge approach.

As ingot diameter or growth rate are raised above the typical current values (∿ 7.5 cm and 10 cm/hr, respectively) structural breakdown of the growing ingot due to constitutional supercooling of the melt may become the limiting factor to maximum impurity concentration in polysilicon feedstock. Common impurities which promote this condition include Ti, Cr, Fe, Mn and Ni. Breakdown concentrations can be calculated from theory but improved experimental data would be valuable. Exceeding the solid solubility limit may impose a restriction on the melt concentration of the impurities C, Cu and Ni. While a number of other impurities have not been introduced into melt grown ingots because they are volatilized from the melt, their occurence in high concentrations in polysilicon feedstock material would probably not be acceptable due to contamination of crystal growth equipment. These impurities include Ca, Mg, Na, and Zn.

Thermal processing also affects the final electrically active state of the impurities in silicon. Our data indicate that both heat treatment and gettering can have a pronounced effect the recombination lifetime of silicon containing common metal contaminants like Ti, Fe, Mn and Al. There appears to be an optimum gettering cycle time at a specific temperature as well as an optimum number of gettering cycles. In particular, for 1 hour gettering cycles at 1000°C, lifetime peaked after one cycle then slowly declined with further processing.

Future work should attempt to improve the analytical data base, particularly for impurities like Ti, V, Mo, and Zr which cannot be readily detected at low levels by conventional analytical methods. Further emphasis should be placed on the processing aspects of impurity effects, particularly gettering. The data base for n-type material should be strengthened and enlarged. Anisotropy effects as well as structural breakdown in larger ingots should be examined. Finally some examination of the time dependence of the effects should be undertaken.

7. PROGRAM STATUS

7.1 Present Status

All elements comprising Phase II of this program have been successfully completed.

7.2 Future Activity

The overall program approach has been to establish what concentrations of the impurities commonly found in silicon starting material (metallurgical grade silicon) can be tolerated in silicon crystals without degrading solar cell performance of common p-base devices (Phase I). With this foundation the data base was then broadened to include the effects of processes such as gettering and heat treatment and impurity redistribution during crystal growth on cell behavior. Studies of base doping type (n vs p), base doping concentration, (lower resistivity), grain boundary effects, and carbon/oxygen interactions were then undertaken. These latter topics formed the heart of the Phase II program.

During the period of Phase I and II the development of new technologies to produce both solar and semiconductor grades of silicon began the transition from laboratory scale studies to the design, costing and fabrication of pilot production facilities. At this same time our understanding of the effects of impurities on solar cell performance has become sufficient to identify the general mechanisms of solar cell degradation and with considerable confidence predict the behavior of devices made from contaminated p-type silicon. For these reasons it is now appropriate that the emphasis of the program shift in order to better reflect the maturing nature of the technical effort and to respond to the emerging needs of the silicon production activities.

The projected Phase III effort encompasses five major activities: (1) expansion of the activity directed to cell processing (2) completion of the data base and modeling of n-base solar cells (3) extension of the p-base studies to include impurities likely to be introduced during silicon production, refining or crystal growth, (4) a consideration of the potential impact of anisotropic impurity distribution in large Czochralski and ribbon solar cells and (5) a preliminary investigation of the permanence of impurity effects in silicon solar cells. A detailed discussion of the Phase III experiments will be presented in subsequent reports.

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9.0 APPENDICES

APPENDIX 1

SEGREGATION COEFFICIENTS

Element	Segregation Coefficient
Al	3×10^{-2} (2.8×10^{-3})
B	0.8
C	0.05
Ca	?
Cu	8.0×10^{-4}
Cr	1.1×10^{-5}
Fe	6.4×10^{-6}
Mg	3.2×10^{-6}
Mn	1.3×10^{-5}
Mo	4.5×10^{-8}
Ni	3.2×10^{-5}
Ph	0.35
Ta	$\sim 10^{-7}$
Ti	2.0×10^{-6}
V	4×10^{-6}
Zn	10^{-5}
Zr	$<1.5 \times 10^{-7}$

APPENDIX 2

SUMMARY OF ELECTRICAL AND DEFECT CHARACTERISTIC FOR ALL INGOTS

Ingot Identification	TGT Resistivity (ohm-cm)	Actual Resistivity (ohm-cm)	Etch Pit Density (/cm^2)
W-001-00-000	4.0 (B)	2.8-3.2	0
W-002-00-000	4.0 (B)	3.0-4.0	0
W-003-00-000	4.0 (B)	3.1-3.6	0
W-004-Cr-001	4.0 (B)	4.6-4.3	0.5-150K**
W-005-Mn-001	4.0 (B)	3.6-3.1	0.6-80K
W-006-Ni-001	4.0 (B)	4.1-3.5	0.3-0.96K
W-007-Cu-001	4.0 (B)	5.2-3.7	0-1.2K
W-008-Ti-001	4.0 (B)	4.2-3.1	1.8-150K
W-009-V-001	4.0 (B)	4.1-3.4	0-150K
W-010-Ni-002	4.0 (B)	3.9-3.4	2-46K
W-011-Zr-001	4.0 (B)	4.4-3.6	0.4-9K
W-012-Cr-002	4.0 (B)	4.1-3.9	0.4-100K
W-013-Mn-002	4.0 (B)	4.3-3.2	0.2-150K
W-014-00-000	4.0 (B)	4.3-3.2	1.0-5K
W-015-Zn-001	4.0 (B)	3.9-3.6	0.5-6K
W-016-Fe-001	4.0 (B)	4.6-5.2	0-1.2K
W-017-Cu-002	4.0 (B)	3.8-3.6	2.2-32K
W-018-Fe-002	4.0 (B)	5.9-5.0	0-1.2K
W-019-Cu-003	4.0 (B)	3.8-3.5	0.2-1.5K
W-020-00-000	4.0 (B)	4.0-2.9	0-0.4K
W-021-Mg-001	4.0 (B)	3.8-3.4	0.5-2.5K
W-022-00-000	4.0 (B)	4.1-3.2	0.5-14K
W-023-00-000	0.2 (B)	0.17-0.16	2.5-72.5K
W-024-Mg-002	4.0 (B)	3.8-3.6	3.7-2.5K
W-025-00-000	4.0 (B)	5.1-4.7	2-2.5K
W-026-Mn-003	4.0 (B)	4.5-3.9	1-16.5K
W-027-Mn/Cu-001	4.0 (B)	8.4-6.3	1.25-4K
W-028-Al-001	4.0 (B)	2.9-2.4	0.75-18K
W-029-Cr-003	4.0 (B)	5.2-4.6	0-0.5K
W-030-Cr/Cu-001	4.0 (B)	7.3-6.9	0.5-45K
W-031-Cr/Mn-001	4.0 (B)	8.8-4.7	1.25-Gross Lineage
W-032-Mg-003	4.0 (B)	4.5-4.1	0-10K
W-033-Ti-002	4.0 (B)	4.5-4.2	0-2.5K

W-034-00-000	4.0 (B)	4.4-4.2	0.25-0.5K
W-035-V-002	4.0 (B)	4.4-3.9	1.5-2K
W-036-Zr-002	4.0 (B)	4.4-4.1	0.5-30K
W-037-Zr/Ti-001	4.0 (B)	5.1-4.5	0.5 - Gross Lineage
W-038-Al-002	4.0 (Al)	2.2-1.6	0-0.75K
W-039-Ni-003	4.0 (B)	5.2-4.3	2-30K
W-040-Cr/Ni-001	4.0 (B)	5.3-4.0	1- Gross Lineage
W-041-Ni/Cr/Cu-001	4.0 (B)	5.1-4.7	2-50K
W-042-Ti-003	4.0 (B)	3.8-3.7	1.5-1.5K
W-043-Fe/Ti-001	4.0 (B)	5.7-2.8	0.75-13.5K
W-044-Fe-003	4.0 (B)	3.8-3.8	0-90K
W-045-Cr/Fe/Ti-001	4.0 (B)	5.3-4.3	0.5-15K
W-046-Fe/V-001	4.0 (B)	5.7-5.3	0.5- Gross Lineage
W-047-Cu/Ni/Zr-001	4.0 (B)	4.8-4.4	1.5-5K
W-048-Ti-004	4.0 (B)	4.5-3.8	0.5-40K
W-049-V-003	4.0 (B)	4.4-3.9	0-2K
W-050-Ti/V-001	4.0 (B)	4.6-4.4	0.5-0.5K
W-051-Cu/Ti-001	4.0 (B)	5.0-4.4	0.5-Clusters
W-052-Ni-004	4.0 (B)	4.2-3.8	4K-Gross Lineage
W-053-Poly	4.0 (B)	4.5-4.2	N/A (poly)
W-054-00-000	4.0 (B)	4.3-3.8	0-4.25 K
W-055-Cu-004	4.0 (B)	4.1-3.7	0.5K-25K
W-056-Cu-005	4.0 (B)	4.4-3.75	2.5K-10K
W*-057-00-000	0.5 (B)	0.46-0.47	0.5K - 1.25K
W*-058-00-000	0.2 (B)	0.22-0.18	0-0.2K
W*-059-00-000	0.05 (B)	0.05-0.053	0-2K
W-060-00-000	1.5 (P)	2.1-1.0	0-1K
W-061-Cr/Ti-001	4.0 (B)	5.0-4.0	3 K-Clusters
W-062-N/Cu-001	1.5 (P)	2.0-0.95	0.4-4K
W-063-N/Cr-001	1.5 (P)	2.2-1.7	1K-40K
W-064-N/Mn-001	1.5 (P)	2.2-1.35	1K-3K
W-065-N/Ti-001	1.5 (P)	1.9-1.7	0-2K
W-066-Ti-005	4.0 (B)	6.0-3.9	1K-4K
W-067-Cr/Mn/Ti-001	4.0 (B)	5.5-5.2	1K-4K
W-068-Cr-004	4.0 (B)	5.2-5.1	1K-5K
W-069-Fe-004	4.0 (B)	5.8-5.0	0.4 K- Gross Lineage

APPENDIX 2 (Cont.)

W-070-Al-003	4.0 (B)	2.2-1.1	0-1K
W-071-00-000	4.0 (B)	4.1-3.3	1K-4K
W-072-Cr-005	4.0 (B)	5.0-4.5	0-2K
W-073-Cr/Mn/Ni/Ti/V-001	4.0 (B)	5.0-3.8	1K-40K
W-074-Cr/Mn/Ni/Ti/V-002	4.0 (B)	4.4	400-30K
W-075-Ti/V-002	4.0 (B)	4.8-3.9	0-10K
W-076-Poly-002	4.0 (B)	4.8-3.0	N/A (Poly)
W-077-Mo-001	4.0 (B)	4.3-3.8	0-Gross Lineage
W-078-00-000	4.9 (B)	4.3-3.3	0-80K
W-079-00-000	1.5 (P)	2.3-1.1	1K-10K
W-080-Ph-001	4.0 (B)	6.3-3.8	0-5K
W-081-N/Ni-001	1.5 (P)	2.2-1.4	1K-4K
W-082-N/V-001	1.5 (P)	1.8-1.5	0-6K
W-083-N/Fe-001	1.5 (P)	2.1-1.3	1K-Gross Lineage
W-084-N/Al-001	1.5 (P)	7.5-1.9	1K-80K
W-085-N/Zr-001	1.5 (P)	2.4-1.5	1K-20K
W-086-C-001	4.0 (B)	4.0-3.5	0K-20K^{+}
W-087-Ca-001	4.0 (B)	3.8-3.4	0^{++}
W*-088-Cr-001	0.2 (B)	0.2-0.18	1K-20K
W*-089-Cu-001	0.2 (B)	0.21-0.19	0-20K
W*-090-Mn-001	0.2 (B)	0.21-0.20	1K-3K
W-091-Cr/Mn-002	4.0 (B)	5.5-3.5	o-Gross Lineage
W-092-Ph-002	4.0 (B)	1.7-5.6	0-1K
W -093-Mn-004	4.0 (B)	4.9-5.3	1K-5K
W-094-Mn-005 (Poly)	4.0 (B)	2.8-4.2	N/A
W-095-Mn-006 (F)	4.0 (B)	4.2-4.9	0-12K
W-096-Mn-007 (S)	4.0 (B)	4.6-4.6	0-2K
W-097-00-000	4.0 (B)	3.2-4.2	0
W-098-Mo-002	4.0 (B)	3.6-4.3	0-10K
W-099-Fz-001	4.0 (B)	4.2-4.4	5K-20K
W-100-Cu/Ti-002	4.0 (B)	3.4-5.2	0-Gross Lineage
W-101-FZ-002	4.0 (B)	4.4-4.9	3K-20K
W-102-Ti-006 (Poly)	4.0 (B)	3.8-6.4	N/A
W*-103-Ti-001	0.2 (B)	0.23-0.25	0-30K
W-104-Cu/Ti-003	4.0 (B)	3.8-4.2	2K-Gross Lineage
W*-105-V-001	0.2 (B)	0.23-0.26	3K-Gross Lineage
W-106-N/Al-002	1.5 (P)	2.1-2.9	0

W-107-Fz/Al-001	2.0 (B)	1.0-2.2	6K-15K
W-108-N/V-002	1.5 (P)	2.3-1.4	0
W-109-C-002	4.0 (B)	4.6-3.6	0-3K
W*-110-Fe-001	0.2 (B)	0.16-0.15	1K
W-111-Cu/V-001	4.0 (B)	4.6-4.3	1K
W-112-Ta-001	4.0 (B)	3.5-2.9	0-Gross Lineage
W-113-Fz/Cr-001	4.0 (B)	5.6-4.9	8K-Twin
W-114-00-000	0.2 (B)	0.19-0.10	0-4K
W-115-N/Cu-002	1.5 (P)	2.2-1.4	2K-10K
W*-116-Ph-001	0.2 (B)	0.44-0.50	0-50K
W-117-00-000	4.0 (B)	4.1-3.7	0-Gross Lineage
W-118-Ph-003	4.0 (B)	1.17 -	0-1K
W-119-N/Fe-002	1.5 (P)	2.1-1.5	1K-Gross Lineage
W-120-N/Cr-002	1.5 (P)	1.9-1.6	0-Gross Lineage
W-121-N/Ti-002	1.5 (P)	2.2-1.4	2K-40K
W-122-Ti-007	4.0 (B)	4.1-4.5	10K-Gross Lineage
W-123-Ti-008	4.0 (B)	3.8-3.6	0-20K
W-124-Mo-003	4.0 (B)	4.1-3.8	0-4K
W-125-Mo-004	4.0 (B)	3.9-3.6	0-Gross Lineage
W-126-Multi-001	4.0 (B)	4.5-3.6	0-Gross Lineage
W-127-Fz/Ti-001	4.0 (B)	7.3-6.2	3K
W-128-Ta-002	4.0 (B)	4.5-3.7	0-3K

* Use of asterisk indicates low resistivity p-type ingot.

** The first figure is etch pit density of the seed; second figure etch pit density of extreme tang end of ingot. The first value shown is indicative of dislocation density in slices used for cell fabrication.

\+ Twinning due to high carbon concentration occurred after approximately three inches of crystal growth.

++ Multiple crystal growth due probably to CaO formation.

APPENDIX 3

CARBON AND OXYGEN CONCENTRATIONS FOR REPRESENTATIVE INGOTS

Ingot Number	Carbon Concentration x 10^{16} atoms/cm^3	Oxygen Concentration x 10^{16} atoms/cm^3
W-001-00-000	7.5	94
W-003-00-000	12.5	94
W-005-Mn-001	6	126
W-007-Cu-001	7.5	49
W-009-V-001	18	100
W-011-Zr-001	8	87
W-013-Mn-002	5	160
W-015-Zn-001	9	100
W-017-Cu-002	5.5	78
W-019-Cu-003	4.2	96
W-021-Mg-001	8	110
W-023-00-000	**	**
W-025-00-000	9.6	96
W-027-Mn/Cu-001	<2	110
W-029-Cr-003	2.5	150
W-031-Cr/Mn-001	11	110
W-033-Ti-002	10	100
W-035-V-002	5.1	135
W-037-Zr/Ti-002	8.3	190
W-039-Ni-003	2	170
W-041-Ni/Cr/Cu-001	9	115
W-043-Fe/Ti-001	7.3	159
W-045-Cr/Fe/Ti-001	10	118
W-047-Cu/Ni/Zr-001	2.3	140
W-049-V-003	10.3	170
W-051-Cu/Ti-001	6.6	166
W-053-Poly	39	142

Ingot Number	Carbon Concentration x 10^{16} atoms/cm^3	Oxygen Concentration x 10^{16} atoms/cm^3
W-055-Cu-004	11.3	118
W*-057-00-000	**	**
W*-059-00-000	**	**
W-061-Cr/Ti-001	<2	181
W-063-N/Cu-001	4.4	164
W-065-N/Ti-001	<2	176
W-067-Cr/Mn/Ti-001	<2	226
W-069-Fe-004	<2	146
W-071-00-000	7.6	115
W-073-Cr/Mn/Ni/Ti/V-001	4.2	145
W-075-Ti/V-002	11.6	194
W-077-Mo-001	2.5	134
W-079-00-000	<2	157
W-081-N/Ni-001	5	216
W-083-N/V-001	5.5	136
W-085-N/Zr-001	<2	96
W-087-Ca-001	4.5	69
W*-089-Cu-001	**	**
W-091-Cr/Mn-002	20	111
W-093-Mn-004	7	161
W-095-Mn-005	4.2	151
W-097-00-000	13.2	142
W-099-FZ-001	<2	<5
W-101-FZ-002	<2	<5
W*-103-Ti-001	**	**
W*-105-V-001	**	**
W-107-FZ/Al-001	< 2	< 5
W-109-C-002	< 2 - 14	190 - 44

APPENDIX 3 (Cont.)

Ingot Number	Carbon Concentration x 10^{16} atoms/cm^3	Oxygen Concentration x 10^{16} atoms/cm^3
W-111-Cu/V-001	12.1	86
W-113-FZ/Cr-001	< 2	< 5
W-115-N/Cu-002	8.3	112
W-117-00-000	4.9	160
W-119-N/Fe-002	5.0	125
W-121-N/Ti-002	4.7	121
W-123-Ti-008	2.7	137
W-125-Mo-004	8.4	128
W-127-FZ/Ti-002	< 2	< 5

** Due to free carrier absorption infrared methods cannot be used for carbon and oxygen determination in these samples.

APPENDIX 4

INGOT IMPURITY CONCENTRATION

Ingot Identification	Target Concentration 10^{15} atoms/cm^3	Calculated Concentration 10^{15} atoms/cm^3	Measured Concentration 10^{15} atoms/cm^3	
W-001-00-000	N/A	N/A	N/A	
W-002-00-000	N/A	N/A	N/A	
W-003-00-000	N/A	N/A	N/A	
W-004-Cr-001	1.0	0.82	1.0	(<4)[+]
W-005-Mn-001	1.0	0.82	1.35	(0.6)
W-006-Ni-001	3.9	0.66	<0.5	
W-007-Cu-001	2.0	2.36	1.80	(1.65)
W-008-Ti-001	0.20	0.16	0.36	(0.15)
W-009-V-001	0.39	0.46	0.31	
W-010-Ni-002	3.9	2.18	4.0	
W-011-Zr-001	0.0007	0.0019	<0.45	(<0.03)
W-012-Cr-002	0.2	0.18	<0.5	
W-013-Mn-002	0.2	0.15	<0.5	
W-014-00-000	N/A	N/A	N/A	
W-015-Zn-001	1.0	<0.0006	<0.5	
W-016-Fe-001	1.0	0.75	<3.0	(0.90)
W-017-Cu-002	19	13.3	32	(25)
W-018-Fe-002	2	1.6	<3	(1.7)
W-019-Cu-003	0.38	0.53	<0.5	
W-020-00-000	N/A	N/A	N/A	
W-021-Mg-001	0.003	0.0018	<0.5	
W-022-00-000	N/A	N/A	N/A	
W-023-00-000	N/A	N/A	N/A	
W-024-Mg-002	0.032	0.023	<0.5	
W-025-00-000	N/A	N/A	N/A	
W-026-Mn-003	0.01	0.0089	<0.5	
W-027-Mn/Cu-001	1/1.9	0.73/1.22	1/1.0	(1.1/2.2)

Ingot Identification	Target Concentration 10^{15} atoms/cm^3	Calculated Concentration 10^{15} atoms/cm^3	Measured Concentration 10^{15} atoms/cm^3	
W-028-Al-001	18		26	
W-029-Cr-003	0.01	0.0083	<0.5	
W-030-Cr/Cu-001	1/1.96	0.82/1.47	1/1.0	(0.5/2.5)
W-031-Cr/Mn-001	1/1	0.85/0.82	1/2.5	
W-032-Mg-003	0.32	0.077	0.32	
W-033-Ti-002	0.0020	0.0024	<0.3	
W-034-00-000	N/A	N/A	N/A	
W-035-V-002	0.004	0.005	<0.2	
W-036-Zr-002	0.0014	0.001	<0.45	<(0.03)
W-037-Zr/Ti-001	0.0007/0.22	0.00066/0.20	<0.45/0.30	
W-038-Al-002	60	32.5	34	
W-039-Ni-003	8	6.6	3.5	
W-040-Cr/Ni-001	0.8/3.5	0.73	1.0/3.5	
W-041-Ni/Cr/Cu-001	3.0/0.8/1.9	3/0.8/1.7	3.0/1.7/2.3	
W-042-Ti-003	0.04	0.02	<0.3	
W-043-Fe/Ti-001	0.8/0.033	0.65/0.033	<3/<0.3	
W-044-Fe-003	0.02	0.0167	<2.0	
W-045-Cr/Fe/Ti-001	0.65/0.5/0.039	0.47/0.37/0.026	(0.26/0.69/<0.07	
W-046-Fe/V-001	0.65/0.06	0.37/0.056	N/A	
W-047-Cu/Ni/Zr-001	1.9/1/0.00021	2.1/0.47/0.00025	2.5/<1/<1	
W-048-Ti-004	0.00020	0.00038	N/A	
W-049-V-003	0.00030	0.00078	N/A	
W-050-Ti/V-001	0.00020/0.0003	0.0002/0.0041	<0.5/<0.5	
W-051-Cu/Ti-001	1.9/0.2	1.62/0.112	4.0/0.36	
W-052-Ni-004	10	5.4	4.0	
W-053-Poly	N/A	N/A	N/A	

Ingot Identification	Target Concentration 10^{15}atoms/cm^3	Calculated Concentration 10^{15}atoms/cm^3	Measured Concentration 10^{15}atoms/cm^3	
W-054-00-000	N/A	N/A	N/A	
W-055-Cu-004	0.1	0.06	<1	(0.5)
W-056-Cu-005	60	90	70	(86)
W*-057-00-000	N/A	N/A	N/A	
W*-058-00-000	N/A	N/A	N/A	
W*-059-00-000	N/A	N/A	N/A	
W-060-00-000	N/A	N/A	N/A	
W-061-Cr/Ti-001	Cr: 1.1 Ti: 0.011	Cr: 1.0 Ti: 0.009	Cr: 1.0 Ti:<1.0	(1.1) (<.2)
W-062-N/Cu-001	2.5	2.0	2.0	(4.7)
W-063-N/Cr-001	0.83	0.88	1.0	
W-064-N/Mn-001	1.0	0.64	2.0	(0.6)
W-065-N/Ti-001	0.20	0.17	0.75***	(0.09)
W-066-Ti-005	0.033	0.027	<0.2	
W-067-Cr/Mn/Ti-001	Cr: 0.44 Mn: 0.50 Ti: 0.0033	Cr: 0.3 Mn: 0.36 Ti: 0.0022	Cr: 0.3 Mn: 0.7 Ti:<0.2	(0.25) (0.66) (<0.2)
W-068-Cr-004	1.0	1.0	1.0	(0.44)
W-069-Fe-004	0.98	0.92	<1.5	(1.1)
W-070-Al-003	50 (4.75)**	20 (1.9)**	100 (3.0)**	
W-071-00-000	None	N/A	N/A	
W-072-Cr-005	0.4	0.21	0.28	
W-073-Cr/Mn/Ni/Ti/V-001	Cr: 0.48 Mn: 0.46 Ni: 2.0 Ti: 0.0024 V: 0.004	Cr: 0.34 Mn: 0.31 Ni: 1.3 Ti: 0.0030 V: 0.007	Cr: 0.28 Mn: 0.8 Ni:<2.0 Ti: < 0.35 V: < 0.35	(0.17) (0.28) (10) (<0.3)
W-074-Cr/Mn/Ni/Ti/V-002	Cr: 0.08 Mn: 0.08 Ni: 0.5 Ti: 0.00033 V: 0.0006	Cr: 0.054 Mn: 0.64 Ni: 0.28 Ti: 0.001 V: 0.0015	Cr: 0.25 Mn: 0.25 Ni:<2.0 Ti:<0.25 V: <0.25	
W-075-Ti/V-002	Ti: 0.056 V: 0.1	Ti: 0.042 V: 0.11	Ti: < 0.25 V: < 0.25	
W-076-Poly-002	None	N/A	N/A	

APPENDIX 4 (Cont.)

Ingot Identification	Target Concentration 10^{15}atoms/cm^3	Calculated Concentration 10^{15}atoms/cm^3	Measured Concentration 10^{15}atoms/cm^3
W-077-Mo-001	0.0042	0.0027	<0.3 (0.0042)
W-078-00-000	None	N/A	None
W-080-Ph-001	0.6	0.7	0.8 **
W-081-N/Ni-001	2.3	0.65	<2
W-082-N/V-001	0.4	0.475	0.85
W-083-N/Fe-001	1.0	0.86	<1.5 (1.0)
W-084-N/Al-001	50 (4.7)**	22 (2.1)**	40 (<2.5)**
W-085-N/Zr-001	0.0007	0.0005	<0.015 (<0.011)
W-086-C-001	300	N/A	200-300
W-087-Ca-001	1.0	0.13	?
W*-088-Cr-001	0.5	0.62	3.3
W*-089-Cu-001	2.3	2.13	0.8 (2.5)
W*-090-Mn-001	0.7	0.52	2.75 (0.69)
W-091-Cr/Mn-002	Cr: 0.5 Mn: 0.3	0.3 0.3	1.0 2.75 (-/0.5)
W-092-Ph-002	28	N/A	27-30 **
W-093-Mn-004	0.66	0.46	2.75 (0.75)
W-094-Mn-005 (Poly)	0.9	0.63	2.75 (1.3) (0.76)
W-095-Mn-006 (F)	0.5	0.42	2.75 (1.0)
W-096-Mn-007 (S)	0.63	0.55	0.25 (0.6)
W-097-00-000	None	N/A	N/A
W-098-Mo-002	0.00092	0.00042	<0.3
W-099-FZ-001	None	N/A	N/A
W-100-Cu/Ti-002	Cu: 1.0 Ti: 0.033	Cu: 1.25 Ti: 0.04	Cu: 0.5 Ti: <0.3
W-101-FZ-002	None	N/A	N/A
W-102-Ti-006 (Poly)	0.11	0.1	0.25
W*-103-Ti-001	0.167	0.13	0.25
W-104-Cu/Ti-003	Cu: 2.0 Ti: 0.14	Cu: 2.2 Ti: 0.08	Cu: 4.0 Ti: 0.25
W*-105-V-001	0.4	0.7	0.85
W-106-N/Al-002	6.6	2.3	8.3 (0.7)**
W-107-FZ/Al-001	30	25	128 (12)**
W-108-N/V-002	0.08	0.098	0.2
W-109-C-002	<20-140	N/A	<20-140
W*-110-Fe-001	0.8	0.67	<2.0

APPENDIX 4 (Cont.)

Ingot Identification	Target Concentration 10^{15}atoms/cm^3	Calculated Concentration 10^{15}atoms/cm^3	Measured Concentration 10^{15}atoms/cm^3
W-111-Cu/V-001	2.5/0.3	2.5/0.34	2.6/0.25
W-112-Ta-001	0.004	0.0028	<0.5
W-113-FZ/Cr-001	0.8	0.48	1.0
W-114-00-000	---	N/A	N/A
W-115-N/Cu-002	10		4.0
W*-116-Ph-001	35	N/A	(100)**
W-117-00-000	--	N/A	N/A
W-118-Ph-003	70	N/A	(140)**
W-119-N/Fe-002	0.3	##	<3
W-120-N/Cr-002	0.3	0.23	1.0
W-121-N/Ti-002	0.039	0.63	<1
W-122-Ti-007	0.084	0.08	<3
W-123-Ti-008	0.105	0.10	<3
W-124-Mo-003	0.000018	0.000018	<0.2
W-125-Mo-004	0.00006	0.00024	<0.2
W-126-Multi-001	#	#	#
W-127-FZ/Ti-001	0.039	0.012	<3
W-128-Ta-002	0.0008	0.0022	<0.5

* Low Resistivity P-Type Ingots

** Value based on resistivity measurement

*** High Ti value possibly due to vacuum leak in M.S.

\+ Value in parenthesis based on Neutron Activation Analysis. Value without parentheses based on SSMS

\# See data sheets for 10 impurities

\#\# No melt sample available

Appendix - 5

WAFER CLEANING PROCEDURES

Clean 1

a. Strip aluminum*
b. Rinse in deionized water, 30 sec.
c. Etch silicon, CP-4A (metal tweezers)
d. Rinse in deionized water, 30 sec.
e. N_2 blow dry.

Clean 2

a. Strip aluminum*, DI rinse, 30 sec.
b. Etch silicon 10 sec, CP-4A, DI rinse
c. Rinse with 4 parts H_2SO_4 + 1 part H_2O_2 @ 87°C
d. Repeat step b.
e. $KMnO_4$ etch+, 10 sec, DI rinse
f. $NH_4OH + H_2O_2$, DI rinse 30 sec.
g. H_2O_2 + HCL +H_2O, DI rinse 30 sec.
h. N_2blow dry.

Clean 3

a. Strip aluminum*, DI rinse 30 sec.
b. Etch silicon CP-4A 10 sec, DI rinse 30 sec.
c. Repeat step b.
d. Rinse in deionized water 1 minute
e. $H_2O_2 + NH_4OH + H_2O$, 10 min. @ 80°C
f. Rinse in deionized water 30 sec.
g. H_2O_2 + HCL + H_2O, 10 min @ 80°C.
h. Rinse in deionized water, 30 sec.
i. Blow dry.

Clean 4

a. Strip aluminum*, DI rinse 30 sec.
b. Ultrasonic clean 5 min 17% sol FL70 @ 25°C.
c. Rinse in deionized water 3 min.
d. Repeat steps b and c.
e. Ultrasonic DI water @ 90°C for 5 min.
f. Rinse in DI for 3 min.
g. H_2O_2+NH_4OH+H_2O, 10 min @ 80°C. DI rinse 30 sec.
h. H_2O_2+HCL+H_2O, 10 min. @ 80°C, DI rinse 30 sec.
i. Repeat steps g and h
j. DI rinse 30 sec. N_2 blow dry.

*Aluminum etch solution = 750 ml H_3PO_4, 140 ml H_2O, 30 ml HNO_3, and 150 ml CH_3COOH

+ Stain removal solution = 2 parts HF, 1 part 0.038M $KMnO_4$

Appendix - 5 (Cont.)

WAFER CLEANING PROCEDURES

Clean 5

a. Strip aluminum*, DI rinse 30 sec.
b. $H_2O_2+NH_4OH+H_2O$, 10 min. @ 80°C, DI rinse 30 sec.
c. $H_2O_2+HCL+H_2O$, 10 min. @ 80°C, DI rinse 30 sec.
d. Repeat steps b and c.
e. DI rinse 30 sec.
f. Rinse 5% HF solution 15 sec. DI rinse.
g. Ultrasonic clean 10 sec. in quartz double distilled H_2O, 5 times
h. Chelate** ultrasonically 1 min., 5 times.
i. Repeat step g.

Clean 6

a. Strip aluminum* DI rinse 30 sec.
b. Rinse 3 min tetrachloroethylene ultrasonically, 3 times
c. Rinse 1 minute in acetone ultrasonically.
d. Rinse in distiller water 3 times.
e. Ultrasonic 5% KOH 3 minutes
f. Ultrasonic distille H_2O 2 min. 10 times.
g. 50% KOH @ 50°C for 10 min.
h. Distilled water rinse 1 min, 3 times.
i. Rinse 1 min. 0.3% HCL ultrasonically
j. Rinse distilled water 1 min, 6 times.
k. Rinse 1 min proponal, 2 times.
l. Dry wafers in vacuum oven 20 min.

**Chelate solution = 1000 ml quartz distilled H_2O + 15 ml NH_4OH + 5 gr Ethylenediaminetetracetic Acid (EDTA)

APPENDIX 6

PHOTOVOLTAIC CHARACTERISTICS OF METAL IMPURITY-DOPED SILICON SOLAR CELLS UNDER AM1 ILLUMINATION

Test Conditions: No AR coatings, nominal cell area 1.03cm^2
Quartz-iodine illumination 91.6 mW/cm^2

Key to Abbreviations:
R - calibrated reference devices
C - wafers from ingot center
T - wafers from ingot tang end
S - wafers from ingot seed end
B - baseline wafer
E or N - end
* - item deleted from averages.

Ingots are listed chronologically in the order they were grown. Column headings are generally self-explanatory; PCDB and PCDA are the photoconductive decay wafer lifetimes before and after cell processing. (see Table 12 for details) Data for ingots W001 to W052 appear in Reference 1.

```
61213 W055CU004 (5E13) W020 00 000
*SOL3             AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R     FF    Eff     OCD    PCDa   PCDb

1R*       22.50 .553 20.24   -6.410 1.94   -.36 .723   9.51     .00    .00    .00
1B        22.90 .555 20.92   -7.065 1.71   -.55 .754  10.13    4.29   7.30   7.00
3B        22.90 .557 21.17   -7.903 1.49   -.34 .771  10.40    5.20   7.30   7.00
5B        22.70 .556 20.57   -6.519 1.90   -.97 .748   9.98    3.90   7.30   7.00
1C        22.70 .552 20.62   -6.634 1.85   -.93 .751   9.95    3.90    .00    .00
2C        23.20 .553 20.96   -6.352 1.96  -1.00 .743  10.08    4.55    .00    .00
3C        23.20 .553 21.14   -6.828 1.78   -.81 .755  10.24    5.20    .00    .00
4C        23.20 .553 20.96   -6.352 1.96  -1.00 .743  10.08    2.86    .00    .00
5C        22.70 .551 20.80   -7.180 1.66   -.72 .763  10.09    4.16    .00    .00
2S        22.80 .552 20.97   -7.479 1.58   -.54 .766  10.19    4.42    .00    .00
3S        23.20 .554 21.35   -7.549 1.56   -.42 .764  10.39    4.94    .00    .00
1T        23.00 .555 21.12   -7.361 1.62   -.57 .763  10.31    4.81    .00    .00
2T        22.90 .553 20.94   -7.070 1.70   -.67 .758  10.15    4.55    .00    .00
3T        23.20 .554 21.30   -7.331 1.62   -.60 .764  10.38    5.20    .00    .00
4T        23.40 .551 21.17   -6.457 1.91   -.85 .743  10.13    3.90    .00    .00

AVERAGES: 61213  BASELINE W020 00 000
          22.83 .556 20.89   -7.162 1.70   -.62 .757  10.17    4.46   7.30   7.00
  STD       .09 .001   .24     .569  .17    .26 .010    .17     .54    *      *
            61213 W055CU004 (5E13)
          23.05 .553 21.03   -6.963 1.75   -.74 .756  10.18    4.41    .00    .00
  STD       .23 .001   .20     .436  .14    .19 .009    .13     .65    *      *
PERCENT OF BASELINE
        100.9  99.4 100.7   102.8  103   81.6  99.8 100.1    98.8     .0     .0
 STD%     1.4    .4   2.2    14.3   20   92.6   2.5   3.0    28.5     .0     .0
 70201 W056CU005 (6.5E16) BEFORE SINTER W020 00 000
 *SOL3            AM1: P0=91.60MW/CM©2  NO AR COATING

 ID       ISC   VOC   IP     LOG(IO)  N      R     FF    Eff     OCD    PCDa   PCDb

 1R*      22.50 .557 20.50   -7.241 1.66    .23 .732   9.70     .00    .00    .00
 1B       22.70 .553 20.80   -7.373 1.61   -.22 .752   9.98    3.90   7.30   7.00
 2B       22.90 .553 20.93   -7.248 1.65   -.17 .746   9.99    3.90   7.30   7.00
 3B.*     23.10 .552 20.28   -5.258 2.55  -1.56 .707   9.53    3.25   7.30   7.00
 1C       22.40 .543 20.00   -5.938 2.12   -.93 .721   9.28    3.25   4.85   6.66
 2C       22.40 .546 19.98   -5.923 2.13   -.90 .720   9.31    3.25   4.85   6.66
 3C       22.70 .546 20.36   -6.129 2.03   -.81 .727   9.53    3.25   4.85   6.66
 4C       22.50 .543 20.00   -5.803 2.18   -.89 .714   9.22    2.86   4.85   6.66
 5C       22.60 .546 20.37   -6.502 1.88   -.35 .726   9.48    3.51   4.85   6.66
 1S       22.50 .544 20.23   -6.349 1.93   -.48 .725   9.38    3.12   4.85   6.66
 2S       22.50 .547 20.33   -6.524 1.87   -.57 .734   9.56    3.51   4.85   6.66
 3S       22.40 .545 20.25   -6.519 1.87   -.66 .737   9.52    3.25   4.85   6.66
 1T       22.40 .546 20.34   -6.824 1.76   -.38 .739   9.56    3.25   4.85   6.66
 2T.*     23.30 .538 19.26   -3.926 3.91  -3.27 .649   8.61    1.95   4.85   6.66
 3T       22.20 .541 19.98   -6.343 1.93   -.63 .729   9.26    3.25   4.85   6.66
 4T       22.30 .547 19.76   -5.907 2.15   -.22 .697   8.99    3.38   4.85   6.66

 AVERAGES: 70201  BASELINE W020 00 000
          22.80 .553 20.86   -7.310 1.63   -.20 .749   9.99    3.90   7.30   7.00
   STD      .10 .000   .07     .062  .02    .02 .003    .01     .00    *      *
            70201 W056CU005 (6.5E16) BEFORE SINTER
          22.45 .545 20.15   -6.251 1.99   -.62 .724   9.37    3.26   4.85   6.66
   STD      .13 .002   .20     .316  .13    .23 .011    .17     .17    *      *
 PERCENT OF BASELINE
          98.4  98.5  96.6   114.5  122  *****  96.7  93.8    83.6   66.4   95.1
  STD%     1.0    .3   1.3     5.1   10  172.0   1.9   1.8     4.4     .0     .1
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70201A W056CU 005 (6.5E16) AFTER SINTER  W020 00 000
*SOL3              AM1: P0=91.60MW/CM©2   NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*       22.50 .558 20.32   -6.657 1.86   -.14 .725   9.63    .00    .00    .00
2B        22.40 .558 20.24   -6.350 1.98 -1.14 .746   9.86   4.29   7.30   7.00
3B.*      22.50 .556 20.06   -5.707 2.29 -1.62 .732   9.68   3.25   7.30   7.00
1C        22.20 .549 20.24   -6.897 1.75   -.75 .754   9.71   3.51   4.85   6.66
2C        22.50 .553 20.52   -6.990 1.73   -.56 .751   9.88   3.51   4.85   6.66
3C.*      22.70 .544 18.10   -3.290 5.49 -6.75 .643   8.39   1.95   4.85   6.66
4C        22.60 .550 20.50   -6.685 1.82   -.64 .743   9.77   3.51   4.85   6.66
5C        22.60 .551 20.75   -7.433 1.59   -.40 .760  10.00   3.90   4.85   6.66
1S        22.40 .547 19.86   -5.551 2.34 -1.56 .722   9.36   2.99   4.85   6.66
2S        22.50 .548 20.47   -6.804 1.78   -.71 .750   9.78   3.51   4.85   6.66
3S        22.30 .547 20.29   -6.801 1.77   -.77 .751   9.69   3.90   4.85   6.66
1T        22.30 .549 20.44   -7.257 1.64   -.57 .760   9.83   3.90   4.85   6.66
2T.*      22.40 .537 17.51   -3.134 5.99 -7.36 .624   7.94   1.69   4.85   6.66
3T        22.20 .544 19.81   -5.759 2.21 -1.52 .731   9.34   3.25   4.85   6.66
4T        22.60 .547 19.08   -4.365 3.36 -2.34 .663   8.66   2.60   4.85   6.66

AVERAGES: 70201A BASELINE W020 00 000
          22.40 .558 20.24   -6.350 1.98 -1.14 .746   9.86   4.29   7.30   7.00
  STD       .00 .000   .00    .000  .00    .00 .000    .00    .00    *      *
            70201A W056CU 005 (6.5E16) AFTER SINTER
          22.42 .549 20.20   -6.454 2.00   -.98 .738   9.60   3.46   4.85   6.66
  STD       .15 .002   .46    .897  .51    .59 .028    .37    .40    *      *
PERCENT OF BASELINE
         100.1  98.3  99.8    98.4  101 113.8  99.0  97.4   80.6   66.4   95.1
 STD%       .7    .4   2.3    14.1   26  51.6   3.7   3.8    9.3     .0     .1
70211 W061 CR-TI 001 (1E15-1.1E13)BEFORE SINTER W020 00 000
*SOL3              AM1: P0=91.60MW/CM©2   NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*       22.50 .557 20.40   -6.889 1.78   -.05 .730   9.68    .00    .00    .00
1B        22.80 .557 20.82   -7.268 1.65   -.01 .741   9.95   4.55   7.30   7.00
2B        23.10 .558 21.06   -7.192 1.68    .02 .738  10.06   4.42   7.30   7.00
3B        23.10 .552 20.82   -6.595 1.86   -.04 .720   9.71   3.90   7.30   7.00
4B        23.20 .554 20.77   -6.125 2.06   -.58 .719   9.78   4.16   7.30   7.00
5B.*      23.70 .551 20.43   -4.866 2.84 -1.40 .678   9.36   3.25   7.30   7.00
1C        17.10 .498 15.33   -6.579 1.73    .23 .707   6.36    .13    .00    .00
2C        17.10 .495 15.22   -6.315 1.82    .27 .695   6.22    .13    .00    .00
3C        17.30 .495 15.34   -6.119 1.90    .08 .692   6.27    .13    .00    .00
4C        17.30 .495 15.42   -6.380 1.79    .34 .696   6.30    .13    .00    .00
5C        17.30 .497 15.43   -6.474 1.76    .59 .693   6.30    .13    .00    .00
1S        16.10 .497 13.55   -4.607 2.95 -1.94 .647   5.47    .13    .00    .00
2S        18.20 .501 15.78   -5.148 2.46 -1.39 .682   6.58    .13    .00    .00
3S        17.60 .500 15.14   -4.903 2.65 -2.00 .679   6.32    .13    .00    .00
1T        15.70 .491 13.87   -6.161 1.88    .56 .680   5.54    .13    .00    .00
2T        17.30 .496 15.42   -6.210 1.86   -.27 .706   6.40    .13    .00    .00
3T        17.30 .496 15.39   -6.263 1.84    .13 .697   6.32    .13    .00    .00
4T        17.10 .493 15.26   -6.295 1.82   -.17 .706   6.30    .13    .00    .00

AVERAGES: 70211  BASELINE W020 00 000
          23.05 .555 20.87   -6.795 1.81   -.15 .730   9.88   4.26   7.30   7.00
  STD       .15 .002   .11    .466  .16    .25 .010    .14    .25    *      *
            70211 W061 CR-TI 001 (1E15-2E13) BEFORE SINTER
          17.12 .496 15.10   -5.955 2.04   -.30 .690   6.20    .13    .00    .00
  STD       .62 .003   .64    .638  .39    .90 .016    .32    .00    *      *
PERCENT OF BASELINE
          74.3  89.4  72.3   112.4  112   6.8  94.5  62.8    3.1     .0     .0
 STD%      3.2    .9   3.5    16.1   34 *****   3.5   4.2     .2     .0     .0
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70211A W061CR-TI001 (1E15-1.1E13)AFTER SINTER W020 00 000
*SOL3              AM1: PO=91.60MW/CM©2  NO AR COATING

ID        ISC    VOC  IP     LOG(IO)  N      R    FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .559 20.41   -6.908 1.78   -.05 .731   9.72    .00    .00    .00
1B       22.70 .560 20.75   -7.153 1.70   -.45 .752  10.12   4.29   7.30   7.00
2B       23.00 .560 21.10   -7.528 1.59   -.04 .750  10.22   4.29   7.30   7.00
3B       23.10 .562 21.28   -7.710 1.55   -.21 .761  10.45   5.20   7.30   7.00
4B       22.90 .562 21.28   -8.530 1.36    .09 .771  10.49   4.55   7.30   7.00
5B       22.90 .559 20.95   -7.256 1.66   -.27 .750  10.15   3.90   7.30   7.00
1C       17.30 .501 15.47   -6.241 1.87   -.57 .715   6.55    .13    .00    .00
2C       17.10 .500 15.54   -7.195 1.54    .18 .730   6.60    .13    .00    .00
3C       17.20 .497 15.36   -6.323 1.82   -.16 .707   6.39    .13    .00    .00
4C.*     17.20 .493 14.29   -4.116 3.50 -4.02 .655   5.87    .13    .00    .00
5C.*     17.40 .492 14.25   -3.953 3.74 -4.01 .637   5.77    .13    .00    .00
1S       14.80 .498 13.30   -6.697 1.71    .10 .713   5.56    .13    .00    .00
2S       17.50 .503 15.63   -6.159 1.91   -.70 .716   6.66    .13    .00    .00
3S       17.50 .502 15.75   -6.574 1.74   -.32 .722   6.71    .13    .00    .00
1T       15.90 .491 14.29   -6.654 1.69   -.01 .715   5.90    .13    .00    .00
2T       16.90 .496 15.33   -7.007 1.58   -.10 .731   6.48    .13    .00    .00
3T       16.80 .495 15.18   -6.805 1.64   -.13 .725   6.37    .13    .00    .00
4T       16.70 .495 14.97   -6.450 1.77   -.25 .714   6.24    .13    .00    .00

AVERAGES: 70211A BASELINE W020 00 000
         22.92 .561 21.07   -7.635 1.57   -.18 .757  10.29   4.45   7.30   7.00
  STD      .13 .001   .20     .489  .12    .18 .008    .16    .43    *      *
            70211A W061CR-TI001 (1E15-2E13) AFTER SINTER
         16.77 .498 15.08   -6.611 1.73   -.20 .719   6.35    .13    .00    .00
  STD      .79 .004   .71     .316  .11    .26 .007    .35    .00    *      *
PERCENT OF BASELINE
          73.2  88.8  71.6   113.4  110   88.1  95.0   61.7    2.9     .0     .0
 STD%      3.9    .8   4.1     9.9   16  425.7   2.0    4.3     .3     .0     .0
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70502 W062N-CU001 (2.5E15) N BASE W060 00 000
*SOL1            AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC   IP    LOG(IO)  N     R     FF    Eff   OCD   PCDa  PCDb

1R*     22.50 .556 20.28  -6.553 1.89  -.21 .723  9.57   .00   .00   .00
1B      22.30 .562 20.61  -8.154 1.44   .21 .758 10.05   .26   .00   .00
2B      22.00 .559 19.84  -6.398 1.97  -.78 .735  9.56  4.03   .00   .00
3B.*    22.70 .565 20.23  -5.857 2.24 -1.00 .719  9.76  3.25   .00   .00
4B      22.30 .560 20.11  -6.393 1.97  -.75 .734  9.70  5.20   .00   .00
5B      22.20 .562 20.44  -7.739 1.54  -.14 .759 10.01  5.85   .00   .00
1C      22.60 .565 20.88  -8.020 1.48   .00 .762 10.29  7.80   .00   .00
2C.*    15.60 .560 13.20  -4.403 3.60 -4.99 .681  6.29  7.15   .00   .00
3C      22.50 .561 20.91  -8.533 1.36   .01 .774 10.33 10.40   .00   .00
4C      22.60 .558 19.64  -5.272 2.57  -.52 .673  8.98  6.50   .00   .00
5C      22.60 .569 21.11  -9.141 1.27   .27 .777 10.57  1.30   .00   .00
6C      21.60 .560 19.75  -7.196 1.69  -.41 .751  9.61  6.50   .00   .00
7C      22.40 .554 19.37  -4.895 2.85 -1.74 .686  9.00  3.64   .00   .00
8C      21.70 .547 18.90  -5.135 2.63 -1.43 .691  8.67  5.85   .00   .00
1S      21.90 .550 19.71  -6.292 1.98  -.84 .733  9.33   .39   .00   .00
2S      22.00 .555 20.03  -6.901 1.77  -.58 .747  9.65  5.20   .00   .00
3S      22.60 .560 21.09  -9.022 1.27   .27 .775 10.37 10.40   .00   .00
4S      22.30 .555 20.49  -7.602 1.56  -.15 .755  9.89  6.50   .00   .00
5S      22.30 .555 20.20  -6.591 1.88  -.70 .741  9.70  6.11   .00   .00
1T      22.10 .572 20.46  -8.267 1.45   .16 .762 10.19  9.10   .00   .00
2T      22.70 .568 21.05  -8.360 1.41   .09 .767 10.46  9.10   .00   .00
3T      22.70 .568 20.95  -7.946 1.51  -.02 .761 10.37  5.20   .00   .00
4T      22.00 .567 20.21  -7.529 1.61  -.27 .757  9.99  8.19   .00   .00
5T      22.50 .568 20.70  -7.636 1.58  -.22 .759 10.25  6.50   .00   .00

AVERAGES: 70502  BASELINE W060 00 000
        22.20 .561 20.25  -7.171 1.73  -.37 .747  9.83  3.84   .00   .00
  STD     .12 .001   .30    .789  .24   .42 .012   .21  2.16    *     *
          70502 W062N-CU001 (1.7E15) N BASE
        22.30 .561 20.32  -7.314 1.76  -.36 .745  9.86  6.39   .00   .00
  STD     .34 .007   .65   1.270  .47   .55 .031   .56  2.71    *     *
PERCENT OF BASELINE
       100.5 100.0 100.3    98.0  101 102.6  99.8 100.3 166.7 ***** *****
 STD%     2.1   1.5   4.7   30.9   45 432.0   5.8   8.0 204.6 ***** *****
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70518 W063N-CR001 ( 8E14   ) W060 00 000
*SOL1               AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC  IP     LOG(IO)  N      R    FF    Eff   OCD   PCDa . PCDb

1R*      22.50 .552 20.27  -6.517 1.89  -.21 .722  9.48   .00   .00   .00
1B       22.10 .555 20.13  -7.211 1.67   .18 .733  9.50  1.04   .00   .00
2B       22.00 .562 20.44  -8.750 1.32   .51 .761  9.96  8.71   .00   .00
3B       21.30 .559 19.64  -7.976 1.48   .13 .756  9.52  7.80   .00   .00
4B       21.50 .560 19.63  -7.187 1.69  -.25 .746  9.49  6.50   .00   .00
5B*      21.40 .551 19.18  -6.219 2.02  -.62 .722  9.00  5.20   .00   .00
1C       18.40 .523 16.12  -5.929 2.08   .83 .664  6.76  1.30   .00   .00
2C       18.50 .522 17.09  -8.465 1.30   .81 .746  7.62  1.69   .00   .00
3C       18.40 .522 16.98  -8.268 1.33   .52 .750  7.62  1.56   .00   .00
4C       18.30 .524 16.96  -8.643 1.27   .65 .755  7.66  1.69   .00   .00
5C.*     18.50 .527 15.06  -3.966 3.94 -3.09 .620  6.39  1.17   .00   .00
6C       19.00 .526 17.59  -8.678 1.26   .91 .747  7.90  1.69   .00   .00
7C       18.60 .524 16.66  -6.229 1.95  -.76 .722  7.44  1.56   .00   .00
8C       18.40 .521 16.21  -5.859 2.11  -.03 .684  6.94  1.30   .00   .00
9C       18.70 .525 17.28  -8.405 1.31   .58 .751  7.80  1.30   .00   .00
1S.*     18.80 .516 14.50  -3.268 5.54 -6.29 .590  6.05  1.04   .00   .00
2S       18.90 .521 17.30  -7.578 1.49   .25 .740  7.71  1.30   .00   .00
3S       19.10 .522 17.66  -8.534 1.28   .77 .748  7.89  1.69   .00   .00
4S.*     19.10 .523 14.89  -3.506 4.87 -3.88 .580  6.13  1.30   .00   .00
5S       19.10 .522 17.49  -7.637 1.47   .34 .739  7.79  1.69   .00   .00
1T       18.70 .524 17.22  -8.024 1.39   .33 .750  7.77  1.69   .00   .00
2T       18.60 .526 17.10  -7.786 1.45   .08 .751  7.77  1.56   .00   .00
3T       18.80 .524 17.22  -7.573 1.50   .12 .744  7.75  1.30   .00   .00
4T       18.80 .524 17.14  -7.345 1.56   .22 .734  7.65  1.30   .00   .00
5T       19.10 .523 17.61  -8.120 1.36   .34 .752  7.94  1.30   .00   .00
6T       18.80 .522 17.18  -7.423 1.53   .04 .742  7.70  1.56   .00   .00

AVERAGES: 70518  BASELINE W060 00 000
         21.73 .559 19.96  -7.781 1.54   .14 .749  9.62  6.01   .00   .00
  STD      .33 .003   .34    .643  .15   .27 .011   .20  2.98   *     *
           70518 W063N-CR001 (2.8E15)
         18.72 .523 17.11  -7.676 1.51   .35 .736  7.63  1.50   .00   .00
  STD      .26 .002   .42    .880  .27   .40 .024   .31   .17   *     *
PERCENT  OF BASELINE
         86.2  93.6  85.7  101.3    98 250.4  98.3  79.3  24.9 ***** *****
 STD%     2.5    .7   3.6   20.4    29 *****   4.7   4.9  16.7 ***** *****
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70519 W064N-MN001 (1E15) W060 00 000
*SOL2              AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC  IP     LOG(IO)  N     R     FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .555 20.22  -6.379 1.96  -.33 .721  9.52    .00    .00    .00
1B       22.60 .568 20.82  -7.770 1.55  -.13 .759 10.31   1.43    .00    .00
2B       22.10 .553 19.81  -6.125 2.07  -.87 .727  9.39   5.85    .00    .00
3B       22.30 .553 20.44  -7.627 1.55   .27 .742  9.67   7.54    .00    .00
4B       22.20 .556 20.06  -6.637 1.86  -.30 .729  9.52   5.20    .00    .00
5B*      21.90 .553 19.35  -5.480 2.42 -1.51 .714  9.15   4.81    .00    .00
1C       21.40 .547 19.40  -6.840 1.77  -.23 .733  9.08   5.20    .00    .00
2C       21.90 .559 20.43  -9.041 1.27   .33 .773 10.01   6.76    .00    .00
3C       21.30 .546 19.73  -8.591 1.32   .66 .753  9.26   5.20    .00    .00
4C       21.00 .541 19.28  -7.926 1.45   .68 .736  8.85   3.25    .00    .00
5C*      17.80 .524 15.33  -5.053 2.65 -1.28 .670  6.61   1.95    .00    .00
6C       21.70 .547 20.16  -8.871 1.27   .70 .757  9.50   6.50    .00    .00
7C       21.50 .550 19.92  -8.387 1.37   .22 .763  9.54   5.20    .00    .00
8C       21.20 .547 19.71  -8.855 1.27   .55 .762  9.34   4.55    .00    .00
9C       21.20 .543 19.39  -7.394 1.59  -.02 .744  9.06   3.90    .00    .00
10C      22.00 .545 19.98  -6.521 1.87 -1.34 .759  9.62   5.20    .00    .00
1S       21.20 .544 19.01  -6.259 1.98  -.55 .721  8.79   3.90    .00    .00
2S       21.80 .546 19.58  -6.368 1.94  -.33 .720  9.06   4.16    .00    .00
3S       21.60 .545 19.90  -8.110 1.41   .57 .744  9.27   5.85    .00    .00
4S       21.90 .555 20.33  -8.566 1.34   .28 .765  9.83   6.50    .00    .00
5S       21.40 .549 19.83  -8.413 1.36   .28 .761  9.46   5.46    .00    .00
6S       21.70 .544 19.95  -7.870 1.46   .35 .745  9.31   4.94    .00    .00
1T       20.80 .549 19.11  -7.660 1.53  -.10 .754  9.11   4.29    .00    .00
2T       21.00 .545 19.20  -7.322 1.61  -.13 .746  9.03   3.90    .00    .00
3T       21.60 .556 19.97  -8.176 1.43   .12 .761  9.67   5.20    .00    .00
4T       21.00 .536 18.45  -5.458 2.37 -1.07 .698  8.31   2.34    .00    .00
5T       21.00 .541 18.98  -6.642 1.82  -.35 .730  8.77   2.99    .00    .00
6T       21.60 .553 19.79  -7.375 1.62  -.32 .754  9.53   3.90    .00    .00

AVERAGES: 70519  BASELINE W060 00 000
         22.30 .558 20.28  -7.040 1.76  -.26 .739  9.72   5.01    .00    .00
  STD      .19 .006   .38    .685  .22   .41 .013   .35   2.23     *      *
           70519 W064N-MN001 (1E15)
         21.42 .547 19.62  -7.650 1.57   .01 .747  9.26   4.72    .00    .00
  STD      .34 .005   .48    .974  .28   .54 .018   .39   1.15     *      *
PERCENT OF BASELINE
         96.0  98.1  96.7    91.3    90 205.6 101.0  95.2   94.4 ***** *****
 STD%     2.4   2.0   4.2    25.8    29 558.3   4.2   7.6   75.2 ***** *****
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70520 W065N-TI001 ( 2E14  ) W060 00 000
*SOL2               AM1: PO=91.60MW/CM©2   NO AR COATING

ID          ISC    VOC   IP     LOG(IO)  N      R     FF    Eff    OCD    PCDa    PCDb

1R*        22.50 .555 20.34   -6.794 1.80    .10 .722   9.53    .00    .00     .00
1B         22.10 .565 20.41   -7.972 1.49   -.07 .763  10.07   9.75    .00     .00
2B         22.40 .569 20.86   -8.805 1.33    .25 .771  10.40  10.40    .00     .00
3B         22.40 .562 20.51   -7.385 1.64   -.14 .749   9.97   8.45    .00     .00
4B         21.90 .563 19.97   -7.068 1.74   -.35 .745   9.72   7.80    .00     .00
5B         22.60 .568 20.95   -8.672 1.35    .72 .753  10.22   9.10    .00     .00
1C         19.10 .531 17.53   -7.643 1.50   -.06 .752   8.06   1.69    .00     .00
2C         19.10 .525 17.37   -6.948 1.68   -.47 .742   7.87   1.56    .00     .00
3C         19.20 .529 17.52   -7.202 1.61   -.28 .745   8.00   1.04    .00     .00
4C         19.20 .529 17.57   -7.380 1.56   -.25 .750   8.05   1.56    .00     .00
5C         19.10 .526 17.18   -6.390 1.88   -.70 .728   7.73   1.30    .00     .00
6C         19.20 .524 17.33   -6.594 1.79   -.46 .729   7.76   1.30    .00     .00
7C         18.90 .534 17.22   -7.105 1.66   -.34 .743   7.93   1.30    .00     .00
8C         19.00 .529 17.30   -7.122 1.64   -.18 .739   7.86   1.30    .00     .00
9C         19.20 .532 17.61   -7.530 1.53   -.18 .752   8.12   1.30    .00     .00
1S         19.30 .531 17.68   -7.518 1.53   -.07 .748   8.11   1.56    .00     .00
2S         19.30 .528 17.59   -7.088 1.64   -.40 .745   8.03   1.30    .00     .00
3S         19.80 .534 18.23   -7.954 1.43    .22 .752   8.40   1.69    .00     .00
4S         19.10 .529 17.48   -7.394 1.56   -.20 .748   8.00   1.30    .00     .00
5S         19.30 .530 17.71   -7.584 1.51   -.10 .751   8.13   1.56    .00     .00
1T         19.10 .531 17.44   -7.327 1.58   -.02 .741   7.95   1.56    .00     .00
2T         19.00 .527 17.29   -7.102 1.64   -.18 .739   7.82   1.56    .00     .00
3T         18.90 .530 17.29   -7.471 1.54    .00 .744   7.89   1.30    .00     .00
4T         19.00 .527 17.11   -6.476 1.85   -.60 .728   7.71   1.30    .00     .00
5T         19.10 .528 17.33   -6.867 1.71   -.40 .737   7.86   1.30    .00     .00
6T         19.10 .528 17.40   -7.074 1.65   -.40 .744   7.94   1.30    .00     .00

AVERAGES: 70520  BASELINE W060 00 000
           22.28 .565 20.54   -7.980 1.51    .08 .756  10.07   9.10    .00     .00
  STD        .25 .003   .35     .685  .16    .37 .010    .23    .92    *       *
            70520 W065N-TI001 (3.6E14)
           19.15 .529 17.46   -7.188 1.62   -.25 .743   7.96   1.40    .00     .00
  STD        .19 .003   .24     .391  .11    .22 .007    .16    .17    *       *
PERCENT OF BASELINE
           86.0  93.6  85.0   109.9   108 *****  98.2   79.0   15.4 ***** *****
 STD%       1.8    .9   2.6    13.0    20 *****   2.2    3.4    3.6 ***** *****
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70422 W066TI005 (3.3E13)W054 00 000
*SOL1              AM1: PO=91.60MW/CM©2  NO AR COATING

ID          ISC   VOC   IP     LOG(IO)  N      R      FF    Eff     OCD    PCDa   PCDb

1R*        22.50 .556 20.22   -6.388 1.96   -.33 .721   9.54    .00    .00    .00
1B         22.70 .558 21.05   -8.267 1.41   -.14 .773  10.35   5.20    .00   6.30
2B         22.70 .553 20.89   -7.610 1.55   -.30 .761  10.11   4.55    .00   6.30
3B         22.90 .554 20.99   -7.311 1.63   -.41 .756  10.15   4.55    .00   6.30
4B         22.50 .553 20.64   -7.336 1.62   -.49 .760  10.00   4.55    .00   6.30
5B         22.80 .558 21.07   -7.958 1.48   -.21 .768  10.33   5.20    .00   6.30
1C         16.50 .500 14.68   -6.210 1.89   -.16 .702   6.12    .26    .00    .00
2C         17.00 .501 15.09   -6.060 1.95   -.33 .700   6.31    .26    .00    .00
3C         16.60 .498 14.72   -6.075 1.94   -.24 .698   6.10    .26    .00    .00
4C         16.60 .498 14.72   -6.075 1.94   -.24 .698   6.10    .26    .00    .00
5C         16.40 .499 14.49   -5.984 1.99   -.12 .690   5.97    .26    .00    .00
6C         17.10 .500 15.10   -5.887 2.03   -.38 .693   6.27    .26    .00    .00
1S         17.30 .503 15.37   -6.123 1.93   -.22 .700   6.44    .26    .00    .00
2S         17.30 .503 15.37   -6.123 1.93   -.22 .700   6.44    .26    .00    .00
3S         16.60 .500 14.80   -6.292 1.85   -.11 .704   6.18    .26    .00    .00
4S         17.10 .502 15.17   -6.084 1.94   -.17 .697   6.33    .26    .00    .00
5S         17.50 .502 15.38   -5.671 2.14   -.63 .690   6.41    .26    .00    .00
1T         16.90 .497 14.92   -5.882 2.02   -.38 .693   6.15    .26    .00    .00
2T         16.60 .499 14.80   -6.314 1.84    .02 .701   6.14    .26    .00    .00
3T         16.50 .497 14.63   -6.044 1.95   -.32 .698   6.06    .26    .00    .00
4T         16.80 .498 14.89   -6.059 1.94   -.14 .695   6.15    .26    .00    .00

AVERAGES: 70422  BASELINE W054 00 000
           22.72 .555 20.93   -7.696 1.54   -.31 .764  10.19   4.81    .00   6.30
  STD        .13 .002   .16     .369  .09    .13 .006    .13    .32     *      *
             70422 W066TI005 (6E13)
           16.85 .500 14.94   -6.059 1.95   -.24 .697   6.21    .26    .00    .00
  STD        .33 .002   .28     .157  .07    .15 .004    .14    .00     *      *
PERCENT OF BASELINE
           74.2   90.0   71.4   121.3   127 122.1   91.3   61.0    5.4 *****     .0
 STD%       1.9     .7    1.9     5.9    12 100.3    1.2    2.2     .4 *****     .0
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70425 W067CR-MN-TI001 (4E14-5E14-3E12) W054 00 000
*SOL1              AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N     R     FF    Eff   OCD   PCDa  PCDb

1R*       22.50 .554 20.24  -6.452 1.93  -.27 .721  9.51   .00   .00   .00
1B        22.70 .553 20.96  -7.898 1.48  -.17 .765 10.15  4.94   .00   .00
2B*       22.70 .548 20.06  -5.591 2.32 -1.01 .707  9.30  3.64   .00   .00
3B        22.70 .549 20.69  -7.113 1.68  -.14 .741  9.76  5.20   .00   .00
4B        22.90 .556 21.18  -8.092 1.44  -.06 .766 10.31  5.85   .00   .00
1C        18.70 .519 16.77  -6.267 1.91  -.79 .725  7.44   .39   .00   .00
2C        19.10 .519 17.13  -6.431 1.84  -.14 .713  7.48   .52   .00   .00
3C        19.70 .529 17.69  -6.464 1.86  -.18 .716  7.90   .78   .00   .00
4C        19.80 .529 17.74  -6.331 1.91  -.34 .716  7.93   .78   .00   .00
5C        19.60 .518 16.61  -4.633 2.96 -1.59 .654  7.02   .52   .00   .00
6C        19.20 .518 17.28  -6.554 1.79  -.22 .721  7.58   .39   .00   .00
7C        19.00 .514 16.59  -5.436 2.31  -.72 .683  7.05   .39   .00   .00
1S        19.30 .529 17.33  -6.252 1.95  -.92 .729  7.87   .78   .00   .00
2S        19.60 .526 17.45  -6.165 1.97  -.08 .701  7.64   .78   .00   .00
3S        19.60 .526 17.50  -6.067 2.02  -.80 .718  7.83   .78   .00   .00
4S        19.30 .525 17.37  -6.546 1.82  -.24 .721  7.72   .78   .00   .00
5S        19.70 .529 17.53  -5.907 2.10  -.94 .715  7.88  1.04   .00   .00
1T        18.60 .516 16.27  -5.382 2.36 -1.21 .692  7.02   .52   .00   .00
2T        19.00 .515 16.73  -5.636 2.20  -.85 .697  7.21   .39   .00   .00
3T        18.90 .511 16.57  -5.598 2.20  -.52 .686  7.00   .26   .00   .00
4T        18.60 .513 16.58  -6.076 1.97  -.67 .713  7.19   .39   .00   .00
5T        18.90 .514 16.91  -6.247 1.90  -.51 .716  7.36   .39   .00   .00

AVERAGES: 70425  BASELINE W054 00 000
          22.77 .553 20.94  -7.701 1.53  -.12 .757 10.07  5.33   .00   .00
  STD       .10 .003   .20    .423  .10   .05 .011   .23   .38    *     *
           70425 W067CR-MN-TI001 (4E14-5E14-6E12)
          19.21 .521 17.06  -5.999 2.06  -.63 .707  7.48   .58   .00   .00
  STD       .39 .006   .45    .498  .28   .40 .019   .33   .21    *     *
PERCENT OF BASELINE
          84.4  94.2  81.5  122.1   135 *****  93.4  74.2  10.9 ***** *****
 STD%      2.1   1.6   2.9   11.1    29 662.9   3.9   5.1   5.1 ***** *****
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70426 W068CR004 (1E15)  W054 00 000
*SOL1              AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC  IP    LOG(IO)  N     R    FF    Eff    OCD   PCDa  PCDb

1R*     22.50 .556 20.22  -6.388 1.96  -.33 .721  9.54   .00   .00   .00
1B      22.30 .556 20.57  -7.730 1.53  -.42 .768 10.08  4.55   .00   .00
2B      22.90 .558 21.21  -8.150 1.43  -.17 .771 10.42  5.60   .00   .00
3B      22.40 .555 20.39  -6.781 1.81  -.87 .754  9.91  5.20   .00   .00
4B      23.10 .556 21.24  -7.520 1.58  -.40 .763 10.36  5.60   .00   .00
5B      22.50 .553 20.72  -7.551 1.56  -.58 .769 10.12  4.81   .00   .00
1C      19.30 .519 17.43  -6.563 1.79  -.65 .734  7.77   .65   .00   .00
2C      20.00 .519 17.89  -6.060 1.99  -.97 .724  7.95   .65   .00   .00
3C      20.10 .518 17.87  -5.790 2.11 -1.19 .718  7.91   .65   .00   .00
5C      19.70 .514 17.24  -5.354 2.35 -1.20 .694  7.43   .52   .00   .00
6C      19.10 .515 16.88  -5.638 2.19 -1.21 .708  7.37   .52   .00   .00
7C      19.90 .520 17.88  -6.241 1.91  -.92 .730  7.99   .65   .00   .00
8C      20.20 .519 17.95  -5.770 2.13 -1.18 .717  7.95   .65   .00   .00
9C      20.60 .524 18.55  -6.312 1.89  -.94 .735  8.39   .78   .00   .00
1S      20.40 .524 18.36  -6.319 1.89  -.85 .732  8.28   .91   .00   .00
2S      20.20 .524 18.15  -6.241 1.93  -.91 .731  8.18   .78   .00   .00
3S      20.20 .524 18.12  -6.223 1.93  -.78 .726  8.12   .78   .00   .00
4S      20.30 .524 18.11  -5.990 2.04  -.88 .719  8.08   .78   .00   .00
5S      20.90 .527 18.90  -6.621 1.78  -.55 .736  8.57   .91   .00   .00
1T      19.60 .520 17.64  -6.414 1.85  -.66 .729  7.86   .78   .00   .00
2T      19.60 .517 17.47  -5.943 2.04 -1.01 .719  7.70   .52   .00   .00
3T      19.80 .517 17.75  -6.244 1.90  -.63 .721  7.81   .52   .00   .00
4T      20.00 .519 17.32  -5.247 2.44  -.57 .669  7.35   .52   .00   .00
5T      19.60 .517 17.51  -6.069 1.98  -.88 .721  7.73   .65   .00   .00

AVERAGES: 70426  BASELINE W054 00 000
        22.64 .556 20.83  -7.546 1.58  -.49 .765 10.18  5.15   .00   .00
  STD     .31 .002   .34    .444  .12   .23 .006   .19   .42   *     *
          70426 W068CR004 (1E15)
        19.97 .520 17.83  -6.058 2.01  -.89 .720  7.91   .68   .00   .00
  STD     .44 .004   .48    .370  .18   .21 .016   .33   .13   *     *
PERCENT OF BASELINE
        88.2  93.6  85.6   119.7  127  18.6  94.1  77.8  13.2 ***** *****
 STD%    3.2    .9   3.8     9.9   22 148.8   2.9   4.7   3.7 ***** *****
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70512 W069FE004 (1E15) W054 00 000
*SOL1              AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC  IP     LOG(IO)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*       22.50 .553 20.21  -6.362 1.96   -.33 .720   9.47    .00    .00    .00
1B.*      22.30 .550 19.87  -5.735 2.25 -1.49 .729   9.45   3.25    .00    .00
2B        22.50 .552 20.60  -7.213 1.66   -.56 .758   9.96   3.25    .00    .00
3B        22.50 .552 20.43  -6.621 1.85   -.93 .750   9.85   3.90    .00    .00
4B*       22.10 .550 19.78  -5.953 2.14 -1.27 .732   9.41   3.12    .00    .00
5B        22.80 .550 20.45  -6.020 2.10 -1.17 .734   9.73   3.64    .00    .00
1C        20.30 .564 17.71  -5.160 2.72 -1.80 .697   8.44    .91    .00    .00
2C        20.90 .571 19.08  -7.067 1.77   -.65 .753   9.51   1.17    .00    .00
3C        20.30 .570 18.59  -7.284 1.70   -.55 .756   9.25   1.30    .00    .00
4C        19.00 .563 17.30  -6.882 1.82   -.92 .751   8.50    .65    .00    .00
5C        20.30 .567 17.72  -5.076 2.80 -2.36 .706   8.60    .91    .00    .00
6C        18.90 .562 17.26  -7.111 1.74   -.77 .755   8.48    .91    .00    .00
7C        20.50 .572 18.60  -6.651 1.93 -1.04 .749   9.29   1.04    .00    .00
8C        20.30 .575 18.52  -6.956 1.82   -.89 .755   9.32   1.30    .00    .00
9C        20.30 .568 17.91  -5.491 2.50 -1.64 .712   8.68   1.30    .00    .00
10C       20.20 .570 18.07  -5.874 2.28 -1.85 .738   8.99   1.30    .00    .00
11C       20.80 .573 18.60  -5.946 2.24 -1.37 .730   9.20   1.30    .00    .00
1S        21.20 .575 18.79  -5.547 2.48 -1.83 .723   9.32   1.17    .00    .00
2S*       20.90 .500 15.67  -4.958 2.55  6.69 .455   5.03    .13    .00    .00
3S        21.40 .573 19.11  -5.855 2.29 -1.44 .729   9.45   1.30    .00    .00
4S        21.40 .571 18.68  -5.066 2.81 -2.18 .705   9.11   1.30    .00    .00
5S*       21.20 .455 15.44  -5.314 2.09  7.74 .424   4.32    .13    .00    .00
1T*       17.10 .551 15.68  -7.404 1.63   -.74 .760   7.58    .65    .00    .00
2T*       17.90 .400 13.25  -5.566 1.75  7.88 .433   3.28    .13    .00    .00
3T*       17.70 .317 13.06  -4.985 1.64  5.36 .442   2.62    .13    .00    .00
4T        18.30 .555 16.69  -7.116 1.72   -.54 .748   8.03    .52    .00    .00
5T*       16.70 .403 12.53  -5.654 1.74  8.17 .443   3.15    .13    .00    .00
6T        17.90 .552 16.42  -7.594 1.58   -.21 .753   7.87    .65    .00    .00

AVERAGES: 70512  BASELINE W054 00 000
          22.60 .551 20.49  -6.618 1.87   -.88 .747   9.85   3.60    .00    .00
  STD       .14 .001   .08    .487  .18    .25 .010    .09    .27     *      *
            70512 W069FE004 (1E15)
          20.13 .568 18.07  -6.292 2.14 -1.25 .735   8.88   1.06    .00    .00
  STD      1.02 .007   .80    .848  .41    .62 .020    .50    .26     *      *
PERCENT  OF BASELINE
          89.0 102.9  88.2  104.9   114   58.4  98.4   90.2   29.6 ***** *****
 STD%      5.1   1.4   4.3   20.7    35 131.2   4.1    5.9   10.1 ***** *****
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70516 W070AL003 (5E16) W054 00 000
*SOL1            AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC   IP    LOG(IO)  N     R    FF    Eff   OCD   PCDa  PCDb

1R*     22.50 .556 20.25  -6.469 1.93  -.27 .722  9.55   .00   .00   .00
1B*     18.60 .549 16.08  -4.746 3.04 -3.53 .705  7.61  2.99   .00   .00
2B      22.00 .551 19.86  -6.306 1.98 -1.20 .745  9.55  3.25   .00   .00
3B*     21.70 .536 17.06  -3.443 5.01 -4.21 .597  7.34  1.56   .00   .00
4B.     21.90 .553 19.34  -5.303 2.53 -2.21 .725  9.29  3.25   .00   .00
5B*     21.50 .535 17.02  -3.583 4.65 -3.38 .596  7.25  1.69   .00   .00
1C.     18.40 .532 15.20  -3.925 4.05 -5.03 .659  6.82   .52   .00   .00
2C.     18.40 .522 14.36  -3.423 5.14 -5.43 .594  6.04   .39   .00   .00
4C      18.20 .537 16.66  -7.423 1.58  -.21 .749  7.74   .78   .00   .00
9C.     18.50 .534 15.51  -4.098 3.77 -4.90 .678  7.08   .65   .00   .00
11C.    17.70 .258 12.32  -4.241 1.73  4.12 .415  2.00   .13   .00   .00
1S      14.40 .519 12.32  -4.973 2.77 -1.90 .665  5.25   .52   .00   .00
2S.     16.90 .494 11.91  -3.075 6.23 -3.82 .488  4.30   .13   .00   .00
3S.     14.00 .517 11.58  -4.285 3.55 -3.73 .637  4.88   .39   .00   .00
4S.     18.70 .523 15.17  -3.898 4.02 -3.32 .619  6.40   .39   .00   .00
5S      17.40 .525 14.57  -4.413 3.30 -2.55 .648  6.26   .39   .00   .00
6S      16.70 .528 14.34  -4.904 2.82 -2.12 .675  6.29   .39   .00   .00
1T.     18.30 .509 12.57  -2.658 8.77 ***** .503  4.95   .26   .00   .00
2T.     18.60 .360 12.84  -4.173 2.46  5.56 .410  2.90   .13   .00   .00
3T      18.60 .539 16.79  -6.544 1.87  -.72 .733  7.77   .52   .00   .00
4T.     19.00 .484 12.28  -2.811 7.20 -2.13 .422  4.10   .65   .00   .00
5T.     18.80 .437 14.66  -2.480 8.85 ***** .806  7.00   .65   .00   .00

AVERAGES: 70516  BASELINE W054 00 000
        22.00 .551 19.86  -6.306 1.98 -1.20 .745  9.55  3.25   .00   .00
  STD     .00 .000   .00    .000  .00   .00 .000   .00   .00    *     *
           70516 W070AL003 (5E16)
        17.06 .530 14.94  -5.651 2.47 -1.50 .694  6.66   .52   .00   .00
  STD    1.48 .007  1.66   1.139  .64   .88 .040   .97   .14    *     *
PERCENT OF BASELINE
        77.5  96.1  75.2   110.4  125  74.7  93.1  69.8  16.0 ***** *****
 STD%    6.7   1.4   8.3    18.1   32  73.8   5.3  10.1   4.4 ***** *****
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70608 W072CR005 (4E14) W054 00 000
*SOL1              AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC   IP     LOG(IO)  N      R    FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .552 20.27   -6.517 1.89   -.21 .722   9.48    .00    .00    .00
1B       21.40 .555 19.70   -7.591 1.57   -.48 .765   9.61   4.81    .00    .00
2B       21.90 .552 19.89   -6.680 1.84   -.88 .749   9.58   3.90    .00    .00
3B       21.70 .552 19.91   -7.366 1.62   -.49 .759   9.62   3.90    .00    .00
4B       21.70 .549 19.52   -6.097 2.07  -1.41 .742   9.35   3.25    .00    .00
5B.*     22.40 .549 19.95   -5.730 2.25  -1.38 .726   9.44   2.34    .00    .00
1S       18.80 .524 16.94   -6.499 1.83   -.64 .730   7.61   1.30    .00    .00
2S       19.50 .162 12.36   -3.815 1.28   2.86 .365   1.22    .13    .00    .00
3S.*     20.80 .387 13.69   -4.056 2.72   6.40 .380   3.24    .13    .00    .00
4S.*     20.40 .527 17.02   -4.099 3.65  -3.57 .660   7.51    .78    .00    .00
5S.*     20.10 .244 13.00   -3.601 2.13   3.26 .381   1.98    .13    .00    .00
1C       21.20 .541 19.36   -7.119 1.66   -.46 .750   9.10   2.34    .00    .00
2C.*     21.30 .528 16.37   -3.137 5.96  -6.52 .594   7.06    .78    .00    .00
3C.*     21.40 .533 17.31   -3.557 4.70  -5.40 .644   7.76   1.04    .00    .00
4C       21.30 .541 19.31   -6.656 1.81   -.73 .743   9.05   2.21    .00    .00
5C       21.40 .544 19.65   -7.466 1.57   -.38 .759   9.34   2.60    .00    .00
6C       21.50 .541 19.55   -6.825 1.75   -.63 .746   9.18   2.21    .00    .00
7C       21.30 .541 19.19   -6.336 1.94   -.90 .736   8.97   1.95    .00    .00
8C       21.50 .542 19.69   -7.329 1.60   -.34 .753   9.28   2.34    .00    .00
9C       21.40 .544 19.57   -7.187 1.65   -.46 .753   9.26   2.60    .00    .00
10C.*    19.00 .132 12.24   -4.964  .68   3.34 .356    .94    .13    .00    .00
11C      20.30 .163 13.02   -3.644 1.39   2.34 .375   1.31    .13    .00    .00
1T       21.30 .537 18.99   -5.859 2.14  -1.19 .724   8.75   1.69    .00    .00
2T       20.80 .537 18.79   -6.470 1.87   -.89 .740   8.74   1.87    .00    .00
3T       21.00 .538 18.95   -6.356 1.92  -1.05 .741   8.85   1.95    .00    .00
4T       20.90 .535 18.83   -6.363 1.91   -.85 .735   8.69   1.56    .00    .00
5T       20.70 .535 18.97   -7.422 1.56   -.22 .751   8.80   1.87    .00    .00
6T       20.90 .536 18.74   -6.097 2.03  -1.10 .731   8.66   1.87    .00    .00

AVERAGES: 70608  BASELINE W054 00 000
         21.68 .552 19.75   -6.933 1.77   -.81 .754   9.54   3.97    .00    .00
  STD      .18 .002   .16     .588  .20    .38 .009    .11    .56    *      *
            70608 W072CR005 (4E14)
         20.86 .491 18.25   -6.340 1.74   -.29 .696   7.93   1.79    .00    .00
  STD      .73 .124  2.19    1.091  .22   1.13 .124   2.55    .71    *      *
PERCENT OF BASELINE
         96.3  89.0  92.4    108.6   98 164.4  92.3   83.1   45.1 *****  *****
 STD%     4.2  23.0  11.9     24.8   25 220.2  17.7   28.0   26.8 *****  *****
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70609B W073CR-MN-NI-TI-V001 (4E14-4E14-2E15-2E12-2E12) W054 00 000
*SOL1              AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)   N      R     FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .555 20.31   -6.666 1.85   -.05 .722   9.54    .00    .00    .00
1B       22.80 .553 21.04   -7.933 1.47    .00 .760  10.13   4.55    .00    .00
2B       22.70 .556 20.97   -7.994 1.46   -.07 .764  10.19   5.07    .00    .00
3B       22.70 .556 20.97   -7.994 1.46   -.07 .764  10.19   5.20    .00    .00
4B       22.70 .555 20.94   -7.951 1.47    .05 .758  10.11   4.94    .00    .00
5B       22.70 .553 20.93   -7.809 1.50   -.14 .761  10.11   4.94    .00    .00
1C       17.50 .501 15.56   -6.047 1.95   -.55 .706   6.55   1.04    .00    .00
2C       17.70 .499 15.58   -5.693 2.12   -.68 .693   6.47    .91    .00    .00
3C       17.60 .500 15.42   -5.449 2.26  -1.27 .695   6.47    .65    .00    .00
4C       17.80 .500 15.83   -6.127 1.91   -.29 .703   6.62    .65    .00    .00
5C       17.60 .496 15.24   -5.211 2.40  -1.03 .675   6.23    .52    .00    .00
6C       17.20 .500 15.14   -5.935 2.00    .21 .680   6.19    .65    .00    .00
7C       17.70 .501 15.86   -6.441 1.78   -.17 .713   6.69    .65    .00    .00
8C       17.50 .500 15.81   -6.830 1.65   -.01 .723   6.69    .65    .00    .00
9C       17.70 .498 15.88   -6.548 1.73    .04 .711   6.63    .65    .00    .00
10C      17.60 .496 15.52   -5.908 1.99   -.05 .686   6.34    .52    .00    .00
11C      17.70 .496 15.42   -5.449 2.24   -.59 .678   6.29    .52    .00    .00
1S       18.00 .507 16.24   -6.625 1.74   -.43 .728   7.03    .65    .00    .00
2S       17.90 .503 16.09   -6.526 1.76   -.27 .720   6.85    .65    .00    .00
3S       17.50 .507 15.73   -6.578 1.76   -.10 .716   6.72    .78    .00    .00
4S       18.00 .505 16.20   -6.500 1.77   -.52 .726   6.98    .78    .00    .00
5S       18.50 .504 16.05   -5.179 2.44  -1.23 .681   6.71    .52    .00    .00
1T       17.50 .499 15.68   -6.423 1.79   -.18 .712   6.58    .78    .00    .00
2T       17.50 .497 15.67   -6.404 1.79   -.18 .712   6.54    .78    .00    .00
3T       17.30 .498 15.61   -6.871 1.63    .30 .716   6.52    .91    .00    .00
4T       17.30 .498 15.48   -6.343 1.82   -.28 .712   6.48    .91    .00    .00
5T       17.10 .496 15.35   -6.526 1.74   -.10 .714   6.40    .52    .00    .00
6T       17.20 .494 15.11   -5.662 2.12   -.66 .690   6.20    .52    .00    .00

AVERAGES: 70609B BASELINE W054 00 000
         22.72 .555 20.97   -7.936 1.47   -.05 .761  10.15   4.94    .00    .00
  STD      .04 .001   .04     .068  .01    .07 .002    .04    .22    *      *
           70609B W073CR-MN-NI-TI-V001 (5E14-5E14-2E15-4E12-4E12)
         17.61 .500 15.66   -6.149 1.93   -.37 .704   6.55    .69    .00    .00
  STD      .31 .004   .31     .504  .23    .41 .016    .23    .15    *      *
PERCENT OF BASELINE
          77.5  90.1  74.7   122.5  131  *****  92.5   64.6   14.0 ***** *****
 STD%      1.5    .9   1.6     7.1   17  *****   2.4    2.5    3.8 ***** *****
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70610 W074MN-CR-NI-TI-V002(8E13-8E13-5E14-3E11-3E11) W054 00 000
*SOL1               AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC    VOC   IP      LOG(IO)   N      R     FF     Eff     OCD    PCDa    PCDb

1R*       22.50 .555 20.16   -6.256 2.01    -.36 .717   9.47     .00    .00     .00
1B        22.00 .554 20.19   -7.413 1.61    -.39 .758   9.77    4.68    .00     .00
2B        22.20 .554 20.38   -7.417 1.61    -.47 .761   9.89    4.55    .00     .00
3B        22.30 .551 20.31   -6.983 1.73    -.41 .745   9.68    4.94    .00     .00
4B        22.50 .551 20.63   -7.362 1.61    -.40 .757   9.93    4.55    .00     .00
5B.*      22.30 .551 19.88   -5.765 2.24   -1.40 .727   9.45    4.29    .00     .00
1C        20.70 .541 18.81   -6.758 1.78    -.78 .747   8.85    1.82    .00     .00
2C        20.60 .538 18.56   -6.399 1.91    -.77 .733   8.59    1.30    .00     .00
3C        20.80 .539 18.83   -6.580 1.84    -.79 .741   8.79    1.56    .00     .00
4C        20.80 .540 18.97   -7.056 1.68    -.46 .748   8.88    1.82    .00     .00
5C        20.60 .538 18.53   -6.310 1.94    -.85 .732   8.58    1.69    .00     .00
6C        21.00 .537 18.98   -6.514 1.85    -.76 .738   8.80    1.56    .00     .00
7C        21.10 .537 18.97   -6.275 1.95    -.84 .731   8.76    1.56    .00     .00
8C        20.90 .539 18.95   -6.674 1.80    -.76 .744   8.86    1.82    .00     .00
9C        21.20 .539 19.06   -6.365 1.92    -.53 .725   8.76    1.95    .00     .00
10C       21.10 .539 19.17   -6.836 1.74    -.51 .742   8.93    1.95    .00     .00
11C       20.50 .533 18.30   -5.999 2.07    -.92 .720   8.32    1.30    .00     .00
1S        20.60 .545 18.83   -7.229 1.64    -.37 .750   8.91    2.34    .00     .00
2S        21.10 .543 18.79   -5.832 2.18   -1.15 .720   8.73    1.95    .00     .00
3S        21.30 .545 19.34   -6.800 1.77    -.51 .741   9.10    2.60    .00     .00
4S        21.30 .545 19.53   -7.387 1.59    -.38 .756   9.28    2.60    .00     .00
5S        21.40 .546 18.94   -5.567 2.34   -1.43 .716   8.84    2.60    .00     .00
1T        20.10 .539 18.16   -6.606 1.83    -.50 .732   8.39    1.30    .00     .00
2T        20.30 .538 18.40   -6.776 1.77    -.44 .737   8.51    1.30    .00     .00
3T        20.50 .538 18.57   -6.591 1.83    -.87 .744   8.67    1.56    .00     .00
4T        20.40 .536 18.44   -6.722 1.78    -.21 .728   8.41    1.69    .00     .00
5T        20.70 .539 18.90   -7.138 1.65    -.44 .749   8.84    1.69    .00     .00
6T        20.40 .537 18.46   -6.639 1.81    -.65 .738   8.55    1.69    .00     .00

AVERAGES: 70610  BASELINE W054 00 000
          22.25 .553 20.38   -7.294 1.64    -.42 .755   9.82    4.68    .00     .00
  STD       .18 .002   .16     .181  .05     .03 .006    .10     .16    *       *
             70610 W074MN-CR-NI-TI-V002(8E13-8E13-5E14-6E11-6E11)
          20.79 .540 18.79   -6.593 1.85    -.68 .737   8.74    1.80    .00     .00
  STD       .35 .003   .33     .426  .17     .27 .010    .22     .40    *       *
PERCENT OF BASELINE
          93.4  97.7  92.2   109.6   113    37.5  97.6   89.0    38.5 ***** *****
 STD%      2.3    .9   2.4     8.2    14    82.1   2.2    3.2    10.2 ***** *****
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70614 W075TI-V002 (6E13 -1E14) W054 00 000
*SOL2              AM1: PO=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)   N      R     FF    Eff    OCD   PCDa   PCDb

1R*      22.50 .554 20.33   -6.747 1.81    .01 .723   9.53    .00    .00    .00
1B.*     22.20 .548 19.81   -5.876 2.17  -1.16 .725   9.33   3.38    .00    .00
2B       22.10 .548 20.03   -6.636 1.84   -.68 .742   9.50   3.90    .00    .00
3B       22.20 .549 20.16   -6.682 1.82   -.83 .748   9.65   3.90    .00    .00
4B       22.20 .549 20.42   -7.620 1.54   -.27 .760   9.80   4.16    .00    .00
1C       15.40 .486 13.79   -6.604 1.69    .38 .702   5.56    .22    .00    .00
2C       15.30 .485 13.62   -6.309 1.80    .03 .699   5.49    .13    .00    .00
3C       15.50 .483 13.79   -6.250 1.82   -.09 .700   5.54    .39    .00    .00
4C       15.50 .483 13.70   -5.953 1.95   -.45 .696   5.51    .39    .00    .00
5C       15.40 .482 13.55   -5.923 1.96    .06 .681   5.35    .91    .00    .00
6C       15.40 .479 13.48   -5.732 2.04   -.16 .677   5.28    .65    .00    .00
7C       15.40 .483 13.66   -6.190 1.84    .08 .693   5.45    .91    .00    .00
8C       15.50 .482 13.71   -6.178 1.84    .44 .684   5.40    .91    .00    .00
9C.*     15.40 .478 12.71   -4.214 3.32  -3.15 .634   4.94    .39    .00    .00
10C      15.70 .483 13.91   -6.176 1.85    .24 .689   5.52    .91    .00    .00
11C      15.60 .480 13.66   -5.729 2.04   -.14 .677   5.36    .91    .00    .00
1S       15.70 .483 13.80   -5.747 2.05   -.59 .689   5.53    .91    .00    .00
2S       15.60 .486 13.91   -6.255 1.83   -.36 .707   5.67    .39    .00    .00
3S       15.90 .486 14.12   -6.117 1.88   -.35 .701   5.73   1.04    .00    .00
4S       15.70 .486 13.97   -6.158 1.86   -.41 .705   5.69    .65    .00    .00
1T       15.10 .483 13.51   -6.568 1.70    .30 .703   5.42    .65    .00    .00
2T       15.10 .480 13.40   -6.316 1.78    .47 .689   5.28    .65    .00    .00
3T       15.10 .481 13.51   -6.608 1.68    .46 .700   5.38    .65    .00    .00
4T       15.10 .481 13.22   -5.823 2.01    .23 .672   5.16    .91    .00    .00
5T       15.30 .482 13.68   -6.545 1.70    .31 .702   5.47    .91    .00    .00
6T       15.30 .483 13.68   -6.514 1.72    .17 .704   5.50    .91    .00    .00

AVERAGES: 70614  BASELINE W054 00 000
         22.17 .549 20.21   -6.980 1.73   -.59 .750   9.65   3.99    .00    .00
  STD      .05 .000   .16     .453  .14    .24 .008    .12    .12     *      *
            70614 W075TI-V002 (1E14-1E14)
         15.43 .483 13.68   -6.185 1.85    .03 .694   5.47    .70    .00    .00
  STD      .22 .002   .20     .287  .12    .32 .010    .14    .26     *      *
PERCENT OF BASELINE
         69.6  88.0  67.7   111.4  107  205.2  92.5   56.6   17.6 ***** *****
 STD%     1.2    .4   1.6    10.1   16   79.0   2.3    2.2    7.3 ***** *****
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70613 W076POLY002 W054 00 000
*SOL1              AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC  IP     LOG(IO)  N      R    FF    Eff    OCD    PCDa   PCDb

1R*     22.50 .553 20.18  -6.315 1.98  -.30 .717  9.44    .00    .00    .00
1B*     21.70 .542 18.85  -4.932 2.77 -2.11 .698  8.68   2.99    .00    .00
2B      22.30 .549 20.39  -7.257 1.64  -.23 .748  9.69   5.46    .00    .00
3B      22.30 .550 20.28  -6.777 1.79  -.74 .749  9.72   4.55    .00    .00
4B*     21.70 .543 19.03  -5.208 2.56 -1.80 .710  8.84   3.51    .00    .00
5B      22.10 .548 20.03  -6.636 1.84  -.68 .742  9.50   5.20    .00    .00
1C      18.40 .508 16.24  -6.051 1.97   .43 .680  6.72   1.04    .00    .00
2C      19.00 .505 16.18  -4.936 2.62  -.50 .646  6.55    .78    .00    .00
3C      18.70 .509 15.92  -5.170 2.47   .59 .631  6.35    .91    .00    .00
4C      18.50 .510 16.34  -5.942 2.02  -.07 .690  6.88   1.04    .00    .00
5C      18.80 .506 16.23  -5.452 2.27   .51 .649  6.53    .78    .00    .00
6C      19.40 .507 16.55  -5.092 2.51   .11 .640  6.66    .91    .00    .00
7C      19.30 .512 17.06  -6.040 1.98   .27 .685  7.16   1.04    .00    .00
8C      19.80 .512 17.17  -5.222 2.43  -.80 .674  7.23   1.04    .00    .00
9C      19.00 .504 16.31  -4.927 2.63 -1.33 .668  6.77    .91    .00    .00
10C     19.20 .514 17.05  -6.011 2.00  -.39 .703  7.34    .91    .00    .00
11C.*   19.00 .359 14.12  -4.258 2.36  3.45 .469  3.39    .39    .00    .00
1S.*    18.70 .412 14.40  -4.475 2.50  3.40 .500  4.07    .39    .00    .00
2S      19.30 .514 17.27  -6.241 1.90  -.47 .715  7.51   1.17    .00    .00
3S      19.40 .509 16.15  -4.220 3.39 -2.65 .645  6.74    .78    .00    .00
4S      18.50 .492 15.52  -4.592 2.87 -1.10 .635  6.12    .52    .00    .00
5S.*    17.90 .427 13.47  -4.310 2.78  3.92 .481  3.89    .26    .00    .00
6S      18.60 .416 14.15  -4.211 2.80  2.85 .497  4.06    .26    .00    .00
7S      18.10 .481 14.58  -3.997 3.56 -1.83 .597  5.49   3.90    .00    .00
1T      20.70 .528 18.61  -6.421 1.86  -.37 .722  8.34   1.30    .00    .00
2T      19.70 .519 17.57  -6.170 1.94  -.26 .707  7.64   1.04    .00    .00
3T      20.20 .515 17.50  -5.130 2.50 -1.12 .679  7.47    .78    .00    .00
4T      20.00 .523 17.88  -6.244 1.92  -.28 .711  7.86   1.17    .00    .00
5T      19.50 .514 17.26  -5.894 2.05  -.39 .698  7.40   1.04    .00    .00
6T      19.70 .517 17.50  -5.970 2.03  -.51 .705  7.60   1.04    .00    .00

AVERAGES: 70613  BASELINE W054 00 000
        22.23 .549 20.23  -6.890 1.76  -.55 .746  9.63   5.07    .00    .00
  STD     .10 .001   .15    .265  .09   .23 .003   .09    .38     *      *
          70613 W076POLY002
        19.23 .505 16.62  -5.425 2.37  -.35 .666  6.88   1.06    .00    .00
  STD     .64 .022  1.03    .731  .48  1.05 .050   .89    .67     *      *
PERCENT OF BASELINE
        86.5  92.1  82.1   121.3   135 136.8  89.2  71.4   21.0 ***** *****
 STD%    3.3   4.2   5.8    14.1    35 293.7   7.1  10.0   15.8 ***** *****
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70615 W077M0001 (4.2E12) W054 00 000
*SOL2              AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC    VOC   IP      LOG(IO)  N       R      FF     Eff     OCD     PCDa    PCDb

1R*       22.50 .551 20.12   -6.149 2.04   -.43 .714   9.37    .00     .00     .00
1B        22.70 .551 20.79   -7.302 1.63   -.32 .753   9.96   5.60     .00     .00
2B        22.00 .548 20.07   -7.072 1.69   -.42 .748   9.54   4.40     .00     .00
3B        22.70 .550 20.98   -7.956 1.46   -.19 .767  10.13   5.20     .00     .00
4B        22.30 .549 20.41   -7.236 1.64   -.45 .755   9.77   5.20     .00     .00
5B        22.60 .549 20.76   -7.672 1.52    .06 .751   9.85   4.55     .00     .00
1C        19.10 .504 17.07   -6.152 1.90   -.66 .718   7.30    .52     .00     .00
2C        18.70 .504 16.74   -6.190 1.89   -.73 .720   7.18   1.04     .00     .00
3C        18.80 .504 16.72   -5.886 2.02  -1.01 .715   7.16    .91     .00     .00
4C        18.80 .503 16.39   -5.214 2.41  -1.60 .694   6.94    .91     .00     .00
5C        18.70 .505 16.78   -6.267 1.86   -.82 .726   7.25    .78     .00     .00
6C        18.80 .505 16.82   -6.100 1.93  -1.02 .725   7.28    .91     .00     .00
7C        18.60 .503 16.24   -5.160 2.45  -2.04 .702   6.95    .91     .00     .00
8C        19.50 .506 17.23   -5.672 2.13  -1.01 .706   7.37    .91     .00     .00
9C        18.70 .503 16.62   -5.912 2.01   -.86 .711   7.08    .65     .00     .00
10C       18.80 .504 16.87   -6.317 1.83   -.64 .723   7.25    .91     .00     .00
1S        18.40 .505 16.51   -6.221 1.88  -1.01 .729   7.17    .65     .00     .00
2S        18.80 .505 16.91   -6.455 1.78   -.52 .725   7.28    .78     .00     .00
3S        19.00 .505 17.03   -6.250 1.86   -.70 .723   7.33    .65     .00     .00
4S        19.00 .503 16.98   -6.099 1.92   -.83 .720   7.28    .78     .00     .00
5S        19.00 .503 17.11   -6.524 1.75   -.44 .726   7.34    .91     .00     .00
1T        19.50 .508 17.47   -6.179 1.90   -.81 .724   7.58    .91     .00     .00
2T        19.30 .508 17.41   -6.533 1.76   -.58 .731   7.58    .91     .00     .00
3T        19.40 .507 17.39   -6.243 1.87   -.71 .723   7.52    .91     .00     .00
4T        19.40 .507 17.42   -6.261 1.86   -.85 .728   7.58   1.04     .00     .00
5T        19.30 .506 17.35   -6.373 1.81   -.63 .726   7.50   1.04     .00     .00
6T        19.40 .505 17.30   -6.046 1.95   -.72 .715   7.41   1.17     .00     .00

AVERAGES: 70615  BASELINE W054 00 000
          22.46 .549 20.60   -7.448 1.59   -.26 .755   9.85   4.99     .00     .00
  STD       .27 .001   .32     .321  .09    .18 .007    .19    .45     *       *
             70615 W077M0001 (4.2E12)
          19.00 .505 16.97   -6.098 1.94   -.87 .720   7.30    .87     .00     .00
  STD       .32 .002   .35     .357  .18    .35 .009    .18    .15     *       *
PERCENT  OF BASELINE
          84.6   91.9  82.4   118.1   122  *****  95.4   74.1   17.4  ***** *****
 STD%      2.5     .5   3.0     8.5    19  457.5   2.1    3.4    4.9  ***** *****
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70721 W080PH001 (7E14)  W054 00 000
*SOL2             AM1: PO=91.60MW/CM©2  NO AR COATING

ID      ISC   VOC   IP     LOG(IO)  N      R    FF     Eff    OCD   PCDa   PCDb

1R*     22.50 .553 20.18  -6.347 1.97  -.21 .715   9.41    .00    .00    .00
1B      21.50 .547 19.73  -7.456 1.58  -.29 .755   9.39   3.90    .00    .00
2B      21.90 .549 19.82  -6.514 1.89  -.86 .743   9.44   3.90    .00    .00
3B      21.40 .546 19.30  -6.312 1.96 -1.11 .741   9.16   3.25    .00    .00
4B      21.60 .546 19.64  -6.823 1.77  -.64 .747   9.31   3.25    .00    .00
1C      22.30 .550 20.37  -7.120 1.68  -.41 .750   9.73   4.55    .00    .00
2C      22.10 .549 20.13  -6.905 1.75  -.59 .748   9.60   4.94    .00    .00
3C      22.20 .550 20.18  -6.794 1.79  -.64 .746   9.64   5.85    .00    .00
4C      22.30 .549 20.47  -7.540 1.56  -.11 .752   9.74   5.20    .00    .00
5C      22.10 .546 20.03  -6.741 1.79  -.41 .737   9.40   5.46    .00    .00
6C      22.20 .546 19.73  -5.860 2.17  -.69 .709   9.09   4.55    .00    .00
7C      22.10 .549 20.24  -7.245 1.64  -.52 .757   9.72   5.85    .00    .00
8C      22.00 .546 19.66  -5.939 2.13 -1.10 .726   9.22   4.55    .00    .00
9C      22.00 .545 19.87  -6.545 1.86  -.51 .732   9.29   5.20    .00    .00
1S      21.70 .548 19.77  -6.961 1.73  -.53 .748   9.40   4.55    .00    .00
2S      22.10 .550 20.38  -7.973 1.45   .11 .757   9.72   6.50    .00    .00
3S      22.00 .548 20.16  -7.349 1.61  -.35 .755   9.62   5.85    .00    .00
4S      22.00 .546 19.90  -6.570 1.86  -.63 .737   9.37   5.20    .00    .00
5S      21.90 .547 20.05  -7.315 1.62  -.32 .753   9.53   5.85    .00    .00
1T      21.70 .548 19.87  -7.440 1.58  -.04 .747   9.39   5.20    .00    .00
2T      21.90 .548 19.98  -7.101 1.68  -.32 .746   9.46   4.55    .00    .00
3T      21.90 .546 19.92  -6.892 1.74  -.44 .743   9.39   4.81    .00    .00
4T      22.30 .546 20.04  -6.250 1.98  -.71 .728   9.37   4.55    .00    .00
5T      22.30 .547 20.34  -7.162 1.66  -.10 .741   9.55   5.59    .00    .00

AVERAGES: 70721  BASELINE W054 00 000
        21.60 .547 19.62  -6.776 1.80  -.73 .746   9.33   3.58    .00    .00
  STD     .19 .001   .19    .432  .15   .30 .005    .11    .33      *      *
          70721 W080PH001  (7E14)
        22.06 .548 20.06  -6.932 1.75  -.44 .743   9.49   5.20    .00    .00
  STD     .18 .002   .23    .522  .18   .27 .012    .18    .58      *      *
PERCENT OF BASELINE
       102.1 100.1 102.2    97.7   97 139.8  99.5  101.7  145.5  *****  *****
 STD%    1.7    .5   2.2    14.7   19  78.3   2.3    3.1   30.9  *****  *****
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70725 W081N-NI001 (1.7E15) W060 00 000
*SOL2             AM1: P0=91.60MW/CM©2  NO AR COATING

ID          ISC    VOC   IP     LOG(IO)  N      R     FF     Eff     OCD    PCDa   PCDb

1R*         22.50 .557 20.26   -6.511 1.91   -.18 .721   9.55    .00    .00    .00
1B          21.40 .557 19.42   -7.077 1.72    .30 .724   9.13   7.80    .00    .00
2B          22.10 .568 20.62   -9.078 1.28    .34 .774  10.27   9.10    .00    .00
3B          21.50 .560 19.80   -7.945 1.49    .29 .750   9.55   7.80    .00    .00
4B          21.30 .559 19.57   -7.810 1.52    .32 .745   9.38   6.76    .00    .00
1C          21.20 .541 17.89   -4.407 3.31  -2.34 .660   8.01   1.95    .00    .00
2C          21.10 .540 17.52   -4.140 3.66  -2.70 .644   7.75   1.56    .00    .00
3C          20.90 .294 15.99   -3.727 2.39    .04 .529   3.44   1.69    .00    .00
4C          21.40 .466 17.08   -4.656 2.61   2.62 .536   5.65   1.04    .00    .00
5C          21.30 .372 16.88   -4.159 2.50    .66 .551   4.62    .65    .00    .00
6CNS        20.60 .371 16.30   -4.353 2.32   1.46 .539   4.35   1.30    .00    .00
7CNS        21.00 .369 16.41   -4.087 2.56    .93 .535   4.38   1.30    .00    .00
8CNS        20.80 .357 16.28   -4.140 2.42   1.04 .535   4.20    .91    .00    .00
9CNS        20.80 .360 16.17   -4.089 2.50   1.11 .528   4.18    .91    .00    .00
10CNS       21.30 .414 17.01   -4.298 2.63    .98 .555   5.17   1.56    .00    .00
1S          21.00 .513 17.04   -4.229 3.36   -.22 .587   6.69   1.56    .00    .00
2S          21.50 .447 16.61   -4.309 2.83   2.68 .508   5.16   1.82    .00    .00
3S          21.10 .498 16.79   -4.100 3.43    .28 .562   6.25    .65    .00    .00
4S          21.30 .436 16.61   -4.274 2.80   2.06 .522   5.12   1.17    .00    .00
5S          21.10 .519 16.98   -3.891 3.91  -1.92 .598   6.92    .78    .00    .00
1T          21.90 .335 17.35   -3.798 2.61   -.88 .576   4.47   1.95    .00    .00
2T          21.30 .345 16.56   -3.958 2.52    .54 .536   4.16   1.82    .00    .00
3T          21.20 .411 16.85   -4.401 2.52   1.61 .542   4.99   2.34    .00    .00
4T          21.40 .365 16.64   -4.107 2.50   1.21 .527   4.35   1.30    .00    .00

AVERAGES: 70725  BASELINE W060 00 000
            21.58 .561 19.85   -7.978 1.50    .31 .748   9.58   7.87    .00    .00
  STD         .31 .004   .46     .716  .16    .02 .018    .42    .83    *      *
              70725 W081N-NI001 (1.7E15)
            21.17 .419 16.79   -4.164 2.81    .48 .556   5.26   1.38    .00    .00
  STD         .29 .074   .47     .219  .46   1.49 .040   1.26    .47    *      *
PERCENT OF BASELINE
            98.1  74.6   84.6   147.8    187 153.8   74.3   54.8   17.6 ***** *****
 STD%        2.8  13.8    4.4     7.7     53 512.3    7.2   16.1    8.5 ***** *****
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70726 W082N-V001 (4E14) W060 00 000
*SOL2            AM1: PO=91.60MW/CM©2  NO AR COATING

ID      ISC   VOC  IP     LOG(IO)  N     R    FF    Eff   OCD   PCDa  PCDb

1R*     22.50 .553 20.21  -6.394 1.95  -.24 .718  9.45   .00   .00   .00
1B.*    21.60 .551 19.30  -5.984 2.13  -.98 .723  9.10  6.50   .00   .00
2B      21.40 .555 19.69  -7.782 1.52   .07 .753  9.45  6.50   .00   .00
3HFB    21.90 .562 20.24  -7.992 1.48  -.16 .766  9.97  9.10   .00   .00
4HFB    21.40 .552 19.61  -7.453 1.59  -.15 .751  9.38  6.54   .00   .00
1CNS    17.20 .511 15.39  -6.333 1.87  -.33 .712  6.62  1.69   .00   .00
3CNS    17.90 .514 16.08  -6.346 1.87  -.80 .727  7.07   .91   .00   .00
4CNS    17.60 .512 15.99  -6.962 1.64  -.40 .739  7.04   .91   .00   .00
5CNS    17.70 .512 15.95  -6.542 1.79  -.61 .729  6.99  1.56   .00   .00
6CNS    17.60 .510 15.72  -6.246 1.90  -.39 .711  6.75  1.56   .00   .00
7C      17.50 .512 15.69  -6.281 1.89  -.86 .725  6.87   .91   .00   .00
8C      17.50 .510 15.44  -5.662 2.18 -1.21 .705  6.65  1.04   .00   .00
9C      17.70 .510 15.88  -6.262 1.89  -.94 .727  6.94  1.30   .00   .00
10C     17.90 .512 16.10  -6.398 1.84  -.83 .730  7.07  1.30   .00   .00
1S      17.60 .513 15.79  -6.478 1.81  -.19 .715  6.83  1.30   .00   .00
2S      17.30 .513 15.61  -6.723 1.73  -.20 .724  6.80  1.04   .00   .00
3S      17.70 .514 15.97  -6.656 1.75  -.35 .726  6.99  1.04   .00   .00
4S      17.60 .513 15.88  -6.678 1.74  -.28 .725  6.92  1.69   .00   .00
1T      17.20 .503 14.83  -5.023 2.58 -1.66 .677  6.19   .78   .00   .00
2T      17.10 .508 14.86  -5.246 2.44 -1.37 .683  6.28  1.30   .00   .00
3T      17.10 .504 14.85  -5.341 2.36  -.81 .675  6.15   .78   .00   .00
4T      17.40 .509 15.51  -6.151 1.94  -.49 .709  6.64  1.82   .00   .00
5T.*    17.30 .508 12.93  -3.692 4.38   .56 .506  4.70  1.56   .00   .00
6T      17.50 .495 14.60  -4.444 3.08 -1.78 .636  5.82   .78   .00   .00

AVERAGES: 70726  BASELINE W060 00 000
        21.57 .556 19.85  -7.743 1.53  -.08 .756  9.60  7.38   .00   .00
  STD     .24 .004   .28    .222  .05   .11 .007   .26  1.22    *     *
          70726 W082N-V001 (4E14)
        17.51 .510 15.56  -6.098 2.02  -.75 .710  6.70  1.21   .00   .00
  STD     .24 .005   .46    .658  .36   .47 .025   .35   .34    *     *
PERCENT OF BASELINE
        81.2  91.6  78.4  121.2  132 *****  93.8  69.8  16.3 ***** *****
 STD%    2.0   1.5   3.5   11.0   28 *****   4.3   5.7   8.0 ***** *****
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70829 W083NFE001 (1E15)  W060 00 000  <70412>
*SOL2              AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC    VOC   IP     LOG(I0)  N      R     FF    Eff    OCD    PCDa   PCDb

1CB       22.70 .567 21.12   -8.705 1.34    .22 .770 10.48    9.10    .00    .00
2CB       22.60 .561 20.99   -8.550 1.36    .17 .769 10.30    9.10    .00    .00
3CB       22.90 .568 21.41   -9.248 1.25    .30 .779 10.71    3.25    .00    .00
4CB       22.90 .565 21.18   -8.093 1.46   -.03 .765 10.47    9.10    .00    .00
5CB       22.80 .568 21.05   -7.944 1.51   -.07 .762 10.44    9.10    .00    .00
1C        19.50 .535 16.97   -5.098 2.64 -1.88 .694  7.66    1.30    .00    .00
2C        20.00 .539 17.53   -5.400 2.43 -1.20 .696  7.93    2.21    .00    .00
3C        19.10 .534 16.74   -5.394 2.43 -1.40 .698  7.53    1.69    .00    .00
4C.*      18.50 .526 15.50   -4.151 3.63 -4.33 .671  6.91    1.56    .00    .00
5C        20.30 .543 18.39   -6.654 1.83   -.70 .740  8.62    2.34    .00    .00
6C        19.40 .534 17.23   -5.890 2.14   -.83 .710  7.77    1.82    .00    .00
7C        19.30 .529 16.99   -5.726 2.20   -.42 .690  7.45    1.69    .00    .00
8C        20.90 .542 17.88   -4.644 3.05 -2.27 .677  8.11    2.34    .00    .00
9C        20.50 .545 18.70   -7.220 1.65   -.11 .742  8.76    3.51    .00    .00
10C       18.80 .530 16.26   -4.833 2.85 -2.86 .699  7.36    1.04    .00    .00
11C       21.00 .544 19.00   -6.915 1.73    .23 .721  8.71    4.55    .00    .00
12C       21.30 .545 18.59   -5.368 2.46   -.69 .682  8.37    3.77    .00    .00
1S        21.40 .550 19.50   -7.204 1.66    .09 .735  9.15    5.85    .00    .00
2S        21.50 .548 19.54   -7.037 1.70    .03 .732  9.12    4.55    .00    .00
5S.*      21.50 .547 17.29   -3.448 5.11 -6.24 .644  8.01    4.55    .00    .00
1T        17.70 .514 15.43   -5.542 2.27   -.25 .673  6.48    1.69    .00    .00
2T        18.30 .521 16.18   -5.824 2.13   -.61 .698  7.04     .91    .00    .00
3T        18.00 .521 16.07   -6.217 1.95   -.37 .709  7.03    1.95    .00    .00
4T        18.40 .525 16.31   -5.888 2.11   -.73 .705  7.20    1.04    .00    .00
5T        18.00 .523 15.94   -5.911 2.10   -.56 .701  6.98    1.69    .00    .00

AVERAGES: 70829  BASELINE W060 00 000   <70412>
          22.78 .566 21.15   -8.508 1.38    .12 .769 10.48    7.93    .00    .00
  STD       .12 .003   .15     .464  .09    .14 .006   .13    2.34     *      *
            70829 W083NFE001 (1E15)
          19.63 .535 17.40   -5.932 2.18   -.81 .706  7.85    2.44    .00    .00
  STD      1.24 .010  1.26     .772  .39    .81 .020   .77    1.37     *      *
PERCENT OF BASELINE
          86.2  94.5  82.3   130.3   158 *****  91.8  74.9    30.8 ***** *****
 STD%      5.9   2.3   6.5    13.4    41 *****   3.3   8.4    31.5 ***** *****
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71104 W084AL001 (5E16) W078 00 000
*SOL6              AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R     FF     Eff    OCD    PCDa   PCDb

1R*      22.50 .558 20.09   -6.064 2.11   -.55 .714   9.49    .00    .00    .00
1B*      22.30 .555 19.70   -5.485 2.42 -1.41 .713   9.33   3.90    .00    .00
2B.*     22.50 .551 20.01   -5.753 2.24 -1.14 .719   9.43   3.64    .00    .00
3B       22.70 .553 20.47   -6.369 1.95   -.80 .736   9.77   3.90    .00    .00
4B*      22.20 .546 19.39   -5.126 2.63 -1.73 .701   8.99   2.99    .00    .00
5B.*     22.90 .551 20.19   -5.472 2.40 -1.16 .706   9.42   3.90    .00    .00
1C       19.50 .520 16.68   -4.955 2.68   -.81 .656   7.04    .65    .00    .00
2C       20.10 .527 17.70   -5.618 2.25   -.77 .696   7.80    .91    .00    .00
3C       19.80 .525 17.47   -5.674 2.21   -.82 .700   7.69    .78    .00    .00
4C       20.20 .526 17.26   -4.987 2.67   -.44 .649   7.30    .78    .00    .00
5C       20.00 .526 17.54   -5.449 2.34 -1.01 .694   7.72    .78    .00    .00
6C       20.10 .523 17.37   -5.022 2.63 -1.41 .679   7.55    .65    .00    .00
7C       20.20 .525 17.50   -5.226 2.48   -.68 .671   7.53    .78    .00    .00
8C       19.90 .524 17.11   -4.926 2.71 -1.37 .671   7.40    .78    .00    .00
9C       19.70 .526 17.37   -5.863 2.11   -.03 .686   7.52    .78    .00    .00
10C      20.00 .525 17.37   -5.187 2.51 -1.14 .682   7.57    .78    .00    .00
11C      19.70 .525 17.30   -5.565 2.27   -.76 .692   7.57    .65    .00    .00
12C      19.60 .521 16.94   -5.048 2.61 -1.37 .678   7.33    .65    .00    .00
13C      19.60 .520 16.94   -5.061 2.59 -1.26 .676   7.29    .65    .00    .00
1S       20.80 .528 17.97   -5.120 2.57   -.82 .670   7.79    .78    .00    .00
2S       19.80 .523 17.28   -5.381 2.38   -.78 .683   7.48    .78    .00    .00
3S       20.00 .524 17.44   -5.534 2.28   -.04 .670   7.43    .91    .00    .00
4S       20.30 .525 17.59   -5.240 2.47   -.61 .671   7.56    .91    .00    .00
5S       19.90 .526 17.30   -5.306 2.44   -.71 .677   7.49    .78    .00    .00
1T       19.50 .523 16.66   -4.821 2.81 -1.40 .663   7.15    .78    .00    .00
2T       20.00 .529 17.55   -5.499 2.33   -.90 .693   7.76    .91    .00    .00
3T       19.30 .524 17.05   -5.789 2.15   -.59 .698   7.47    .91    .00    .00
4T       19.60 .525 17.21   -5.534 2.29   -.85 .693   7.54    .91    .00    .00
5T       19.70 .527 17.46   -5.889 2.10   -.56 .703   7.71   1.04    .00    .00
6T       20.00 .525 17.44   -5.239 2.48 -1.30 .690   7.66    .91    .00    .00

AVERAGES: 71104   BASELINE W078 00 000
         22.70 .553 20.47   -6.369 1.95   -.80 .736   9.77   3.90    .00    .00
  STD      .00 .000   .00     .000  .00    .00 .000    .00    .00    *      *
           71104 W084AL001  (5E16)
         19.89 .525 17.31   -5.331 2.43   -.85 .681   7.51    .80    .00    .00
  STD      .31 .002   .30     .304  .20    .38 .014    .19    .10    *      *
PERCENT OF BASELINE
         87.6   94.9   84.6  116.3   124    93.2   92.5   76.9   20.6 ***** *****
 STD%     1.4     .4    1.4    4.8    10    47.4    1.9    2.0    2.7 ***** *****
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80524 W085N/ZR001 (7E11) REPEAT W079 00 000
SOL9             AM1: PO=91.60MW/CM©2  NO AR COATING

ID        ISC    VOC  IP     LOG(IO)  N      R    FF    Eff    OCD    PCDa   PCDb

2R*       21.90 .556 19.67   -6.001 2.14 -1.55 .742  9.56    .00    .00    .00
1B        21.20 .546 19.27   -7.121 1.67   .15 .730  8.94   5.20    .00    .00
2B*       21.40 .540 19.28   -6.534 1.85  -.22 .722  8.83   4.55    .00    .00
3B        21.70 .546 19.69   -6.936 1.73  -.03 .730  9.15   5.85    .00    .00
4B        21.70 .550 19.75   -6.975 1.73  -.38 .743  9.38   4.29    .00    .00
5B*       21.40 .525 17.98   -4.455 3.15 -1.56 .645  7.66   1.56    .00    .00
1C        21.90 .553 18.32   -4.508 3.24  -.85 .629  8.06   7.15    .00    .00
2C        21.40 .547 19.73   -7.995 1.44   .18 .755  9.34   5.20    .00    .00
3C        21.50 .548 19.85   -7.986 1.45  -.01 .761  9.48   5.20    .00    .00
1S        21.20 .547 19.54   -7.876 1.47   .00 .757  9.29   5.85    .00    .00
2S        21.70 .553 19.96   -7.671 1.54  -.14 .757  9.60   8.18    .00    .00
2T        21.00 .546 19.02   -6.703 1.81  -.48 .736  8.93   5.20    .00    .00
3T        21.60 .553 19.99   -8.239 1.41   .10 .764  9.64   5.20    .00    .00

AVERAGES: 80524  BASELINE W079 00 000
          21.53 .547 19.57   -7.010 1.71  -.08 .735  9.16   5.11    .00    .00
  STD       .24 .002   .21     .080  .03   .22 .006   .18    .64     *      *
            80524 W085N/ZR001 (7E11) REPEAT
          21.47 .550 19.49   -7.283 1.77  -.17 .737  9.19   6.00    .00    .00
  STD       .28 .003   .57    1.222  .62   .34 .045   .51   1.11     *      *
PERCENT OF BASELINE
          99.7 100.4  99.6     96.1  103  -5.3 100.3 100.4 117.3  ***** *****
 STD%      2.4    .9   4.0     18.8   38 *****   7.0   7.7  39.1  ***** *****
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70926 W086C001       (4E17) W078 00 000
*SOL6                AM1: PO=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC   IP     LOG(IO)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*     22.50 .556 20.23   -6.452 1.93   -.15 .718  9.49    .00    .00    .00
1B      21.50 .553 19.82   -7.732 1.52   -.37 .766  9.63   3.51    .00    .00
2B      21.70 .555 20.08   -8.062 1.45   -.25 .771  9.82   4.94    .00    .00
3B      21.50 .553 19.73   -7.399 1.61   -.48 .760  9.55   4.94    .00    .00
4B      21.40 .552 19.61   -7.295 1.64   -.56 .759  9.48   4.16    .00    .00
5B      21.60 .552 19.94   -7.824 1.50   -.37 .768  9.69   4.94    .00    .00
1C      21.50 .549 19.16   -5.768 2.24 -1.44 .727  9.07   3.64    .00    .00
2C      21.50 .551 19.78   -7.527 1.57   -.54 .766  9.59   4.55    .00    .00
3C      21.60 .551 19.63   -6.714 1.82   -.87 .750  9.44   3.90    .00    .00
4C      21.30 .553 19.44   -7.061 1.71   -.53 .750  9.35   4.29    .00    .00
5C      21.60 .552 19.18   -5.569 2.36 -1.79 .727  9.17   3.64    .00    .00
6C      21.00 .546 18.12   -4.690 3.03 -2.93 .700  8.48   2.60    .00    .00
7C      21.40 .549 18.97   -5.544 2.37 -1.74 .724  8.99   3.14    .00    .00
8C      21.50 .550 19.24   -5.865 2.19 -1.63 .737  9.22   3.90    .00    .00
9C      21.80 .551 19.70   -6.413 1.94 -1.03 .744  9.45   3.64    .00    .00
10C     21.70 .551 19.59   -6.328 1.97 -1.13 .743  9.40   3.90    .00    .00
11C     21.60 .549 19.08   -5.468 2.41 -1.61 .716  8.98   3.25    .00    .00
1S      21.50 .547 18.76   -4.998 2.74 -2.38 .709  8.82   2.99    .00    .00
2S      21.50 .551 19.44   -6.415 1.94 -1.13 .746  9.35   4.29    .00    .00
3S      21.40 .543 18.76   -5.242 2.54 -1.74 .706  8.68   2.60    .00    .00
4S      21.30 .549 19.43   -6.922 1.75   -.88 .757  9.36   3.64    .00    .00
5S      21.60 .550 19.77   -7.214 1.66   -.54 .756  9.50   4.16    .00    .00
1T      21.50 .544 18.55   -4.805 2.90 -2.12 .688  8.51   2.34    .00    .00
2T      21.50 .550 19.19   -5.813 2.22 -1.47 .730  9.13   3.64    .00    .00
3T      21.80 .548 19.24   -5.418 2.44 -1.65 .715  9.04   3.12    .00    .00
4T      21.50 .548 19.54   -6.748 1.80   -.79 .748  9.32   3.38    .00    .00
5T      21.90 .548 19.71   -6.138 2.04 -1.35 .743  9.42   3.38    .00    .00
6T      21.90 .548 19.65   -6.002 2.11 -1.40 .738  9.37   3.90    .00    .00

AVERAGES: 70926  BASELINE W078 00 000
        21.54 .553 19.84   -7.662 1.54   -.40 .765  9.63   4.50    .00    .00
  STD     .10 .001   .16     .281  .07    .11 .005   .11    .58     *      *
          70926 W086C001        (4E17)
        21.54 .549 19.27   -6.030 2.17 -1.39 .733  9.16   3.54    .00    .00
  STD     .20 .002   .42     .773  .39    .60 .020   .31    .57     *      *
PERCENT OF BASELINE
       100.0  99.3  97.1   121.3  141 *****  95.8  95.1   78.7 ***** *****
 STD%    1.4    .6   2.9    13.3   33 277.7   3.2   4.4   24.4 ***** *****
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70930 W087CA001 (1E15)??                W078 00 000
*SOL6                AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(I0)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*       22.50 .557 20.17  -6.303 2.00   -.27 .716   9.48    .00    .00    .00
1B        22.50 .553 20.21  -6.094 2.08  -1.16 .736   9.68   4.29    .00    .00
2B        22.80 .556 20.83  -7.135 1.69   -.41 .751  10.06   4.55    .00    .00
3B.*      22.40 .549 20.05  -5.972 2.12  -1.14 .730   9.49   3.90    .00    .00
4B.*      22.50 .550 19.90  -5.476 2.40  -1.57 .718   9.40   3.90    .00    .00
5B        22.50 .550 20.20  -6.214 2.01   -.70 .726   9.50   4.55    .00    .00
1C        22.70 .549 20.34  -6.301 1.97   -.22 .714   9.41   4.55    .00    .00
2C        22.60 .555 20.82  -7.878 1.49    .12 .754  10.00   5.59    .00    .00
3C        22.30 .552 20.08  -6.354 1.96   -.66 .730   9.51   4.16    .00    .00
4C        22.40 .556 20.08  -6.107 2.08   -.87 .726   9.57   4.42    .00    .00
5C        22.50 .552 19.93  -5.609 2.33  -1.23 .715   9.38   3.90    .00    .00
6C        22.40 .553 20.17  -6.338 1.97   -.72 .732   9.58   4.29    .00    .00
7C        22.30 .551 20.08  -6.260 2.00   -.93 .735   9.55   3.90    .00    .00
8C        23.10 .555 21.04  -7.003 1.73   -.27 .742  10.06   5.20    .00    .00
9C        22.70 .556 20.87  -7.561 1.57   -.27 .759  10.13   4.55    .00    .00
10C       22.50 .551 20.04  -5.814 2.21  -1.07 .720   9.44   3.90    .00    .00
1S        22.60 .558 20.50  -6.664 1.86   -.71 .744   9.92   4.94    .00    .00
2S        22.60 .555 20.55  -6.828 1.79   -.58 .746   9.89   4.55    .00    .00
3S        22.60 .553 20.11  -5.729 2.26  -1.27 .722   9.55   4.55    .00    .00
4S        22.60 .552 20.30  -6.115 2.06  -1.10 .735   9.70   4.42    .00    .00
5S        22.60 .551 20.30  -6.137 2.05  -1.00 .733   9.65   4.81    .00    .00
1T        22.70 .550 19.93  -5.323 2.50  -1.35 .703   9.28   4.42    .00    .00
2T        22.60 .553 20.40  -6.493 1.91   -.53 .732   9.67   3.51    .00    .00
3T        22.60 .551 20.01  -5.583 2.34  -1.28 .715   9.42   3.77    .00    .00
4T        22.60 .550 19.98  -5.565 2.34  -1.16 .710   9.34   3.77    .00    .00
5T        22.80 .552 20.66  -6.676 1.83   -.47 .737   9.81   4.55    .00    .00

AVERAGES: 70930  BASELINE W078 00 000
          22.60 .553 20.41  -6.481 1.93   -.75 .738   9.75   4.46    .00    .00
  STD       .14 .002   .30    .465  .17    .31 .010    .23    .12     *      *
            70930 W087CA001 (1E15)??
          22.59 .553 20.31  -6.317 2.01   -.78 .730   9.64   4.39    .00    .00
  STD       .17 .002   .32    .645  .26    .41 .014    .24    .50     *      *
PERCENT OF BASELINE
         100.0 100.0  99.5  102.5   104   96.7  99.0   98.9   98.3 ***** *****
 STD%      1.4    .9   3.1   17.7    24  117.7   3.3    5.0   14.2 ***** *****
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70919 W088CR001(5E14)              W058 00 000
*SOL6                AM1: PO=91.60MW/CM©2  NO AR COATING

ID          ISC    VOC   IP     LOG(I0)   N       R     FF     Eff     OCD     PCDa    PCDb

1R*         22.50 .558 20.18   -6.311 2.00    -.27 .716    9.51     .00     .00     .00
1B.*        20.10 .561 16.98   -4.784 3.04    -.44 .635    7.57     .65     .00     .00
2B          20.90 .595 18.98   -6.821 1.93    -.61 .743    9.77    1.56     .00     .00
3B.*        20.90 .576 17.59   -4.563 3.34   -1.27 .641    8.15     .91     .00     .00
4B          20.50 .595 18.99   -8.208 1.52    -.19 .771    9.95    1.69     .00     .00
5B          21.00 .596 19.40   -7.903 1.60    -.36 .769   10.17    1.56     .00     .00
2C          21.50 .585 18.38   -4.641 3.29   -2.27 .675    8.98    1.04     .00     .00
3C          20.60 .552 17.55   -5.254 2.58    1.07 .625    7.51     .65     .00     .00
4C          20.60 .594 18.61   -6.460 2.08   -1.00 .740    9.57    1.56     .00     .00
5C          21.50 .596 19.51   -6.701 1.98    -.77 .744   10.08    1.69     .00     .00
6C          21.40 .599 19.69   -7.568 1.70    -.55 .766   10.38    1.95     .00     .00
7C          20.80 .587 17.92   -4.759 3.19   -2.57 .689    8.89    1.04     .00     .00
8C          20.50 .594 18.72   -7.080 1.84    -.74 .755    9.72    1.56     .00     .00
9C          20.80 .431 15.33   -3.659 3.63    1.31 .487    4.62     .52     .00     .00
1S          21.30 .592 19.21   -6.379 2.10    -.92 .736    9.81    1.56     .00     .00
2S          21.50 .574 18.07   -4.388 3.52   -2.11 .650    8.48     .65     .00     .00
3S          21.50 .574 18.12   -4.573 3.30   -1.24 .643    8.39     .65     .00     .00
4S          21.10 .586 19.00   -6.371 2.08    -.74 .730    9.54    1.17     .00     .00
5S          21.50 .597 20.02   -8.615 1.44    -.17 .781   10.60    1.95     .00     .00
1T          21.20 .569 17.69   -4.337 3.57   -1.85 .638    8.14     .91     .00     .00
2T          20.60 .587 18.23   -5.559 2.53   -1.69 .717    9.17    1.30     .00     .00
3T          20.80 .565 17.63   -4.788 3.04    -.65 .642    7.98     .65     .00     .00
4T          20.50 .580 17.74   -4.953 2.97   -1.99 .687    8.64     .91     .00     .00

AVERAGES: 70919  BASELINE W058 00 000
            20.80 .595 19.12   -7.644 1.69    -.38 .761    9.96    1.60     .00     .00
  STD         .22 .000   .19     .595  .18     .17 .013     .17     .06      *       *
          70919 W088CR001(5E14) 0.5 OHMCM
            21.04 .574 18.32   -5.652 2.64    -.99 .688    8.85    1.16     .00     .00
  STD         .39 .038  1.05    1.306  .70    1.04 .070    1.35     .46      *       *
PERCENT OF BASELINE
           101.2  96.5  95.8    126.1  156  -58.3  90.5    88.9    72.5  *****  *****
 STD%        3.0   6.5   6.5     24.2   63  504.0  10.8    15.3    32.7  *****  *****
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70922 W089CU001 (2E15) W058 00 000
*SOL6              AM1: PO=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R    FF    Eff    OCD   PCDa  PCDb

1R*      22.50 .559 20.18   -6.289 2.01   -.36 .718   9.55   .00   .00   .00
1B.*     20.30 .586 17.97   -5.585 2.51  -1.67 .717   9.02  2.34   .00   .00
2B.*     20.20 .582 17.41   -4.806 3.12  -2.49 .688   8.55  2.34   .00   .00
3B       20.90 .594 18.90   -6.710 1.97   -.31 .730   9.59  1.82   .00   .00
4B       20.30 .590 18.80   -8.131 1.53   -.34 .773   9.79  1.56   .00   .00
1C       21.30 .589 18.57   -5.036 2.92  -2.28 .703   9.33  1.30   .00   .00
2C.*     21.20 .585 17.69   -4.067 4.08  -3.98 .663   8.69  1.04   .00   .00
3C       21.40 .599 19.86   -8.319 1.50   -.18 .774  10.50  2.60   .00   .00
4C       21.30 .597 19.54   -7.368 1.75   -.56 .760  10.22  1.95   .00   .00
5C       21.20 .598 19.59   -7.949 1.59   -.34 .770  10.32  2.60   .00   .00
6C       21.20 .597 19.57   -7.825 1.62   -.40 .768  10.28  2.60   .00   .00
7C       21.40 .581 18.45   -4.917 2.99  -1.59 .677   8.91  1.04   .00   .00
8C       21.10 .586 18.61   -5.461 2.59  -1.63 .711   9.30  1.30   .00   .00
9C       21.30 .574 17.93   -4.518 3.37  -1.49 .644   8.33   .78   .00   .00
1S       21.40 .596 19.36   -6.491 2.06  -1.02 .743  10.02  1.95   .00   .00
2S       21.10 .595 19.45   -7.734 1.64   -.40 .765  10.16  1.56   .00   .00
3S       21.40 .596 19.10   -5.740 2.45  -1.92 .735   9.91  2.21   .00   .00
4S       21.40 .589 18.93   -5.552 2.53  -1.53 .715   9.52  1.56   .00   .00
5S       21.30 .590 18.68   -5.205 2.79  -2.09 .709   9.42  1.56   .00   .00
1T       21.30 .595 19.34   -6.745 1.96   -.77 .745   9.99  1.82   .00   .00
2T       21.50 .595 19.32   -6.162 2.21  -1.20 .735   9.94  1.56   .00   .00
3T       21.40 .604 19.85   -8.213 1.54   -.37 .777  10.62  2.60   .00   .00
4T       20.70 .597 19.05   -7.510 1.71   -.79 .770  10.06  2.34   .00   .00
5T       21.30 .601 19.90   -9.001 1.37   -.08 .786  10.64  2.60   .00   .00
6T       21.50 .599 20.03   -8.724 1.42   -.06 .780  10.62  2.60   .00   .00

AVERAGES: 70922  BASELINE W058 00 000
         20.60 .592 18.85   -7.421 1.75   -.32 .752   9.69  1.69   .00   .00
  STD      .30 .002   .05     .711  .22    .01 .022    .10   .13   *     *
           70922 W089CU001 (2E15)
         21.29 .594 19.22   -6.762 2.11   -.99 .740   9.90  1.92   .00   .00
  STD      .18 .007   .56    1.382  .60    .70 .038    .61   .58   *     *
PERCENT OF BASELINE
        103.3 100.3 101.9   108.9   120 *****  98.5 102.2 113.8 ***** *****
 STD%     2.4   1.5   3.2    29.1    54 230.7   8.0   7.4  45.8 ***** *****
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71028 W090MN001 LOW RESISTIVITY (7E14) W058 00 000
*SOL6             AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC  IP     LOG(IO)  N      R     FF     Eff    OCD    PCDa   PCDb

1R*      22.50 .551 20.12  -6.149 2.04   -.43 .714   9.37    .00    .00    .00
1B*      20.80 .518 16.50  -4.075 3.61    .27 .560   6.38    .39    .00    .00
2B.*     20.90 .586 18.39  -5.402 2.63 -1.63 .707   9.16   1.04    .00    .00
3B*      21.00 .544 16.99  -4.169 3.65   -.41 .586   7.08    .52    .00    .00
4B.*     20.70 .578 17.74  -4.749 3.15 -2.03 .674   8.53   1.04    .00    .00
5B       20.40 .587 18.55  -6.955 1.86   -.41 .741   9.38   1.30    .00    .00
1C.*     19.60 .582 16.78  -4.563 3.40 -3.51 .690   8.33   1.04    .00    .00
2C       17.90 .580 16.18  -6.678 1.96   -.68 .735   8.06   1.04    .00    .00
3C       20.50 .547 16.58  -4.143 3.72   -.67 .589   6.98    .52    .00    .00
4C       19.00 .532 15.54  -4.361 3.37   -.33 .597   6.38    .65    .00    .00
5C*      19.10 .477 14.96  -4.038 3.43    .61 .544   5.24    .52    .00    .00
6C*      19.80 .487 15.69  -4.065 3.44    .16 .559   5.70    .52    .00    .00
7C       19.10 .567 16.23  -4.707 3.17 -1.72 .657   7.53    .91    .00    .00
8C*      19.80 .502 15.38  -3.902 3.81    .27 .540   5.68    .39    .00    .00
9C       20.10 .564 16.72  -4.296 3.62 -2.06 .635   7.61    .65    .00    .00
10C      20.10 .549 16.12  -4.039 3.91   -.84 .581   6.78    .65    .00    .00
11C      18.00 .582 16.69  -8.489 1.44    .17 .766   8.49   1.17    .00    .00
1S*      17.90 .486 14.07  -4.174 3.34   1.19 .542   4.99    .65    .00    .00
2S       18.90 .583 16.54  -5.302 2.72 -1.82 .699   8.15    .78    .00    .00
3S       20.30 .593 18.56  -7.193 1.80   -.57 .753   9.59   1.30    .00    .00
4S       20.00 .593 18.67  -8.939 1.37   -.06 .783   9.83   1.69    .00    .00
5S*      20.00 .504 15.92  -4.136 3.45    .34 .562   5.99    .52    .00    .00
1T.*     17.50 .570 14.67  -4.315 3.72 -3.68 .659   6.95    .91    .00    .00
2T*      19.80 .525 16.06  -4.364 3.30    .45 .579   6.37    .52    .00    .00
3T*      17.70 .527 14.14  -3.979 3.95 -1.59 .583   5.76    .52    .00    .00
4T.*     19.70 .476 13.63  -3.238 5.15    .66 .450   4.46    .39    .00    .00
5T       19.00 .556 15.59  -4.296 3.61 -1.10 .608   6.79    .39    .00    .00

AVERAGES: 71028  BASELINE W058 00 000
         20.40 .587 18.55  -6.955 1.86   -.41 .741   9.38   1.30    .00    .00
  STD      .00 .000   .00    .000  .00    .00 .000    .00    .00     *      *
           71028 W090MN001 LOW RESISTIVITY (7E14)
         19.35 .568 16.67  -5.677 2.79   -.88 .673   7.84    .89    .00    .00
  STD      .86 .019   .99   1.746  .93    .69 .073   1.08    .37     *      *
PERCENT OF BASELINE
          94.9  96.7  89.9  118.4  150 -16.2  90.8   83.5   68.2 ***** *****
 STD%      4.2   3.3   5.3   25.1   50 170.5   9.9   11.5   28.2 ***** *****
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71031 W091CR-MN002 (5E14-3E14) W078 00 000
*SOL6              AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP    LOG(IO)  N      R     FF    Eff    OCD   PCDa   PCDb

1R*      22.50 .551 20.01  -5.905 2.16   -.63 .710   9.31   .00    .00    .00
1B.*     22.40 .547 20.01  -5.944 2.13  -1.02 .724   9.39  4.16    .00    .00
2B.*     22.40 .548 20.04  -5.965 2.12  -1.14 .729   9.47  3.51    .00    .00
3B       22.20 .548 20.08  -6.595 1.85   -.55 .736   9.47  4.29    .00    .00
4B.*     22.10 .544 19.23  -5.029 2.69  -1.77 .696   8.85  2.60    .00    .00
1C       15.60 .474 13.48  -5.253 2.30   -.93 .669   5.24   .65    .00    .00
2C       17.50 .500 15.63  -6.352 1.82   -.02 .705   6.52   .91    .00    .00
3C       16.70 .489 14.74  -5.792 2.03   -.79 .699   6.04   .91    .00    .00
4C       17.10 .495 15.15  -5.940 1.98   -.54 .700   6.27   .65    .00    .00
5C       16.80 .492 14.38  -4.881 2.65  -1.74 .668   5.84   .65    .00    .00
6C       15.70 .476 13.39  -4.920 2.55  -1.35 .657   5.20   .65    .00    .00
7C       17.50 .501 15.72  -6.543 1.75   -.17 .717   6.65   .78    .00    .00
8C       17.80 .500 15.56  -5.420 2.28  -1.10 .690   6.49   .65    .00    .00
9C       16.70 .483 14.10  -4.645 2.81  -1.75 .650   5.54   .52    .00    .00
10C      15.40 .474 13.14  -4.872 2.59  -1.80 .663   5.12   .65    .00    .00
1S       17.80 .504 15.80  -5.888 2.03   -.91 .709   6.73   .65    .00    .00
2S       17.10 .498 15.14  -5.922 2.00   -.56 .700   6.30   .78    .00    .00
3S       17.20 .499 15.25  -5.900 2.02   -.83 .706   6.41   .91    .00    .00
4S       17.80 .502 15.63  -5.529 2.22  -1.12 .696   6.58   .78    .00    .00
5S       17.50 .498 15.27  -5.398 2.28  -1.02 .685   6.32   .65    .00    .00
1T       16.00 .484 13.79  -5.168 2.40  -1.00 .667   5.46   .65    .00    .00
2T       16.50 .484 14.41  -5.554 2.14   -.53 .679   5.74   .78    .00    .00
3T       16.10 .480 14.00  -5.420 2.21   -.74 .676   5.53   .78    .00    .00
4T       16.00 .480 13.88  -5.342 2.26   -.84 .674   5.47   .78    .00    .00
5T       15.90 .478 13.61  -4.962 2.52  -1.41 .663   5.33   .65    .00    .00
6T       15.90 .476 13.39  -4.593 2.84  -2.07 .650   5.20   .78    .00    .00

AVERAGES: 71031  BASELINE W078 00 000
         22.20 .548 20.08  -6.595 1.85   -.55 .736   9.47  4.29    .00    .00
  STD      .00 .000   .00    .000  .00    .00 .000    .00   .00     *      *
           71031 W091CR-MN002 (5E14-3E14)
         16.70 .489 14.55  -5.442 2.27  -1.01 .682   5.90   .72    .00    .00
  STD      .78 .010   .88    .521  .30    .52 .020    .54   .10     *      *
PERCENT OF BASELINE
         75.2  89.2  72.4   117.5  123   16.1  92.7   62.3  16.9 ***** *****
 STD%     3.5   1.9   4.4     7.9   16   94.8   2.7    5.8   2.4 ***** *****
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71101 W092PH002 (2.8E16) W078 00 000
*SOL6             AM1: PO=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*       22.50 .555 20.11  -6.138 2.06   -.40 .713   9.41    .00    .00    .00
1B        22.40 .550 20.05  -6.113 2.06   -.69 .721   9.39   4.55    .00    .00
2B        22.10 .553 20.02  -6.608 1.87   -.74 .742   9.59   4.55    .00    .00
3B.       22.30 .550 19.85  -5.724 2.26  -1.37 .724   9.40   3.90    .00    .00
4B.*      21.80 .545 17.69  -3.556 4.79  -5.61 .650   8.16   3.12    .00    .00
5B.*      22.40 .547 19.13  -4.490 3.22  -2.71 .684   8.86   2.60    .00    .00
1C        22.30 .566 19.52  -5.144 2.71  -1.91 .706   9.43   3.51    .00    .00
2C        22.10 .561 19.05  -4.751 3.03  -2.29 .690   9.04   3.12    .00    .00
3C        22.30 .550 18.66  -4.275 3.50  -2.18 .648   8.40   1.30    .00    .00
4C        22.60 .564 19.78  -5.134 2.70  -1.90 .707   9.53   5.20    .00    .00
5C        22.10 .562 19.22  -4.960 2.84  -2.13 .700   9.19   2.73    .00    .00
6C        22.40 .565 19.60  -5.136 2.71  -1.86 .705   9.43   3.90    .00    .00
7C        22.60 .562 19.78  -5.104 2.71  -1.99 .708   9.51   4.55    .00    .00
8C        21.70 .564 19.30  -5.705 2.33  -1.48 .724   9.37   3.38    .00    .00
9C        22.40 .567 19.89  -5.672 2.35  -1.32 .719   9.66   4.55    .00    .00
10C       22.40 .566 19.51  -4.987 2.83  -2.10 .702   9.41   2.99    .00    .00
11C       22.00 .563 19.08  -4.894 2.91  -2.17 .696   9.12   2.99    .00    .00
12C       22.20 .565 19.64  -5.490 2.46  -1.60 .718   9.52   4.16    .00    .00
1S        22.20 .568 19.85  -5.918 2.23  -1.28 .730   9.73   4.55    .00    .00
2S        21.70 .565 18.85  -4.844 2.97  -2.71 .706   9.16   3.64    .00    .00
3S        22.30 .565 19.56  -5.234 2.63  -1.70 .706   9.40   3.25    .00    .00
4S        22.10 .565 19.45  -5.353 2.55  -1.62 .710   9.38   3.64    .00    .00
5S        22.50 .565 19.81  -5.319 2.57  -1.76 .714   9.59   3.90    .00    .00
1T        21.90 .563 19.43  -5.760 2.29   -.94 .711   9.27   4.16    .00    .00
2T        22.00 .567 19.68  -6.045 2.16   -.93 .724   9.55   3.51    .00    .00
3T        22.30 .562 20.13  -6.467 1.95   -.66 .734   9.73   4.68    .00    .00
4T        22.10 .561 19.93  -6.445 1.96   -.59 .731   9.58   4.55    .00    .00
5T        22.50 .559 19.80  -5.435 2.47  -1.19 .703   9.35   3.90    .00    .00

AVERAGES: 71101  BASELINE W078 00 000
          22.25 .552 20.04  -6.361 1.96   -.71 .732   9.49   4.55    .00    .00
  STD       .15 .002   .01    .248  .10    .03 .011    .10    .00   *      *
            71101 W092PH002 (2.8E16)
          22.21 .563 19.52  -5.367 2.58  -1.65 .709   9.38   3.73    .00    .00
  STD       .25 .004   .36    .528  .36    .54 .017    .28    .83   *      *
PERCENT  OF BASELINE
          99.8 102.2  97.4  115.6   132 -32.0  96.9   98.8   82.1 ***** *****
 STD%      1.8    .9   1.9   11.9    26  87.4   3.8    4.0   18.2 ***** *****
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71108 W093MN004 (6.6E14) W078 00 000
*SOL6            AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC   IP     LOG(IO)  N      R     FF     Eff    OCD    PCDa   PCDb

1R*      22.50 .556 20.08   -6.076 2.10  -.46 .712   9.42    .00    .00    .00
1B       22.40 .548 20.32   -6.899 1.74  -.08 .731   9.50   5.85    .00    .00
2B.      22.50 .548 19.88   -5.637 2.29  -.84 .704   9.17   4.29    .00    .00
3B       21.40 .525 15.56   -3.164 5.82 -2.36 .506   6.01    .65    .00    .00
4B.*     22.50 .539 18.74   -4.255 3.45 -1.86 .639   8.19   1.95    .00    .00
5B.*     22.40 .545 19.37   -4.989 2.73 -1.27 .679   8.76   3.64    .00    .00
1B       21.90 .551 19.71   -6.363 1.96  -.62 .729   9.30   4.55    .00    .00
2B       21.90 .549 19.70   -6.346 1.96  -.62 .728   9.26   4.16    .00    .00
3B       22.20 .547 19.59   -5.547 2.35 -1.05 .705   9.05   3.90    .00    .00
4B       22.20 .549 19.84   -6.007 2.11  -.88 .722   9.31   3.90    .00    .00
1C       21.00 .536 18.17   -5.056 2.65 -1.24 .679   8.08   1.30    .00    .00
2C       20.70 .538 18.12   -5.287 2.49 -1.43 .698   8.22   1.04    .00    .00
3C       20.70 .531 17.49   -4.558 3.09 -1.61 .652   7.58    .91    .00    .00
4C       20.50 .531 17.84   -5.145 2.57 -1.44 .689   7.93    .91    .00    .00
5C       20.80 .529 17.85   -5.031 2.64  -.57 .657   7.65   1.04    .00    .00
6C       20.90 .533 18.16   -5.193 2.53 -1.05 .682   8.03   1.30    .00    .00
7C       20.70 .534 18.04   -5.174 2.56 -1.48 .693   8.10   1.30    .00    .00
8C       20.90 .534 18.23   -5.224 2.52 -1.31 .691   8.16   1.30    .00    .00
9C       20.60 .534 18.18   -5.545 2.31 -1.24 .707   8.23   1.30    .00    .00
10C      20.40 .528 17.58   -4.884 2.76 -1.76 .680   7.75    .78    .00    .00
11C      20.80 .534 18.50   -5.941 2.09  -.64 .710   8.33   1.30    .00    .00
12C      21.00 .539 19.08   -6.973 1.70  -.16 .735   8.80   2.08    .00    .00
1S       20.70 .536 18.11   -5.296 2.48 -1.32 .695   8.16   1.30    .00    .00
2S       21.00 .543 19.09   -6.959 1.72  -.26 .738   8.90   1.95    .00    .00
3S       21.20 .540 19.01   -6.248 1.97  -.59 .722   8.74   1.82    .00    .00
4S       20.60 .533 17.55   -4.816 2.84  -.95 .653   7.58    .91    .00    .00
5S       21.20 .544 19.35   -7.241 1.63  -.11 .743   9.06   2.21    .00    .00
1T       20.30 .532 17.82   -5.381 2.41 -1.43 .703   8.02    .91    .00    .00
2T       20.90 .535 18.55   -5.801 2.17  -.90 .711   8.41   1.96    .00    .00
3T       20.40 .528 17.63   -4.947 2.71 -1.72 .684   7.79    .91    .00    .00
4T       20.40 .529 17.79   -5.142 2.56 -1.70 .696   7.95   1.04    .00    .00
5T.*     20.40 .424 17.36   -3.334 4.28 ***** .852   7.79    .78    .00    .00
6T.*     20.40 .424 17.07   -3.159 4.78 ***** .825   7.54    .65    .00    .00

AVERAGES: 71108  BASELINE W078 00 000
         22.40 .548 20.32   -6.899 1.74  -.08 .731   9.50   5.85    .00    .00
  STD      .00 .000   .00     .000  .00   .00 .000    .00    .00     *      *
           71108 W093MN004 (6.6E14)
         20.75 .534 18.20   -5.516 2.40 -1.09 .696   8.16   1.31    .00    .00
  STD      .25 .004   .54     .732  .38   .51 .025    .41    .43     *      *
PERCENT OF BASELINE
         92.6  97.5  89.5   120.0   138 *****  95.2   86.0   22.4 ***** *****
 STD%     1.1    .8   2.6    10.6    22 627.5   3.4    4.4    7.3 ***** *****
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80509 W094MN005 (2E15)(POLY REPEAT RUN WITH 76 POLY BASE PB) W079 00 000
SOL8             AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC   IP     LOG(IO)  N      R     FF    Eff   OCD   PCDa  PCDb

2R*     21.90 .558 19.75  -6.225 2.04 -1.35 .746  9.64   .00   .00   .00
1B      22.00 .549 20.08  -7.016 1.71  -.60 .752  9.61  4.55   .00   .00
2B*     22.20 .549 19.54  -5.372 2.47 -1.48 .708  9.13  3.64   .00   .00
3B      22.20 .547 20.23  -7.055 1.69  -.30 .744  9.55  3.90   .00   .00
4B*     22.20 .544 19.89  -6.155 2.02  -.67 .722  9.23  2.99   .00   .00
5B      22.40 .548 20.02  -5.952 2.13 -1.02 .725  9.41  4.55   .00   .00
1BP*    17.10 .225 10.21  -5.642  .97  8.07 .318  1.29   .00   .00   .00
2BP*    18.30 .496 16.13  -5.860 2.01  -.13 .687  6.60   .65   .00   .00
3BP*    19.40 .502 16.69  -5.003 2.55 -1.12 .669  6.89   .91   .00   .00
4BP*    19.20 .506 16.95  -5.768 2.09  -.58 .697  7.16  1.17   .00   .00
5BP*    18.90 .503 16.67  -5.773 2.07  -.46 .693  6.97   .91   .00   .00
1C*     18.60 .325 11.44  -5.578 1.41 10.12 .330  2.11   .52   .00   .00
2C*     17.80 .302 10.89  -6.828  .99 10.88 .322  1.83   .52   .00   .00
3C      20.60 .515 17.47  -4.652 2.90 -1.38 .654  7.34   .52   .00   .00
4C*     17.70 .259 10.72  -8.352  .66 10.11 .315  1.53   .52   .00   .00
5C*     16.60 .198 10.02  -8.184  .52  8.24 .314  1.09   .52   .00   .00
6C      19.10 .505 16.96  -6.070 1.94  -.17 .699  7.13   .91   .00   .00
7C*     18.90 .407 11.46  -4.666 2.31 11.28 .330  2.69   .39   .00   .00
8C*     18.50 .318 10.91  -5.428 1.44 10.58 .314  1.95   .39   .00   .00
1S*     19.10 .380 11.61  -5.138 1.86 11.20 .328  2.51   .39   .00   .00
2S      20.40 .517 17.38  -4.719 2.85 -1.46 .660  7.37   .78   .00   .00
3S*     18.90 .375 11.63  -4.823 2.02 10.35 .335  2.51   .26   .00   .00
4S*     17.70 .261 10.67  -6.497  .92  9.50 .318  1.55   .00   .00   .00
1T*     16.90 .230 10.21  -8.595  .56  9.50 .314  1.29   .00   .00   .00
2T*     16.70 .192 10.00  -9.826  .40  8.36 .309  1.05   .00   .00   .00
3T*     16.70 .205 10.08  -8.246  .53  8.50 .314  1.14   .00   .00   .00

AVERAGES: 80509  BASELINE W079 00 000
        22.20 .548 20.11  -6.674 1.84  -.64 .740  9.52  4.33   .00   .00
  STD     .16 .001   .09    .511  .20   .29 .012   .08   .31    *     *
          80509 W094MN005 (2E15)(POLY REPEAT RUN WITH 76 POLY BASE PB)
        20.03 .512 17.27  -5.147 2.56 -1.00 .671  7.28   .74   .00   .00
  STD     .67 .005   .22    .653  .44   .59 .020   .10   .16    *     *
PERCENT OF BASELINE
        90.2  93.5  85.9  122.9  139  42.7  90.7  76.4  17.0 ***** *****
 STD%    3.7   1.1   1.5   16.4   42 207.3   4.1   1.8   5.2 ***** *****
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71208 W095MN006(F) (1E15) W097 00 000 (Rapid Growth)
*SOL6              AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R    FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .555 20.19   -6.332 1.98   -.30 .718   9.48    .00    .00    .00
1B.*     22.80 .551 20.36   -5.951 2.14   -.90 .722   9.59   3.90    .00    .00
2B*      20.40 .525 17.65   -5.209 2.49   -.61 .669   7.58    .65    .00    .00
3B       22.70 .550 20.66   -7.009 1.71   -.21 .740   9.77    .49    .00    .00
4B.      22.40 .546 19.87   -5.754 2.22   -.87 .710   9.19   3.25    .00    .00
5B.      22.90 .543 19.73   -4.774 2.89 -1.87 .684   9.00   2.60    .00    .00
6B.      22.70 .543 19.52   -4.862 2.82 -1.28 .671   8.75   3.77    .00    .00
1C       20.50 .534 18.17   -5.632 2.26 -1.47 .718   8.32    .91    .00    .00
2C       20.50 .534 18.47   -6.373 1.90   -.85 .734   8.50   1.17    .00    .00
3C       20.50 .524 17.46   -4.579 3.03 -2.24 .671   7.62    .65    .00    .00
4C       20.50 .531 18.01   -5.354 2.42 -1.59 .706   8.13    .91    .00    .00
5C       20.20 .526 17.56   -5.003 2.66 -2.11 .698   7.85    .91    .00    .00
6C       20.50 .529 17.98   -5.268 2.47 -1.77 .707   8.10   1.04    .00    .00
7C       20.30 .537 18.13   -5.911 2.13 -1.33 .728   8.39   1.17    .00    .00
8C       20.40 .533 17.66   -4.954 2.73 -1.87 .688   7.91    .91    .00    .00
9C       20.40 .528 17.60   -4.868 2.78 -1.98 .685   7.81    .78    .00    .00
10C      20.40 .528 17.46   -4.649 2.98 -2.34 .679   7.73    .78    .00    .00
11C.*    20.30 .525 16.91   -4.119 3.61 -3.28 .654   7.37    .65    .00    .00
1S       20.70 .536 18.17   -5.262 2.50 -1.89 .710   8.33    .91    .00    .00
2S       20.70 .534 18.04   -5.050 2.65 -2.05 .701   8.20    .91    .00    .00
3S       21.00 .539 18.81   -5.984 2.09 -1.34 .733   8.78   1.30    .00    .00
4S       21.00 .535 18.34   -5.110 2.60 -1.95 .704   8.36   1.17    .00    .00
5S       20.80 .535 18.48   -5.791 2.17 -1.09 .716   8.42   1.17    .00    .00
6S       20.80 .535 18.48   -5.791 2.17 -1.09 .716   8.42   1.17    .00    .00
1T.*     20.30 .523 16.81   -4.009 3.77 -3.62 .651   7.31    .52    .00    .00
2T       20.50 .527 17.65   -4.778 2.85 -2.22 .686   7.84    .65    .00    .00
3T       20.70 .526 17.65   -4.561 3.05 -2.40 .675   7.77    .52    .00    .00
4T.*     20.30 .525 17.09   -4.285 3.38 -3.06 .666   7.50    .65    .00    .00
5T       20.30 .531 17.95   -5.519 2.32 -1.68 .718   8.19   1.04    .00    .00
6T       20.60 .526 17.74   -4.789 2.83 -2.13 .685   7.85    .65    .00    .00

AVERAGES: 71208  BASELINE W097 00 000
         22.70 .550 20.66   -7.009 1.71   -.21 .740   9.77    .49    .00    .00
  STD      .00 .000   .00     .000  .00    .00 .000    .00    .00     *      *
          71208 W095MN006(F) (1E15)
         20.57 .531 17.99   -5.261 2.53 -1.77 .703   8.13    .94    .00    .00
  STD      .22 .004   .38     .506  .33    .44 .019    .31    .21     *      *
PERCENT OF BASELINE
         90.6  96.6  87.1   124.9   148 *****  95.0   83.2  189.5 ***** *****
 STD%      .9    .8   1.8     7.2    19 210.4   2.5    3.1   42.9 ***** *****
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71213 W096MN007^S(6.3E14) W097 00 000 (Slow Growth)
*SOL6 AM1: P0=91.60MW/CM©2 NO AR COATING

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ID        ISC   VOC   IP     LOG(IO)  N     R     FF    Eff   OCD   PCDa  PCDb

1R*       22.50 .553 20.18  -6.285 1.99  -.39 .719  9.46   .00   .00   .00
1B.*      22.50 .549 19.79  -5.289 2.52 -1.73 .712  9.31  4.16   .00   .00
2B.*      22.30 .545 19.85  -5.809 2.19 -1.04 .718  9.23  3.77   .00   .00
3B        22.20 .548 19.88  -6.100 2.06  -.82 .725  9.32  4.03   .00   .00
4B        22.20 .548 20.13  -6.626 1.84  -.79 .745  9.59  3.90   .00   .00
1C        22.50 .547 19.78  -5.315 2.49 -1.55 .708  9.22  3.64   .00   .00
2C        22.70 .548 20.21  -5.809 2.20 -1.05 .720  9.47  3.90   .00   .00
3C        22.60 .539 19.14  -4.490 3.17 -1.85 .660  8.50  2.21   .00   .00
4C        22.60 .543 19.15  -4.380 3.32 -2.54 .670  8.70  2.60   .00   .00
5C        22.30 .546 19.57  -5.228 2.55 -1.74 .708  9.12  3.25   .00   .00
6C        22.60 .548 20.09  -5.717 2.25 -1.18 .719  9.42  3.77   .00   .00
7C        22.30 .549 20.04  -6.176 2.03  -.99 .734  9.50  4.55   .00   .00
8C        22.30 .547 19.76  -5.587 2.32 -1.36 .717  9.25  4.42   .00   .00
9C        22.50 .546 19.77  -5.327 2.48 -1.45 .706  9.17  2.99   .00   .00
1S        22.40 .548 20.04  -5.990 2.11 -1.05 .728  9.44  3.38   .00   .00
2S        22.30 .546 19.80  -5.684 2.26 -1.24 .719  9.25  3.90   .00   .00
3S        22.60 .548 20.17  -5.885 2.16 -1.08 .724  9.48  4.55   .00   .00
4S        22.50 .541 19.88  -5.530 2.33 -1.23 .711  9.15  4.29   .00   .00
5S        22.40 .546 20.14  -6.220 2.00  -.90 .733  9.48  3.64   .00   .00
6S        22.40 .546 19.81  -5.482 2.38 -1.50 .716  9.27  3.64   .00   .00
1T        21.60 .541 19.16  -5.748 2.21  -.94 .711  8.78  1.95   .00   .00
2T        21.90 .535 18.88  -4.885 2.77 -1.56 .679  8.42  1.30   .00   .00
3T        22.00 .542 19.76  -6.332 1.94  -.44 .722  9.10  2.60   .00   .00
4T        22.10 .536 19.21  -5.122 2.58 -1.20 .685  8.58  1.69   .00   .00
5T        22.10 .543 20.14  -7.239 1.62   .18 .734  9.31  2.99   .00   .00
6T        22.00 .536 19.04  -4.997 2.68 -1.36 .681  8.50  1.69   .00   .00

AVERAGES: 71213  BASELINE W097 00 000
          22.20 .548 20.01  -6.363 1.95  -.81 .735  9.45  3.97   .00   .00
  STD       .00 .000   .12    .263  .11   .01 .010   .13   .06    *     *
            71213 W096MN007 (6.3E14)
          22.32 .544 19.69  -5.578 2.37 -1.24 .709  9.10  3.19   .00   .00
  STD       .27 .004   .41    .632  .38   .52 .021   .36   .97    *     *
PERCENT OF BASELINE
         100.5  99.2  98.4  112.3  122  46.1  96.5  96.3  80.4 ***** *****
 STD%      1.2    .8   2.7   14.0   28  68.0   4.2   5.2  26.2 ***** *****
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71214 W098 MO 002 (9.2E11) W097 00 000
*SOL6              AM1: PO=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP    LOG(IO)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .555 20.25  -6.493 1.91   -.18 .720   9.51    .00    .00    .00
1B.*     22.70 .546 19.94  -5.328 2.48  -1.37 .704   9.23   3.51    .00    .00
2B       22.40 .547 20.20  -6.440 1.91   -.60 .732   9.48   4.29    .00    .00
3B.*     22.70 .547 19.89  -5.251 2.53  -1.41 .701   9.20   3.64    .00    .00
4B.*     22.60 .550 20.18  -5.901 2.16  -1.08 .725   9.53   3.77    .00    .00
1C       20.80 .522 18.13  -5.161 2.51  -1.46 .693   7.95   1.04    .00    .00
2C       21.10 .524 18.61  -5.632 2.21   -.79 .700   8.18   1.43    .00    .00
4C       21.00 .524 18.88  -6.413 1.85   -.37 .722   8.40   1.30    .00    .00
5C       20.80 .518 18.14  -5.214 2.45  -1.28 .691   7.87    .78    .00    .00
6C       20.80 .514 17.62  -4.631 2.91  -1.33 .651   7.37   1.04    .00    .00
7C       20.80 .521 18.37  -5.551 2.25  -1.28 .710   8.14   1.04    .00    .00
8C       20.80 .519 18.18  -5.186 2.47  -1.68 .701   8.00   1.04    .00    .00
9C       20.80 .517 18.00  -4.998 2.60  -1.53 .684   7.78   1.04    .00    .00
10C      21.00 .520 18.54  -5.529 2.26  -1.28 .710   8.19   1.04    .00    .00
11C      21.10 .519 18.38  -5.279 2.41   -.84 .682   7.90   1.04    .00    .00
1S       20.90 .527 18.65  -6.040 2.02   -.68 .716   8.34   1.30    .00    .00
2S       20.90 .527 18.58  -5.964 2.05   -.48 .706   8.22   1.17    .00    .00
3S       21.30 .526 18.82  -5.578 2.25  -1.17 .709   8.40   1.30    .00    .00
4S       21.00 .525 18.65  -5.786 2.13   -.97 .713   8.32   1.04    .00    .00
5S       20.80 .525 18.48  -5.787 2.14  -1.05 .715   8.26   1.30    .00    .00
6S       20.80 .522 18.31  -5.470 2.30  -1.23 .704   8.09    .91    .00    .00
1T       21.30 .524 18.60  -5.321 2.40   -.94 .688   8.12   1.04    .00    .00
2T       20.90 .525 18.73  -6.256 1.92   -.50 .719   8.35   1.43    .00    .00
3T       20.90 .521 18.22  -5.283 2.42   -.98 .686   7.90    .91    .00    .00
4T       20.80 .523 18.38  -5.729 2.16   -.65 .700   8.05   1.30    .00    .00
5T       20.80 .523 18.54  -5.962 2.04   -.78 .715   8.23   1.04    .00    .00

AVERAGES: 71214  BASELINE W097 00 000
         22.40 .547 20.20  -6.440 1.91   -.60 .732   9.48   4.29    .00    .00
  STD      .00 .000   .00    .000  .00    .00 .000    .00    .00    *      *
           71214 W098 MO 002 (9.2E11)
         20.92 .522 18.42  -5.560 2.27  -1.01 .701   8.10   1.12    .00    .00
  STD      .16 .003   .29    .421  .24    .36 .016    .24    .17    *      *
PERCENT OF BASELINE
         93.4  95.5  91.2  113.7   119   29.9 95.7   85.4   26.1 ***** *****
 STD%      .7    .6   1.4    6.5    13   59.7  2.2    2.6    4.0 ***** *****
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71216 W100CU-TI002 (1E15-3E13) W097 00 000
SOL7              AM1: PO=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC  IP     LOG(IO)  N     R     FF    Eff   OCD   PCDa  PCDb

1R*      22.50 .555 20.25  -6.561 1.89   .01 .717  9.46   .00   .00   .00
1B.      22.70 .547 20.00  -5.490 2.38 -1.05 .703  9.23  3.64   .00   .00
2B.*     22.80 .540 19.07  -4.320 3.37 -1.73 .642  8.36  2.08   .00   .00
3B.      22.70 .546 19.80  -5.136 2.61 -1.43 .694  9.10  3.25   .00   .00
4B       22.70 .550 20.46  -6.378 1.94  -.70 .733  9.68  4.42   .00   .00
5B       22.70 .552 20.50  -6.413 1.93  -.82 .739  9.79  4.55   .00   .00
1C       15.40 .488 13.57  -6.009 1.94   .21 .682  5.42   .91   .00   .00
2C       15.60 .486 13.59  -5.625 2.13  -.06 .670  5.37   .91   .00   .00
3C       15.50 .486 13.66  -6.016 1.93   .20 .682  5.44  1.04   .00   .00
4C       15.70 .484 13.63  -5.513 2.18  -.14 .666  5.35   .91   .00   .00
5C       15.90 .488 13.94  -5.822 2.03   .08 .677  5.55   .78   .00   .00
6C       15.60 .484 13.61  -5.659 2.10  -.09 .672  5.37   .78   .00   .00
7C       15.40 .484 13.45  -5.679 2.09  -.10 .673  5.30   .91   .00   .00
8C       16.20 .486 14.00  -5.337 2.29  -.42 .663  5.52   .91   .00   .00
9C       16.20 .485 14.00  -5.329 2.29  -.42 .663  5.51   .91   .00   .00
10C      15.20 .483 12.95  -5.027 2.51  -.71 .648  5.03   .91   .00   .00
11C      15.60 .489 13.69  -5.803 2.04  -.14 .681  5.49   .91   .00   .00
12C      15.70 .486 13.64  -5.561 2.16   .01 .665  5.36   .52   .00   .00
1S       15.70 .490 13.81  -5.861 2.02  -.11 .683  5.56  1.04   .00   .00
2S       15.50 .486 13.61  -5.870 2.00   .11 .678  5.40   .91   .00   .00
3S       16.00 .489 13.93  -5.564 2.17  -.23 .671  5.55   .91   .00   .00
4S       15.80 .487 13.75  -5.550 2.17  -.25 .671  5.46   .91   .00   .00
5S       15.80 .489 13.85  -5.766 2.06  -.17 .680  5.56  1.04   .00   .00
6S       15.50 .487 13.67  -6.102 1.90   .49 .679  5.42  1.04   .00   .00
1T       15.30 .486 13.14  -5.256 2.36  -.30 .654  5.14   .91   .00   .00
2T       15.40 .489 13.52  -5.913 1.99   .27 .676  5.38  1.04   .00   .00
3T       15.70 .491 13.81  -5.870 2.02  -.11 .684  5.57   .65   .00   .00
4T       15.50 .488 13.65  -6.052 1.92   .52 .676  5.41   .91   .00   .00
5T       15.60 .489 13.75  -6.029 1.93   .25 .682  5.50   .91   .00   .00

AVERAGES: 71216  BASELINE W097 00 000
         22.70 .551 20.48  -6.395 1.94  -.76 .736  9.74  4.49   .00   .00
  STD      .00 .001   .02    .017  .00   .06 .003   .05   .06    *     *
            71216 W100CU-TI002 (1E15-6E13)
         15.64 .487 13.66  -5.705 2.10  -.05 .673  5.42   .90   .00   .00
  STD      .25 .002   .24    .277  .15   .29 .009   .13   .12    *     *
PERCENT OF BASELINE
         68.9  88.4  66.7  110.8   108 193.6  91.4  55.7  20.0 ***** *****
 STD%     1.1    .5   1.2    4.6     8  40.9   1.6   1.6   3.0 ***** *****
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80106 W102TI006 POLY (1.1E14) W097 00 000
SOL7  8 /10/78   AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N.     R     FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .552 20.24   -6.402 1.94   -.36 .723   9.49   .00    .00    .00
1B       22.80 .547 20.54   -6.381 1.93   -.58 .730   9.63  3.90    .00    .00
2B.*     22.70 .545 20.08   -5.582 2.31  -1.13 .711   9.30  3.51    .00    .00
3B.*     23.30 .548 20.36   -5.156 2.60  -1.45 .698   9.42  3.25    .00    .00
4B       23.30 .549 20.88   -6.144 2.03   -.64 .722   9.77  4.29    .00    .00
1C       14.00 .457 11.77   -4.810 2.58   -.87 .633   4.28   .39    .00    .00
2C       13.90 .450 11.34   -4.207 3.20  -2.58 .614   4.06   .39    .00    .00
3C.*     13.00 .382  8.77   -4.180 2.78   8.61 .398   2.09   .26    .00    .00
4C.*     13.60 .420  9.68   -3.377 4.60  -1.25 .480   2.90   .26    .00    .00
5C.*     13.60 .433  9.89   -3.231 5.23  -5.34 .519   3.23   .26    .00    .00
6C.*     13.50 .528  9.42   -4.795 3.01  13.44 .407   3.06   .26    .00    .00
7C       13.10 .421  9.78   -3.933 3.42   1.88 .497   2.90   .26    .00    .00
8C.*     13.60 .429 10.31   -3.577 4.17  -3.16 .544   3.36   .26    .00    .00
9C       13.60 .451 11.37   -4.706 2.65  -1.15 .629   4.08   .78    .00    .00
10C.*    13.30 .442 10.49   -3.758 3.91  -4.55 .592   3.68   .39    .00    .00
11C      13.70 .445 10.99   -4.056 3.39  -2.51 .595   3.83   .52    .00    .00
1S       14.10 .462 12.25   -5.667 2.02    .29 .661   4.56   .91    .00    .00
2S       13.10 .446 10.89   -4.574 2.77  -1.67 .626   3.87   .65    .00    .00
3S.*     14.20 .438 10.45   -3.217 5.27  -6.08 .536   3.53   .39    .00    .00
1T.*     13.70 .453 10.91   -3.845 3.81  -4.26 .601   3.94   .91    .00    .00
2T.*     13.20 .439  9.97   -3.465 4.59  -4.94 .551   3.38   .39    .00    .00
3T       13.50 .453 11.27   -4.622 2.75  -1.68 .633   4.09   .91    .00    .00
4T       13.80 .456 11.53   -4.655 2.72  -1.39 .631   4.20   .91    .00    .00
5T.*     13.30 .432  9.81   -3.433 4.60  -3.29 .520   3.16   .26    .00    .00
6T.*     13.20 .445 10.26   -3.726 4.01  -3.71 .570   3.54   .52    .00    .00

AVERAGES: 80106  BASELINE W097 00 000
         23.05 .548 20.71   -6.263 1.98   -.61 .726   9.70  4.10    .00    .00
  STD      .25 .001   .17     .118  .05    .03 .004    .07   .19     *      *
            80106 W102TI006 POLY (1.8E14)
         13.64 .449 11.24   -4.581 2.83  -1.08 .613   3.99   .64    .00    .00
  STD      .34 .011   .64     .482  .42   1.32 .044    .43   .24     *      *
PERCENT OF BASELINE
         59.2  81.9  54.3    126.8  143   23.9  84.4   41.1   15.5 ***** *****
 STD%     2.1   2.2   3.6      9.2   25  233.3   6.5    4.8    6.9 ***** *****
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80109 W103TI001 (1.7E14) LOW RESISTIVITY W058 00 000
SOL7  8 /13/78   AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R     FF    Eff   OCD   PCDa  PCDb

1R*      22.50 .551 20.20  -6.314 1.97   -.42 .721  9.45   .00   .00   .00
1B*      20.30 .487 16.13  -4.088 3.39    .19 .562  5.87   .52   .00   .00
2B       20.50 .575 17.72  -4.905 2.99  -2.10 .687  8.57  1.30   .00   .00
3B*      20.40 .532 17.09  -4.857 2.81    .66 .611  7.01   .65   .00   .00
4B*      20.70 .570 17.56  -4.659 3.20  -1.47 .653  8.15   .78   .00   .00
5B       20.30 .582 17.62  -4.950 2.98  -2.43 .698  8.72  1.17   .00   .00
1C       11.50 .489  8.80  -3.779 4.42  -3.03 .546  3.25   .65   .00   .00
2C       11.60 .471  8.86  -3.771 4.27  -2.70 .543  3.14   .52   .00   .00
3C       11.70 .508  9.62  -4.285 3.60  -4.57 .631  3.97   .91   .00   .00
4C       11.60 .467  9.32  -4.313 3.28  -1.09 .582  3.34   .52   .00   .00
5C       11.70 .457  9.19  -4.100 3.52  -1.03 .560  3.17   .65   .00   .00
6C       11.80 .520 10.30  -5.467 2.45  -2.50 .695  4.51  1.30   .00   .00
7C       11.90 .502  9.74  -4.304 3.52  -3.40 .618  3.90   .91   .00   .00
8C       11.50 .482  8.83  -3.701 4.55  -4.61 .557  3.27   .91   .00   .00
9C       11.80 .504  9.49  -3.975 4.11  -5.67 .612  3.85   .91   .00   .00
10C      11.80 .491  9.53  -4.247 3.53  -2.48 .597  3.66   .65   .00   .00
11C      11.60 .482  9.28  -4.185 3.58  -2.12 .584  3.45   .65   .00   .00
12C      11.80 .525 10.80  -7.642 1.53   -.10 .746  4.88  1.56   .00   .00
1S       11.60 .498  9.53  -4.422 3.34  -2.72 .617  3.77   .78   .00   .00
2S       11.70 .520 10.31  -5.801 2.24  -1.76 .701  4.51  1.04   .00   .00
3S       11.70 .521 10.17  -5.334 2.56  -2.83 .692  4.46  1.04   .00   .00
4S       11.40 .507  9.57  -4.665 3.11  -3.36 .648  3.96   .91   .00   .00
5S       11.70 .523 10.58  -6.862 1.77   -.99 .735  4.76  1.17   .00   .00
1T       11.50 .515  9.84  -4.973 2.83  -3.21 .671  4.20  1.17   .00   .00
2T       11.20 .502  9.32  -4.554 3.22  -3.40 .637  3.79   .91   .00   .00
3T       11.70 .525 10.77  -8.276 1.38    .77 .746  4.85  1.69   .00   .00
4T       11.70 .501  9.57  -4.278 3.56  -3.87 .621  3.85   .91   .00   .00
5T       11.30 .519 10.00  -6.328 1.98    .57 .685  4.25  1.43   .00   .00
6T       11.80 .515 10.09  -4.978 2.82  -2.89 .668  4.29  1.04   .00   .00

AVERAGES: 80109  BASELINE W058 00 000
         20.40 .579 17.67  -4.927 2.99  -2.27 .692  8.64  1.24   .00   .00
  STD      .10 .004   .05    .022  .00    .17 .005   .07   .06    *     *
           80109 W103TI001 (2.5E14) LOW RESISTIVITY
         11.63 .502  9.72  -4.967 3.10  -2.48 .639  3.96   .97   .00   .00
  STD      .17 .019   .57   1.221  .87   1.58 .061   .53   .31    *     *
PERCENT  OF BASELINE
         57.0  86.8  55.0   99.2  104   90.9  92.3  45.8  78.3 ***** *****
 STD%     1.1   3.9   3.4   25.3   29   82.5   9.6   6.6  30.2 ***** *****
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80110 W104CU-TI003 (2E15-1.4 E14) W097 00 000
SOL7  8 /10/78    AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R     FF    Eff     OCD    PCDa   PCDb

1R*       22.50 .552 20.15  -6.231 2.01   -.36 .716   9.40    .00    .00    .00
1B.*      23.20 .546 20.51  -5.629 2.28   -.85 .705   9.45   3.90    .00    .00
2B        23.30 .551 21.30  -7.293 1.63   -.04 .743  10.09   5.20    .00    .00
3B        23.00 .552 21.10  -7.473 1.58   -.16 .753  10.11   4.94    .00    .00
4B*       22.70 .542 19.48  -4.672 2.99  -2.07 .682   8.87   2.99    .00    .00
5B*       23.10 .547 19.65  -4.777 2.91   -.68 .648   8.66   3.51    .00    .00
1C        14.50 .472 12.48  -5.310 2.27   -.38 .657   4.76   1.04    .00    .00
2C        14.60 .473 12.73  -5.639 2.08   -.19 .672   4.91   1.04    .00    .00
3C        14.70 .470 12.64  -5.229 2.31   -.67 .659   4.82    .78    .00    .00
4C        14.50 .471 12.73  -5.876 1.95    .01 .679   4.91   1.17    .00    .00
5C        14.70 .471 12.86  -5.773 2.00    .00 .674   4.94   1.04    .00    .00
6C        14.50 .469 12.64  -5.593 2.09   -.39 .674   4.85    .91    .00    .00
7C        14.70 .475 12.81  -5.614 2.10   -.28 .673   4.97   1.04    .00    .00
8C        14.50 .471 12.67  -5.729 2.02   -.10 .674   4.87   1.04    .00    .00
9C        14.90 .473 12.91  -5.441 2.19   -.39 .666   4.96    .91    .00    .00
10C       14.70 .469 12.79  -5.603 2.08   -.12 .668   4.87    .91    .00    .00
11C       14.70 .470 12.73  -5.402 2.20   -.57 .668   4.88   1.04    .00    .00
1S        14.70 .474 12.84  -5.739 2.03   -.02 .672   4.95   1.30    .00    .00
2S        14.60 .469 12.71  -5.572 2.10   -.35 .672   4.87   1.04    .00    .00
3S        14.30 .471 12.46  -5.636 2.07   -.18 .671   4.78   1.04    .00    .00
4S        14.40 .469 12.54  -5.645 2.06   -.06 .669   4.78   1.04    .00    .00
5S        14.80 .471 12.85  -5.499 2.14   -.34 .668   4.92   1.17    .00    .00
6S        14.60 .468 12.68  -5.480 2.14   -.49 .670   4.84   1.04    .00    .00
1T        14.10 .467 12.38  -5.979 1.89    .44 .674   4.69    .91    .00    .00
2T        14.60 .466 12.55  -5.248 2.28   -.55 .658   4.73    .91    .00    .00
3T        14.20 .466 12.36  -5.595 2.08   -.26 .670   4.69   1.04    .00    .00
4T        14.80 .469 12.84  -5.483 2.14   -.34 .667   4.90    .91    .00    .00
5T        15.20 .472 13.11  -5.243 2.30   -.82 .665   5.05   1.17    .00    .00
6T        14.40 .465 12.50  -5.504 2.12   -.35 .668   4.73    .91    .00    .00

AVERAGES: 80110  BASELINE W097 00 000
          23.15 .552 21.20  -7.383 1.60   -.10 .748  10.10   5.07    .00    .00
  STD       .15 .000   .10    .090  .02    .06 .005    .01    .13     *      *
            80110 W104CU-TI003 (2E15-2.5E14)
          14.60 .470 12.69  -5.558 2.11   -.28 .669   4.85   1.02    .00    .00
  STD       .23 .003   .18    .191  .11    .26 .005    .09    .11     *      *
PERCENT OF BASELINE
          63.0  85.2  59.8  124.7   132  -74.2  89.4   48.1   20.1  ***** *****
 STD%      1.4    .5   1.1    3.5     9  568.9   1.3     .9    2.8  ***** *****
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80113 W105V001 (4E14) W057 00 000
SOL7            AM1: P0=91.60MW/CM^2  NO AR COATING

ID       ISC   VOC   IP    LOG(IO)  N      R    FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .552 20.12  -6.128 2.06  -.52 .716   9.41   .00    .00    .00
1B       21.80 .589 19.58  -5.996 2.27 -1.72 .744  10.10  2.47    .00    .00
2B       21.40 .581 19.02  -5.735 2.39 -1.36 .720   9.47  1.56    .00    .00
3B       21.60 .580 19.40  -6.202 2.14  -.93 .730   9.67  1.69    .00    .00
4B*      21.60 .581 18.74  -4.931 2.97 -2.16 .695   9.22   .91    .00    .00
5B       21.90 .586 19.65  -6.085 2.21 -1.18 .732   9.94  1.56    .00    .00
6B*      21.60 .568 18.45  -4.754 3.07 -1.44 .663   8.60   .91    .00    .00
1C       14.20 .480 11.00  -3.902 3.90  -.88 .547   3.94   .39    .00    .00
2C       14.10 .541 12.45  -5.743 2.32 -1.71 .706   5.70  1.04    .00    .00
3C       14.00 .468 10.99  -4.073 3.52  -.27 .554   3.84   .52    .00    .00
4C       14.20 .526 11.20  -3.698 4.73 -5.54 .595   4.70   .91    .00    .00
5C       13.90 .543 12.36  -6.080 2.15 -1.13 .711   5.68  1.04    .00    .00
6C       14.20 .545 12.61  -5.950 2.22 -1.56 .714   5.85   .91    .00    .00
7C       14.30 .549 13.11  -7.632 1.58  -.35 .753   6.26  1.56    .00    .00
8C       14.30 .546 13.05  -7.373 1.65  -.31 .745   6.15  1.30    .00    .00
9C       14.40 .525 12.17  -4.764 3.00 -1.92 .649   5.18   .91    .00    .00
10C      14.50 .525 12.13  -4.595 3.18 -1.99 .636   5.12   .78    .00    .00
11C      14.20 .502 11.56  -4.368 3.33  -.92 .595   4.49   .65    .00    .00
1S       14.30 .538 12.28  -5.013 2.84 -2.23 .672   5.47  1.04    .00    .00
2S       14.50 .541 12.60  -5.314 2.60 -1.83 .685   5.69  1.17    .00    .00
3S       14.50 .549 12.45  -4.841 3.05 -3.54 .685   5.76  1.17    .00    .00
4S       14.40 .544 12.88  -6.311 2.03  -.89 .718   5.95  1.17    .00    .00
5S       14.40 .552 13.44  -9.234 1.25   .43 .775   6.52  1.30    .00    .00
6S       14.50 .547 13.20  -7.189 1.71  -.48 .743   6.23  1.56    .00    .00
1T       14.30 .534 12.11  -4.724 3.10 -2.63 .658   5.31   .91    .00    .00
2T       14.30 .492 11.60  -4.394 3.22  -.29 .586   4.36   .52    .00    .00
3T       14.10 .403 10.70  -3.941 3.21   .97 .515   3.10   .65    .00    .00
4T       14.20 .525 11.76  -4.347 3.51 -3.24 .635   5.01   .91    .00    .00
5T       14.20 .525 12.22  -5.192 2.62 -1.26 .666   5.25   .91    .00    .00
6T       14.30 .548 13.15  -7.915 1.51  -.02 .754   6.25  1.30    .00    .00

AVERAGES: 80113  BASELINE W057 00 000
         21.68 .584 19.41  -6.005 2.25 -1.30 .731   9.79  1.82    .00    .00
  STD      .19 .004   .24    .172  .09   .29 .009    .24   .38    *      *
           80113 W105V001 (4E14)
         14.27 .524 12.22  -5.504 2.71 -1.37 .665   5.29   .98    .00    .00
  STD      .16 .034   .75   1.457  .85  1.41 .071    .86   .31    *      *
PERCENT OF BASELINE
         65.9 89.7   62.9   108.3  120  94.0  90.9   54.1   54.0 ***** *****
 STD%     1.3  6.5    4.7    27.6   44 156.4  10.9   10.4   31.6 ***** *****
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80116 W106N-AL002 W079 00 000   (1E16)
SOL7               AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(I0)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .553 20.24   -6.443 1.93   -.27 .721   9.49    .00    .00    .00
1B       22.10 .558 20.24   -7.353 1.64   -.22 .750   9.79   9.75    .00    .00
2B.*     21.60 .552 18.90   -5.250 2.57 -1.45 .698   8.80   4.16    .00    .00
3B       22.00 .561 20.45   -8.602 1.35    .12 .771  10.07  11.05    .00    .00
4B.*     22.00 .547 19.22   -5.102 2.65 -1.86 .703   8.95   5.85    .00    .00
1C       22.00 .551 20.04   -6.940 1.74   -.52 .747   9.58   8.45    .00    .00
2C.*     21.70 .539 18.32   -4.244 3.49 -3.30 .675   8.35   5.20    .00    .00
3C       21.60 .548 19.45   -6.262 1.99 -1.03 .737   9.23   6.50    .00    .00
4C       21.70 .549 19.39   -5.845 2.19 -1.47 .732   9.22   7.80    .00    .00
5C       22.20 .547 19.45   -5.163 2.60 -1.88 .708   9.10   8.06    .00    .00
6C       22.20 .538 18.96   -4.577 3.07 -2.20 .676   8.54   5.20    .00    .00
7C       21.90 .541 18.72   -4.479 3.20 -2.95 .688   8.62   6.50    .00    .00
8C       21.90 .550 19.70   -6.192 2.03 -1.06 .736   9.37   9.78    .00    .00
9C       21.80 .550 19.93   -7.215 1.65   -.34 .750   9.51  11.70    .00    .00
10C      22.00 .544 18.98   -4.735 2.95 -2.39 .693   8.77   6.50    .00    .00
11C      22.10 .546 20.22   -7.249 1.63   -.34 .751   9.59  10.80    .00    .00
1S       22.10 .547 19.93   -6.402 1.92   -.72 .734   9.38   8.45    .00    .00
2S       22.20 .541 19.98   -6.372 1.92   -.54 .727   9.24   8.84    .00    .00
3S.*     21.90 .536 18.36   -4.145 3.60 -3.27 .666   8.26   6.50    .00    .00
4S       22.00 .545 19.88   -6.508 1.88   -.66 .736   9.33   9.75    .00    .00
1T       22.30 .548 20.04   -6.222 2.00   -.81 .730   9.43   8.45    .00    .00
2T       21.90 .549 19.77   -6.437 1.92   -.78 .737   9.37   9.75    .00    .00
3T       21.70 .543 19.23   -5.591 2.31 -1.44 .718   8.95   7.80    .00    .00

AVERAGES: 80116   BASELINE W079 00 000
         22.05 .560 20.34   -7.977 1.49   -.05 .761   9.93  10.40    .00    .00
  STD      .05 .002   .11     .625  .14    .17 .010    .14    .65     *      *
          80116 W106N-AL002
         21.98 .546 19.60   -6.012 2.19 -1.20 .725   9.20   8.40    .00    .00
  STD      .20 .004   .44     .853  .49    .76 .022    .31   1.66     *      *
PERCENT OF BASELINE
         99.7  97.6  96.4   124.6   147 *****  95.3   92.7   80.7 ***** *****
 STD%     1.1    .9   2.7    17.4    50 *****   4.2    4.5   22.0 ***** *****
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80202 REPEAT RUN OF W107FZ-AL001 (3E16)  W101FZ001
*SOL6            AM1: PO=91.60MW/CM©2  NO AR COATING

ID         ISC   VOC   IP     LOG(IO)   N      R      FF    Eff    OCD    PCDa   PCDb

1R*        22.50 .551 20.29  -6.560 1.87   -.23 .725   9.50   .00    .00    .00
2CZB.      22.20 .540 19.43  -5.188 2.55  -1.65 .703   8.92  3.64    .00    .00
3CZB*      22.30 .545 20.41  -7.363 1.59   -.09 .746   9.59  4.55    .00    .00
1FZB.      22.50 .543 19.86  -5.512 2.35  -1.20 .709   9.16  4.29    .00    .00
2FZB       22.70 .544 20.29  -5.991 2.09   -.85 .722   9.43  4.29    .00    .00
3FZB.      22.50 .544 19.98  -5.677 2.26  -1.23 .719   9.30  4.29    .00    .00
4FZB.      22.60 .539 19.57  -4.938 2.73  -1.63 .688   8.86  3.64    .00    .00
1C         21.90 .560 19.24  -5.300 2.57  -1.68 .708   9.19  2.60    .00    .00
2C         22.30 .573 20.18  -6.578 1.94   -.69 .739   9.99  3.25    .00    .00
3C         22.30 .566 19.79  -5.641 2.37  -1.39 .719   9.60  3.25    .00    .00
4C         22.20 .572 20.08  -6.511 1.97   -.77 .739   9.93  3.38    .00    .00
5C         22.40 .575 20.39  -6.875 1.84   -.60 .747  10.18  3.77    .00    .00
6C         22.30 .560 19.50  -5.226 2.62  -1.40 .697   9.20  2.47    .00    .00
7C         22.50 .572 20.43  -6.783 1.86   -.48 .740  10.07  3.64    .00    .00
8C         22.10 .564 19.07  -4.757 3.04  -2.38 .692   9.12  1.95    .00    .00
9C         22.30 .567 20.26  -6.747 1.86   -.73 .747   9.99  1.95    .00    .00
10C        22.20 .559 19.23  -4.923 2.86  -1.84 .690   9.05  2.86    .00    .00
11C        22.20 .567 19.94  -6.191 2.09   -.87 .729   9.71  1.30    .00    .00
12C        22.30 .555 18.63  -4.194 3.65  -2.59 .651   8.52  1.30    .00    .00
13C        22.60 .567 20.33  -6.252 2.06   -.88 .733   9.94  3.90    .00    .00
14C        22.30 .563 19.55  -5.205 2.65  -1.79 .707   9.39  2.21    .00    .00
15C        22.40 .556 19.40  -4.928 2.83  -1.77 .689   9.07  2.21    .00    .00

AVERAGES: 80202  BASELINE W101FZ001
           22.70 .544 20.29  -5.991 2.09   -.85 .722   9.43  4.29    .00    .00
  STD        .00 .000   .00    .000  .00    .00 .000    .00   .00     *      *
             80202 REPEAT RUN OF W107FZ-AL001 (3E16)
           22.29 .565 19.73  -5.741 2.41  -1.32 .715   9.53  2.67    .00    .00
  STD        .16 .006   .53    .840  .52    .64 .027    .47   .82     *      *
PERCENT OF BASELINE
           98.2 103.9  97.3   104.2  115   44.4  99.1 101.1  62.2 ***** *****
 STD%        .7   1.1   2.6    14.0   25   75.7   3.7   5.0  19.2 ***** *****
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80222 W108N/V002 (8E13) W079 00 000
SOL8              AM1: PO=91.60MW/CM©2  NO AR COATING

ID      ISC   VOC   IP     LOG(IO)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*     22.50 .552 20.21   -6.386 1.95   -.24 .718   9.43    .00    .00    .00
1B      20.90 .550 18.89   -6.599 1.87   -.55 .734   8.92   6.89    .00    .00
2B.*    21.20 .545 18.62   -5.374 2.46  -1.38 .703   8.59   4.55    .00    .00
3B      21.00 .547 18.83   -6.126 2.05   -.98 .728   8.85   4.55    .00    .00
4B      21.50 .552 19.51   -6.943 1.75   -.05 .731   9.18   7.80    .00    .00
5B.*    20.90 .546 18.69   -6.014 2.10  -1.05 .725   8.75   5.85    .00    .00
1C      18.30 .523 16.37   -6.219 1.95   -.65 .718   7.26   1.95    .00    .00
2C      18.00 .522 16.01   -5.985 2.06   -.80 .711   7.06   1.43    .00    .00
3C      18.30 .523 16.27   -5.925 2.09   -.97 .713   7.22   1.04    .00    .00
4C      18.20 .522 16.21   -6.000 2.05   -.92 .715   7.19   1.30    .00    .00
5C      18.10 .524 16.33   -6.579 1.81   -.57 .730   7.32   1.56    .00    .00
6C      18.40 .525 16.52   -6.220 1.96  -1.11 .731   7.47   1.69    .00    .00
7C      18.10 .515 15.95   -5.773 2.13   -.44 .691   6.81   1.56    .00    .00
8C      17.80 .517 15.66   -5.639 2.22   -.89 .695   6.77   1.82    .00    .00
9C      18.20 .519 16.13   -5.885 2.09   -.70 .704   7.03   1.56    .00    .00
10C     18.90 .528 17.17   -6.892 1.71   -.53 .741   7.82   1.95    .00    .00
11C     18.60 .519 16.12   -5.227 2.48   -.89 .674   6.88   1.56    .00    .00
12C     18.30 .520 16.39   -6.273 1.92   -.57 .718   7.22   2.47    .00    .00
1S      19.00 .527 17.26   -6.842 1.72   -.68 .745   7.88   1.95    .00    .00
2S      19.00 .527 17.26   -6.842 1.72   -.68 .745   7.88   1.56    .00    .00
3S      18.50 .519 16.22   -5.534 2.28   -.82 .690   7.00    .65    .00    .00
4S      18.40 .520 16.37   -6.101 1.99   -.37 .705   7.13   1.30    .00    .00
5S      18.50 .520 16.33   -5.697 2.19   -.95 .702   7.14   1.30    .00    .00
1T      17.90 .527 16.32   -7.225 1.61   -.17 .741   7.39   1.56    .00    .00
2T      17.80 .522 15.76   -5.827 2.14   -.85 .704   6.92   1.95    .00    .00
3T      17.80 .520 15.85   -6.149 1.97   -.37 .706   6.91   1.56    .00    .00
4T      17.90 .518 16.05   -6.562 1.80    .19 .708   6.94   2.08    .00    .00
5T      17.90 .517 15.67   -5.493 2.31   -.95 .689   6.75   1.95    .00    .00

AVERAGES: 80222  BASELINE W079 00 000
        21.13 .550 19.08   -6.556 1.89   -.53 .731   8.98   6.41    .00    .00
  STD     .26 .002   .31     .335  .13    .38 .002    .14   1.37     *      *
           80222 W108N/V002 (8E13)
        18.27 .522 16.28   -6.131 2.01   -.67 .712   7.18   1.63    .00    .00
  STD     .36 .004   .44     .504  .22    .30 .019    .33    .38     *      *
PERCENT OF BASELINE
        86.4  94.9  85.4   106.5  106   73.2  97.4   80.0   25.3 ***** *****
 STD%    2.8   1.0   3.7    12.9   19  188.9   3.0    5.0   12.6 ***** *****
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80220 W109C002 (3.7E16) W097 00 000
SOL8            AM1: PO=91.60MW/CM©2  NO AR COATING

ID      ISC   VOC   IP     LOG(IO)  N     R     FF    Eff   OCD   PCDa  PCDb

1R*     22.50 .552 20.15  -6.231 2.01  -.36 .716  9.40   .00   .00   .00
1B*     22.70 .538 18.52  -3.768 4.22 -3.65 .637  8.22  2.08   .00   .00
2B.*    22.90 .544 19.57  -4.547 3.13 -2.30 .679  8.95  3.12   .00   .00
3B      22.90 .548 20.59  -6.267 1.98  -.72 .730  9.68  4.94   .00   .00
4B      22.60 .548 20.38  -6.381 1.93  -.72 .734  9.61  5.20   .00   .00
5B*     22.80 .538 18.71  -3.875 4.02 -3.21 .638  8.28  2.21   .00   .00
1C      22.20 .548 19.40  -5.014 2.72 -2.32 .712  9.16  4.16   .00   .00
2C      22.10 .543 19.24  -4.955 2.75 -2.21 .704  8.94  2.86   .00   .00
3C      22.10 .542 19.65  -5.765 2.20 -1.14 .719  9.11  4.42   .00   .00
4C      22.40 .544 19.79  -5.509 2.35 -1.32 .712  9.18  4.55   .00   .00
5C      22.30 .542 19.53  -5.144 2.59 -1.88 .708  9.05  4.42   .00   .00
6C      21.90 .543 19.63  -6.050 2.07 -1.07 .730  9.18  4.42   .00   .00
7C      22.10 .541 19.79  -6.063 2.05  -.90 .726  9.18  4.29   .00   .00
8C      22.50 .540 19.80  -5.366 2.43 -1.42 .708  9.10  3.25   .00   .00
9C.*    21.70 .540 18.56  -4.434 3.26 -3.36 .695  8.61  3.64   .00   .00
10C     22.80 .543 19.76  -4.903 2.78 -1.84 .692  9.06  3.90   .00   .00
1S      22.10 .547 19.59  -5.626 2.30 -1.26 .716  9.15  4.16   .00   .00
2S      22.30 .547 19.90  -5.967 2.12  -.83 .719  9.28  5.85   .00   .00
4S      22.20 .544 19.47  -5.271 2.51 -1.50 .704  8.99  3.90   .00   .00
5S      22.00 .544 19.83  -6.447 1.90  -.50 .728  9.22  4.94   .00   .00
6S      22.00 .546 19.75  -6.169 2.02  -.88 .729  9.26  4.55   .00   .00
1T      22.70 .547 20.00  -5.609 2.30  -.59 .694  9.12  4.16   .00   .00
2T      22.30 .546 19.90  -5.959 2.12  -.83 .719  9.26  4.94   .00   .00
3T      21.90 .541 19.24  -5.367 2.44 -1.35 .704  8.82  4.42   .00   .00
4T      22.40 .543 19.84  =5.630 2.28 -1.11 .712  9.16  4.03   .00   .00
5T      22.30 .543 19.89  -5.911 2.13  -.92 .720  9.22  4.94   .00   .00

AVERAGES: 80220  BASELINE W097 00 000
        22.75 .548 20.49  -6.324 1.96  -.72 .732  9.65  5.07   .00   .00
  STD     .15 .000   .11    .057  .02   .00 .002   .04   .13    *     *
          80220 W109C002 (3.7E16)
        22.24 .544 19.68  -5.617 2.32 -1.26 .713  9.13  4.32   .00   .00
  STD     .24 .002   .21    .430  .26   .50 .011   .11   .63    *     *
PERCENT OF BASELINE
        97.8  99.3  96.1   111.2  119  24.8  97.5  94.6  85.3 ***** *****
 STD%    1.7    .4   1.6     7.7   15  69.7   1.8   1.5  14.8 ***** *****
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80224 W110FE001 (8E14) W058 00 000
SOL8  8 /13/78    AM1: P0=91.60MW/CM©2  NO AR COATING

ID         ISC   VOC   IP     LOG(IO)  N     R     FF    Eff    OCD   PCDa  PCDb

1R*       22.50 .555 20.00   -5.844 2.21  -.74 .710   9.38   .00   .00   .00
1B*       19.30 .552 15.76   -4.118 3.83 -1.94 .612   6.89   .52   .00   .00
2B*       19.50 .570 15.78   -3.786 4.58 -4.18 .623   7.32   .65   .00   .00
3B        20.10 .588 18.01   -6.057 2.25 -1.41 .733   9.16  1.56   .00   .00
4B*       19.30 .467 14.94   -3.920 3.53   .51 .535   5.10   .52   .00   .00
1C        18.30 .580 15.23   -4.008 4.26 -5.53 .669   7.51   .91   .00   .00
2C        18.30 .572 14.60   -3.454 5.54 -7.76 .635   7.03   .91   .00   .00
3C        18.40 .570 15.78   -4.797 3.11 -2.37 .677   7.51   .91   .00   .00
4C        18.30 .577 15.98   -5.199 2.78 -2.26 .702   7.83  1.04   .00   .00
5C        18.30 .584 16.24   -5.654 2.49 -2.07 .724   8.18  1.17   .00   .00
6C        18.30 .573 15.18   -4.112 4.03 -3.99 .649   7.20   .91   .00   .00
7C        18.10 .568 15.42   -4.641 3.27 -2.72 .671   7.30   .91   .00   .00
8C        18.40 .585 16.47   -5.983 2.30 -1.83 .735   8.36  1.30   .00   .00
9C        18.50 .583 16.21   -5.190 2.82 -2.71 .712   8.12  1.04   .00   .00
10C       18.10 .574 15.22   -4.339 3.69 -3.63 .663   7.29   .65   .00   .00
11C       18.20 .584 16.42   -6.358 2.11 -1.49 .743   8.35  1.30   .00   .00
1S        18.50 .583 16.65   -6.367 2.10 -1.07 .733   8.37  1.30   .00   .00
2S        18.60 .581 16.47   -5.642 2.48 -1.72 .716   8.18  1.17   .00   .00
3S        18.50 .566 15.16   -3.962 4.24 -4.04 .635   7.03   .91   .00   .00
4S        18.50 .553 15.03   -4.048 3.99 -2.31 .609   6.59   .39   .00   .00
1T        17.10 .503 13.11   -3.990 3.78  1.42 .521   4.74   .52   .00   .00
2T        17.70 .582 16.24   -7.501 1.69  -.56 .759   8.27  1.56   .00   .00
3T        17.80 .560 14.60   -4.103 3.97 -3.04 .626   6.60   .65   .00   .00
4T        18.10 .580 15.98   -5.579 2.53 -1.78 .712   7.90  1.30   .00   .00

AVERAGES: 80224  BASELINE W058 00 000
          20.10 .588 18.01   -6.057 2.25 -1.41 .733   9.16  1.56   .00   .00
  STD       .00 .000   .00     .000  .00   .00 .000    .00   .00    *     *
             80224 W110FE001 (8E14)
          18.21 .571 15.58   -4.996 3.22 -2.60 .678   7.49   .99   .00   .00
  STD       .35 .018   .86    1.045  .96  1.88 .056    .87   .29    *     *
PERCENT OF BASELINE
          90.6  97.2  86.5   117.5  143   14.7  92.6  81.8  63.6 ***** *****
 STD%      1.7   3.1   4.8    17.3   43  133.6   7.7   9.5  18.8 ***** *****
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80227 W111CU-V001 (2.5E15-3E14) W097 00 000
SOL8               AM1: PO=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .552 19.90  -5.666 2.29   -.84 .705  9.26    .00    .00    .00
1B.*     21.60 .542 18.55  -4.741 2.94 -1.96 .679  8.41   3.51    .00    .00
2B       21.70 .547 19.46  -6.159 2.03   -.83 .726  9.12   4.81    .00    .00
3B.*     21.30 .539 18.70  -5.361 2.44 -1.37 .702  8.53   3.90    .00    .00
4B.*     21.40 .540 18.60  -5.675 2.25    .87 .652  7.96   3.64    .00    .00
1C       15.00 .476 13.17  -5.965 1.92    .42 .674  5.09    .52    .00    .00
2C       15.60 .476 13.55  -5.546 2.13   -.06 .665  5.23    .52    .00    .00
3C       15.00 .474 12.98  -5.355 2.24   -.70 .669  5.03    .65    .00    .00
4C.*     14.20 .463 11.34  -3.871 3.81 -3.93 .601  4.18    .65    .00    .00
5C       15.30 .475 13.43  -5.832 1.98   -.05 .679  5.22    .65    .00    .00
6C       15.10 .469 12.97  -5.174 2.34   -.79 .660  4.94    .65    .00    .00
7C       15.20 .476 13.47  -6.141 1.84   -.03 .693  5.31    .78    .00    .00
8C       15.50 .476 13.71  -5.986 1.90   -.33 .694  5.42    .65    .00    .00
9C       15.40 .469 13.07  -4.920 2.52   -.87 .645  4.93    .39    .00    .00
10C      15.40 .474 13.35  -5.427 2.19   -.47 .668  5.16    .65    .00    .00
11C      15.60 .472 13.50  -5.377 2.21   -.48 .666  5.19    .78    .00    .00
12C      15.10 .476 13.39  -6.078 1.87   -.37 .699  5.31    .91    .00    .00
1S       15.60 .481 13.95  -6.393 1.75   -.27 .711  5.64    .91    .00    .00
2S       15.50 .477 13.71  -6.033 1.89   -.18 .693  5.42    .78    .00    .00
3S       15.40 .478 13.64  -6.031 1.89   -.36 .697  5.43    .91    .00    .00
4S       15.10 .478 13.47  -6.315 1.78   -.21 .706  5.39    .91    .00    .00
5S       15.40 .478 13.75  -6.391 1.74   -.05 .705  5.49    .91    .00    .00
1T       15.10 .474 12.88  -4.913 2.56 -1.52 .659  4.99    .91    .00    .00
2T.*     14.80 .462 10.82  -3.980 3.58  4.01 .469  3.39    .39    .00    .00
3T       15.20 .468 12.83  -4.746 2.67 -1.45 .645  4.85    .65    .00    .00
4T       14.90 .469 12.86  -5.257 2.28   -.90 .667  4.93    .65    .00    .00
5T       15.10 .469 13.02  -5.236 2.29   -.87 .666  4.99    .78    .00    .00

AVERAGES: 80227  BASELINE W097 00 000
         21.70 .547 19.46  -6.159 2.03   -.83 .726  9.12   4.81    .00    .00
  STD      .00 .000   .00    .000  .00    .00 .000   .00    .00     *      *
           80227 W111CU-V001 (2,5E15-3E14)
         15.28 .474 13.34  -5.656 2.10   -.48 .678  5.20    .73    .00    .00
  STD      .22 .004   .33    .509  .28    .47 .020   .22    .15     *      *
PERCENT  OF BASELINE
         70.4  86.7  68.5  108.2   103 142.3  93.3  57.0   15.1 ***** *****
 STD%     1.0    .7   1.7    8.3    14  57.0   2.7   2.4    3.1 ***** *****
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80522 W111CU/V001 (2.5E15/3E14) REPEAT RUN W097 00 000
SOL9            AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC    VOC  IP     LOG(IO)  N       R     FF     Eff     OCD     PCDa    PCDb

2R*      21.90 .558 20.04  -7.143 1.70   -.67 .758   9.80    .00     .00     .00
1B       22.30 .549 20.04  -6.176 2.03   -.99 .734   9.50   4.16     .00     .00
2B       22.30 .551 20.34  -6.965 1.73   -.62 .752   9.77   4.42     .00     .00
3B.*     22.30 .544 19.84  -5.848 2.17   -.86 .715   9.17   3.64     .00     .00
4B.*     22.50 .548 19.84  -5.441 2.41  -1.33 .709   9.24   3.38     .00     .00
1C       15.60 .481 13.93  -6.369 1.76   -.09 .705   5.60    .91     .00     .00
2C       15.80 .480 14.03  -6.043 1.89   -.62 .705   5.66    .91     .00     .00
1S       15.70 .480 14.01  -6.337 1.77   -.16 .706   5.63   1.30     .00     .00
2S       15.70 .479 13.97  -6.163 1.84   -.44 .706   5.61    .91     .00     .00
3S       15.70 .474 13.09  -4.391 3.06  -2.56 .642   5.05    .65     .00     .00
1T       14.10 .467 12.74  -7.629 1.35   2.16 .691   4.81    .39     .00     .00
2T.*     15.00 .461 12.00  -3.923 3.66  -3.06 .598   4.37    .39     .00     .00
3T       15.60 .475 13.63  -5.587 2.10   -.59 .681   5.34    .78     .00     .00

AVERAGES: 80522  BASELINE W097 00 000
         22.30 .550 20.19  -6.570 1.88   -.81 .743   9.63   4.29     .00     .00
  STD      .00 .001   .15    .394  .15    .19 .009    .13    .13     *       *
           80522 W111CU/V001 (2.5E15/3E14) REPEAT RUN
         15.46 .477 13.63  -6.074 1.97   -.33 .691   5.38    .84     .00     .00
  STD      .56 .005   .48    .899  .49   1.28 .022    .31    .26     *       *
PERCENT OF BASELINE
         69.3  86.6  67.5   107.5   105 159.2  93.0   55.9   19.5  *****   *****
 STD%     2.5   1.0   2.9    20.1    36 204.7   4.1    4.0    6.8  *****   *****
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80301 W112TA001  (4E12)  W097 00 000
SOL8              AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC   IP     LOG(IO)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .553 20.07   -6.052 2.10   -.46  .711  9.36    .00    .00    .00
1B.*     21.70 .536 17.94   -4.038 3.77  -2.87  .641  7.89   1.82    .00    .00
2B.*     22.00 .547 18.90    4.500 3.12  -2.79  .692  8.81   3.64    .00    .00
3B.*     21.20 .541 16.75   -4.385 3.33   2.36  .535  6.49   2.99    .00    .00
4B       21.40 .544 19.21   -6.176 2.02   -.90  .729  8.97   3.90    .00    .00
5B       22.00 .548 19.92   -6.612 1.85   -.66  .740  9.43   4.42    .00    .00
1C       19.20 .525 16.31   -4.537 3.11  -2.58  .670  7.14    .91    .00    .00
2C       19.20 .528 16.97   -5.736 2.19   -.86  .703  7.53    .91    .00    .00
3C       19.60 .521 16.71   -4.815 2.80  -1.17  .657  7.09    .65    .00    .00
4C       19.60 .534 17.69   -6.734 1.77   -.05  .722  8.00   1.17    .00    .00
5C       19.40 .523 16.80   -5.113 2.57  -1.30  .680  7.30    .91    .00    .00
6C       19.20 .532 16.98   -5.692 2.24  -1.11  .707  7.64   1.04    .00    .00
8C       19.10 .528 16.23   -4.507 3.16  -2.84  .673  7.18    .91    .00    .00
9C       19.50 .533 17.61   -6.732 1.77   -.10  .724  7.96   1.04    .00    .00
10C      19.70 .529 17.45   -5.798 2.16   -.79  .705  7.77    .91    .00    .00
1S       19.10 .529 16.70   -5.287 2.48  -1.57  .697  7.45   1.04    .00    .00
2S       19.70 .529 17.35   -5.633 2.25   -.76  .696  7.67    .91    .00    .00
3S       18.80 .521 16.43   -5.445 2.34   -.81  .685  7.09    .65    .00    .00
4S       20.30 .534 18.20   -6.543 1.84    .30  .705  8.08   1.04    .00    .00
5S       19.90 .532 17.64   -5.875 2.13   -.57  .702  7.86    .91    .00    .00
6S       19.20 .534 17.24   -6.436 1.89   -.32  .719  7.79   1.04    .00    .00
1T       19.30 .527 16.54   -4.764 2.89  -2.08  .676  7.27    .78    .00    .00
2T       19.20 .525 16.65   -5.076 2.61  -1.68  .687  7.32    .65    .00    .00
3T       19.10 .528 16.91   -5.763 2.18   -.99  .708  7.55    .91    .00    .00
4T       19.50 .517 16.34   -4.352 3.27  -2.33  .649  6.92    .52    .00    .00
5T       19.60 .525 17.08   -5.198 2.51  -1.48  .691  7.52    .91    .00    .00

AVERAGES: 80301   BASELINE W097 00 000
         21.70 .546 19.57   -6.394 1.93   -.78  .734  9.20   4.16    .00    .00
  STD      .30 .002   .36     .218  .08    .12  .006   .23    .26    *      *
           80301 W112TA001  (1E13)
         19.41 .528 16.99   -5.502 2.41  -1.15  .693  7.51    .89    .00    .00
  STD      .33 .005   .52     .712  .44    .83  .020   .33    .16    *      *
PERCENT OF BASELINE
         89.4  96.6   86.8   114.0  125   51.8  94.3   81.6   21.4  *****  *****
 STD%     2.8   1.2    4.3    14.4   29  145.2   3.5    5.7    5.4  *****  *****
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805221 W113FZ/CR001 (8E14)               W101 00 000
SOL9              AM1: PO=91.60MW/CM©2  NO AR COATING

ID         ISC    VOC   IP     LOG(IO)  N       R     FF     Eff     OCD     PCDa    PCDb

2R*       21.90 .556 20.05   -7.171 1.69   -.71 .761    9.79     .00     .00     .00
1B        22.30 .549 20.22   -6.634 1.84   -.76 .745    9.64    3.90     .00     .00
2B        22.00 .548 19.94   -6.617 1.85   -.73 .742    9.47    3.90     .00     .00
3B        22.10 .548 19.82   -6.050 2.08  -1.17 .733    9.39    3.90     .00     .00
4B        22.60 .549 20.38   -6.324 1.96   -.90 .738    9.68    4.16     .00     .00
1C        20.00 .515 17.82   -5.945 2.03   -.88 .716    7.80     .91     .00     .00
2C        19.90 .515 17.77   -6.008 2.00   -.94 .721    7.81    1.04     .00     .00
3C        20.10 .515 18.02   -6.244 1.89   -.63 .722    7.90    1.04     .00     .00
1S        20.00 .511 17.08   -4.644 2.90  -2.19 .674    7.29     .91     .00     .00
2S        20.00 .514 17.73   -5.699 2.15  -1.22 .714    7.77    1.04     .00     .00
3S        20.20 .516 17.96   -5.781 2.11  -1.20 .718    7.92    1.04     .00     .00
4S        20.30 .515 18.13   -5.983 2.00  -1.01 .723    7.99    1.17     .00     .00
1T        20.00 .515 17.82   -5.900 2.05  -1.08 .720    7.84     .91     .00     .00
2T        20.00 .515 17.69   -5.646 2.18  -1.14 .709    7.73     .91     .00     .00
3T        20.20 .515 17.97   -5.957 2.02   -.64 .710    7.81    1.04     .00     .00

AVERAGES: 805221 BASELINE W101 00 000
          22.25 .549 20.09   -6.406 1.93   -.89 .740    9.55    3.97     .00     .00
  STD       .23 .000   .22     .240  .10    .17 .004     .12     .11      *       *
            805221 W113FZ/CR001 (8E14) REPEAT RUN
          20.07 .515 17.80   -5.781 2.13  -1.09 .713    7.79    1.00     .00     .00
  STD       .12 .001   .27     .412  .27    .42 .014     .18     .08      *       *
PERCENT OF BASELINE
          90.2  93.8  88.6   109.8   110   77.2  96.4    81.6    25.2   *****   *****
 STD%      1.5    .3   2.4    10.0    20   79.6   2.4     2.9     2.9   *****   *****
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80317 W115N/CU 002 (1E16) W079 00 000
SOL8              AM1: PO=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)   N      R     FF     Eff    OCD    PCDa   PCDb

1R*      22.50 .552 20.15   -6.261 2.00   -.27 .714   9.38    .00    .00    .00
1B*      20.20 .526 15.72   -3.292 5.46 -5.95 .600   6.74    .00    .00    .00
2B       20.60 .541 18.52   -6.317 1.95   -.72 .728   8.58   5.85    .00    .00
3B       21.00 .544 19.16   -7.134 1.67   -.31 .745   9.01   4.94    .00    .00
4B       21.20 .551 19.43   -7.315 1.63   -.48 .757   9.35   4.94    .00    .00
1C       21.50 .545 19.14   -5.938 2.13   -.70 .712   8.82   3.90    .00    .00
2C.*     20.70 .533 17.03   -3.859 4.09 -4.24 .650   7.59   1.43    .00    .00
3C       20.90 .534 17.71   -4.498 3.16 -2.17 .663   7.83   1.43    .00    .00
4C       21.30 .540 18.27   -4.706 2.97 -2.10 .679   8.26   2.34    .00    .00
5C       20.40 .537 17.92   -5.349 2.45 -1.62 .706   8.18   2.21    .00    .00
6C       20.80 .536 18.06   -5.027 2.68 -1.75 .691   8.15   2.21    .00    .00
7C       21.00 .535 18.00   -4.753 2.91 -1.82 .674   8.01   1.56    .00    .00
8C       20.70 .537 18.25   -5.554 2.32 -1.14 .705   8.28   2.60    .00    .00
9C       20.40 .540 17.91   -5.359 2.46 -1.49 .703   8.19   2.21    .00    .00
10C      20.20 .519 17.24   -4.873 2.73   -.91 .655   7.26   1.69    .00    .00
11C      20.90 .537 17.71   -4.435 3.25 -2.57 .668   7.93   1.30    .00    .00
1S       22.20 .555 19.29   -4.932 2.83 -2.12 .699   9.11   4.42    .00    .00
2S       20.60 .525 16.88   -4.101 3.63 -1.90 .617   7.06    .78    .00    .00
3S       20.80 .533 17.60   -4.475 3.19 -2.20 .661   7.75   1.30    .00    .00
4S       20.00 .537 17.63   -5.499 2.36 -1.46 .709   8.05   2.08    .00    .00
5S       21.70 .548 19.55   -6.429 1.92   -.53 .728   9.16   4.55    .00    .00
1T       20.80 .538 18.15   -5.197 2.56 -1.51 .695   8.22   1.95    .00    .00
2T       20.90 .537 18.10   -4.993 2.71 -1.62 .685   8.13   1.95    .00    .00
3T       21.00 .543 18.41   -5.292 2.51 -1.55 .702   8.47   2.34    .00    .00
4T       20.50 .539 18.05   -5.479 2.38 -1.34 .706   8.25   2.34    .00    .00

AVERAGES: 80317  BASELINE W079 00 000
         20.93 .545 19.03   -6.922 1.75   -.50 .743   8.98   5.24    .00    .00
  STD      .25 .004   .38     .434  .14    .17 .012    .32    .43     *      *
          80317 W115N/CU 002 (1E16)
         20.87 .538 18.10   -5.099 2.69 -1.61 .687   8.16   2.27    .00    .00
  STD      .51 .007   .64     .549  .41    .52 .025    .50    .99     *      *
PERCENT OF BASELINE
         99.7  98.6  95.1   126.3   154 *****  92.5   90.9   43.3 ***** *****
 STD%     3.7   2.1   5.3    13.0    38 245.8   4.9    9.0   23.9 ***** *****
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80321 W116PH001 (1E17) LOW RESISTIVITY RUN  W057 00 000
SOL8  8 /13/78   AM1: PO=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC   IP     LOG(IO)   N      R     FF    Eff    OCD    PCDa   PCDb

1R*     22.50 .556 20.03   -5.941 2.16   -.59 .710   9.39    .00    .00    .00
1B      21.20 .577 17.26   -3.692 4.77 -5.04 .643   8.31   1.04    .00    .00
2B      21.40 .581 18.65   -5.084 2.84 -1.92 .698   9.18   1.69    .00    .00
3B      21.40 .577 18.79   -5.374 2.60 -1.37 .701   9.15   1.30    .00    .00
4B      21.40 .568 17.89   -4.274 3.64 -2.41 .648   8.32    .91    .00    .00
5B      21.60 .568 18.83   -5.299 2.61   -.88 .683   8.87   1.04    .00    .00
1C      21.30 .565 17.77   -4.366 3.50 -1.63 .635   8.09    .91    .00    .00
2C      21.00 .584 18.57   -5.497 2.55 -1.81 .718   9.32   1.95    .00    .00
3C      21.30 .579 18.73   -5.425 2.58 -1.37 .703   9.17   1.56    .00    .00
4C      21.40 .560 17.82   -4.392 3.43 -1.23 .628   7.96    .91    .00    .00
5C      21.30 .580 19.18   -6.315 2.09   -.93 .734   9.59   1.95    .00    .00
6C      21.40 .561 18.29   -4.899 2.90   -.78 .655   8.31    .91    .00    .00
7C      20.90 .550 17.47   -4.707 3.03    .15 .615   7.48    .91    .00    .00
8C      21.10 .572 18.02   -4.707 3.15 -1.80 .667   8.51   1.30    .00    .00
9C      21.00 .534 17.16   -4.312 3.39   -.25 .595   7.05    .52    .00    .00
10C     21.00 .535 16.65   -4.163 3.59    .93 .552   6.56    .39    .00    .00
11C     21.30 .572 18.14   -4.653 3.20 -1.80 .664   8.55   1.04    .00    .00
12C     21.30 .576 18.55   -5.048 2.85 -2.06 .699   9.07   1.69    .00    .00
13C     21.30 .580 18.99   -5.934 2.27   -.96 .718   9.38   1.56    .00    .00
1S      20.30 .579 18.15   -6.080 2.20   -.92 .721   8.96   1.56    .00    .00
2S      20.70 .565 17.49   -4.537 3.31 -1.84 .653   8.08    .91    .00    .00
3S      20.80 .577 18.32   -5.475 2.54 -1.40 .706   8.96   1.30    .00    .00
4S      21.00 .582 19.18   -7.200 1.76   -.35 .748   9.67   2.08    .00    .00
5S      21.10 .583 19.05   -6.471 2.03   -.78 .735   9.56   1.95    .00    .00
1T      21.30 .529 17.55   -4.538 3.08    .40 .596   7.10    .78    .00    .00
2T      21.10 .570 17.78   -4.384 3.51 -2.46 .658   8.36   1.30    .00    .00
3T      21.00 .569 17.13   -3.841 4.39 -3.75 .631   7.98   1.04    .00    .00
4T      21.00 .575 18.16   -4.935 2.95 -1.91 .686   8.76    .91    .00    .00
5T      20.80 .563 17.86   -4.915 2.91 -1.27 .667   8.27   1.17    .00    .00
6T      21.30 .551 17.85   -4.509 3.24 -1.09 .634   7.87    .91    .00    .00

AVERAGES: 80321  BASELINE W057 00 000
        21.40 .574 18.28   -4.745 3.29 -2.33 .674   8.77   1.20    .00    .00
  STD     .13 .005   .62     .656  .83  1.45 .025    .38    .28     *      *
          80321 W116PH001 (1E17) LOW RESISTIVITY RUN
        21.08 .566 18.08   -5.054 2.94 -1.20 .667   8.44   1.23    .00    .00
  STD     .26 .016   .66     .817  .59   .96 .050    .83    .46     *      *
PERCENT OF BASELINE
        98.5  98.6  98.9    93.5   89 148.2  99.0   96.3 102.8  *****  *****
 STD%    1.8   3.7   7.0    34.3   45  99.4  11.3   14.1  71.1  *****  *****
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805241 W115N/CU 002 (1E16) REPEAT W079 00 000
SOL9              AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R     FF    Eff    OCD    PCDa   PC

2R*      21.90 .556 19.67  -6.001 2.14 -1.55 .742   9.56    .00    .00    .00
1B       21.20 .546 19.27  -7.121 1.67   .15 .730   8.94   5.20    .00    .00
2B*      21.40 .540 19.28  -6.534 1.85  -.22 .722   8.83   4.55    .00    .00
3B       21.70 .546 19.69  -6.936 1.73  -.03 .730   9.15   5.85    .00    .00
4B       21.70 .550 19.75  -6.975 1.73  -.38 .743   9.38   4.29    .00    .00
5B*      21.40 .525 17.98  -4.455 3.15 -1.56 .645   7.66   1.56    .00    .00
1C       21.30 .539 18.60  -5.269 2.50 -1.15 .690   8.38   2.86    .00    .00
2C       21.20 .543 19.34  -7.310 1.61   .14 .737   8.97   5.20    .00    .00
3C       21.00 .541 18.69  -5.850 2.17 -1.07 .718   8.63   3.64    .00    .00
1S       21.20 .543 19.24  -6.889 1.74  -.19 .734   8.93   4.55    .00    .00
2S       21.20 .539 19.20  -6.903 1.72   .12 .724   8.75   4.55    .00    .00
3S       21.80 .552 19.88  -7.088 1.70  -.36 .746   9.50   4.68    .00    .00
1T       21.60 .551 19.85  -7.615 1.55  -.18 .756   9.52   5.46    .00    .00
2T       21.60 .535 18.34  -4.574 3.07 -1.79 .662   8.09   1.69    .00    .00
3T       21.70 .540 19.02  -5.329 2.46 -1.25 .698   8.65   2.34    .00    .00

AVERAGES: 805241 BASELINE W079 00 000
         21.53 .547 19.57  -7.010 1.71  -.08 .735   9.16   5.11    .00    .00
  STD      .24 .002   .21    .080  .03   .22 .006    .18    .64    *      *
          805241 W115N/CU 002 (1E16) REPEAT
         21.40 .543 19.13  -6.314 2.06  -.64 .718   8.82   3.89    .00    .00
  STD      .26 .005   .50   1.015  .49   .65 .028    .45   1.25    *      *
PERCENT OF BASELINE
         99.4  99.1  97.7  109.9  120 *****  97.8   96.4   76.0 ***** *****
 STD%     2.3   1.3   3.7   15.7   31 *****   4.7    6.8   37.0 ***** *****

80403 W118PH003 (7E16) LOW RESISTIVITY W057 00 000
SOL8  8 /10/78    AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)  N      R     FF    Eff    OCD    PCDa   PCDb

1R*      22.50 .550 20.06  -6.001 2.11  -.55 .712   9.32    .00    .00    .00
1B.*     21.10 .559 17.97  -4.736 3.05 -1.32 .657   8.20    .65    .00    .00
2B.*     21.00 .561 17.90  -4.751 3.05 -1.37 .659   8.21   1.69    .00    .00
3B.*     21.40 .579 18.85  -5.387 2.60 -1.72 .711   9.32    .91    .00    .00
1C       21.60 .573 18.42  -4.530 3.34 -2.60 .676   8.85   2.60    .00    .00
2C       22.00 .581 19.94  -6.621 1.96  -.80 .743  10.05   6.50    .00    .00
3C       21.50 .579 19.62  -6.975 1.82  -.76 .754   9.93   5.85    .00    .00
4C       21.70 .561 18.95  -5.215 2.64 -1.38 .694   8.93   3.90    .00    .00
5C       21.90 .570 18.94  -4.909 2.93 -1.86 .687   9.07   2.34    .00    .00
6C       21.60 .566 18.66  -4.892 2.93 -1.86 .685   8.86   2.21    .00    .00
7C       21.60 .576 19.49  -6.391 2.04  -.94 .738   9.71   5.20    .00    .00
1S       21.20 .564 18.18  -4.685 3.13 -2.33 .681   8.61   1.82    .00    .00
2S       21.60 .565 18.60  -4.841 2.97 -1.81 .680   8.77   2.34    .00    .00
3S       21.50 .558 18.40  -4.863 2.92 -1.05 .660   8.37   1.43    .00    .00
1T       22.70 .552 20.12  -5.775 2.23  -.68 .706   9.35  21.00    .00    .00
2T       22.20 .547 20.31  -7.394 1.59   .02 .744   9.55  26.00    .00    .00
3T       22.00 .554 18.23  -4.155 3.70 -2.24 .636   8.19   2.60    .00    .00

AVERAGES: 80403  BASELINE W057 00 000
NO BASELINE
          80403 W118PH003 (7E16) LOW RESISTIVITY
         21.78 .565 19.07  -5.480 2.63 -1.41 .699   9.10   6.45    .00    .00
  STD      .37 .010   .72    .998  .62   .75 .035    .56   7.50    *      *
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80404 W119N/FE002     (3E14)                         W079 00 000
SOLS                    AM1: P0=91.60MW/CM12  NO AR COATING
      ,
ID         ISC    VOC  IP      LOG(IO)   N      R      FF     EFF     OCD     RCDA    RCDF

1E*        22.50 .552 20.21   -6.386 1.95   -.24  .718   9.43     .00     .00     .00
 1E.*      22.30 .547 18.83   -4.459 3.25  -1.83  .655   8.45    2.12     .00     .00
2E         22.00 .561 19.74   -6.144 2.09   -.95  .729   9.52    5.85     .00     .00
3E.*       22.20 .549 18.65   -4.305 2.46  -2.35  .655   8.44    2.25     .00     .00
4E*        22.20 .513 17.85   -4.086 3.52   -.34  .580   6.98     .91     .00     .00
5E.*       21.90 .547 19.17   -5.257 2.54  -1.42  .699   8.85    4.94     .00     .00
 1C        21.40 .536 17.73   -4.109 3.67  -2.60  .640   7.76    1.95     .00     .00
2C         21.30 .525 17.32   -3.900 3.93  -2.64  .618   7.31    1.17     .00     .00
3C         21.20 .536 17.96   -4.451 3.22  -2.38  .666   8.00    1.69     .00     .00
 4C        21.20 .528 17.49   -4.093 3.64  -2.40  .633   7.49    1.04     .00     .00
 5C        21.00 .544 18.24   -4.956 2.77  -2.12  .697   8.42    2.73     .00     .00
 6C        21.30 .531 17.81   -4.277 3.40  -2.27  .648   7.75    1.56     .00     .00
 7C.*      21.10 .516 16.87   -3.320 5.21  -7.16  .649   7.48    1.56     .00     .00
 8C        21.50 .525 17.57   -4.028 3.71  -2.00  .617   7.36     .78     .00     .00
 9C        21.40 .534 18.11   -4.491 3.16  -2.00  .660   7.98    1.95     .00     .00
 10C       21.50 .532 17.97   -4.245 3.45  -2.38  .649   7.85    1.82     .00     .00
 11C       21.50 .546 19.06   -5.708 2.26  -1.06  .712   8.84    3.25     .00     .00
 12C       20.90 .527 17.20   -4.041 3.73  -2.63  .632   7.36     .91     .00     .00
 13C       21.20 .524 17.41   -4.094 3.61  -1.99  .622   7.31     .91     .00     .00
 1S        21.60 .547 18.94   -5.294 2.52  -1.47  .702   8.77    3.90     .00     .00
 2S        21.40 .540 18.26   -4.571 3.11  -2.32  .675   8.25    2.34     .00     .00
 3S        21.60 .531 17.91   -4.126 3.60  -2.49  .640   7.77    1.69     .00     .00
 4S        21.40 .534 17.85   -4.208 3.51  -2.50  .648   7.83    1.69     .00     .00
 5S        21.40 .535 17.97   -4.316 3.38  -2.37  .654   7.92    1.95     .00     .00
 6S        21.10 .520 16.99   -3.894 3.91  -1.97  .599   6.96    1.04     .00     .00
 1T.*      18.50 .516 14.91   -3.738 4.29  -4.37  .622   6.28     .39     .00     .00
 2T        18.60 .527 16.45   -5.725 2.20  -1.03  .705   7.31     .91     .00     .00
 3T        18.60 .515 15.61   -4.429 3.19  -2.19  .648   6.57     .39     .00     .00
 4T        18.50 .427 14.29   -4.105 3.00   1.60  .522   4.36     .65     .00     .00
 5T        18.70 .507 15.43   -4.259 3.34  -1.76  .623   6.24     .65     .00     .00

AVERAGES: 80404  BASELINE W079 00 000
           22.00 .561 19.74   -6.144 2.09   -.95  .729   9.52    5.85     .00     .00
  STD        .00 .000   .00     .000  .00    .00  .000    .00     .00      *       *
             80404 W119N/FE002 DOUBLE METALIZATION
           20.83 .526 17.43   -4.424 3.29  -1.95  .646   7.52    1.59     .00     .00
  STD       1.07 .024  1.10     .518  .48    .89  .040    .92     .86      *       *
PERCENT OF BASELINE
           94.7  93.8  88.3    128.0  157   -6.5  88.5   79.0    27.2  *****   *****
 STD%       4.8   4.2   5.6      8.4   23   94.4   5.5    9.7    14.3  *****   *****
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80405 W120N/CR002 (3E14)                          W079 00 000
SOL8              AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC  IP    LOG(IO)  N      R    FF   Eff    OCD    PCDa   PCDb

1R*      22.50 .552 20.18  -6.307 1.98   -.30 .717  9.42    .00    .00    .00
1B       21.70 .549 19.57  -6.510 1.89   -.41 .728  9.17   5.20    .00    .00
2B.*     21.70 .531 18.11  -4.306 3.35  -1.81 .639  7.79   1.82    .00    .00
3B       21.60 .548 19.96  -8.212 1.40    .32 .755  9.45   7.28    .00    .00
4B       21.30 .541 19.10  -6.442 1.89    .01 .711  8.66   4.94    .00    .00
1C.*     20.40 .546 17.37  -4.448 3.31  -3.20 .683  8.04   1.95    .00    .00
2C       21.00 .555 18.62  -5.567 2.38  -1.73 .723  8.91   3.90    .00    .00
3C       20.70 .547 18.28  -5.577 2.35  -1.23 .708  8.48   2.60    .00    .00
4C       21.50 .548 19.01  -5.698 2.27   -.81 .704  8.77   4.16    .00    .00
5C       21.70 .564 20.12  -8.301 1.42   -.05 .770  9.96   9.10    .00    .00
6C       21.90 .556 19.97  -7.093 1.71   -.28 .744  9.58   6.50    .00    .00
7C       21.40 .563 19.18  -6.078 2.13  -1.06 .729  9.28   5.20    .00    .00
8C       21.00 .548 17.89  -4.535 3.20  -2.53 .675  8.21   2.34    .00    .00
9C       21.90 .556 18.94  -4.829 2.93  -2.21 .693  8.92   4.29    .00    .00
10C      20.30 .541 17.49  -4.867 2.85  -1.91 .682  7.92   1.56    .00    .00
11C      21.70 .569 19.83  -7.156 1.73   -.48 .752  9.82   7.15    .00    .00
12C      21.60 .558 19.91  -8.035 1.46    .30 .752  9.58   4.55    .00    .00
13C      21.80 .559 20.09  -8.078 1.46    .43 .748  9.65   7.15    .00    .00
1S       21.70 .563 19.54  -6.365 2.00   -.72 .731  9.45   5.20    .00    .00
2S       22.10 .566 20.54  -8.680 1.35    .28 .768 10.15   9.10    .00    .00
4S       21.50 .532 17.87  -4.288 3.39  -1.63 .632  7.64   1.95    .00    .00
5S       22.20 .558 19.49  -5.344 2.53  -1.34 .702  9.19   4.29    .00    .00
6S       21.70 .552 18.88  -5.021 2.75  -1.89 .697  8.83   5.20    .00    .00
1T       20.80 .550 18.14  -5.045 2.73  -2.22 .704  8.52   2.34    .00    .00
2T       20.60 .543 17.72  -4.744 2.97  -2.33 .685  8.11   1.56    .00    .00
3T.*     20.80 .546 17.16  -3.804 4.29  -5.08 .663  7.96   1.95    .00    .00
4T       20.70 .548 18.16  -5.225 2.59  -2.03 .711  8.52   2.99    .00    .00
5T       20.60 .533 17.34  -4.398 3.28  -2.24 .655  7.60   1.30    .00    .00

AVERAGES: 80405  BASELINE W079 00 000
         21.53 .546 19.54  -7.054 1.73   -.03 .731  9.10   5.81    .00    .00
  STD      .17 .004   .35    .819  .23    .30 .018   .33   1.05    *      *
          80405 W120N/CR002
         21.35 .553 18.91  -5.949 2.36  -1.22 .713  8.91   4.40    .00    .00
  STD      .55 .010   .95   1.359  .63    .94 .035   .74   2.30    *      *
PERCENT OF BASELINE
          99.2 101.2  96.7  115.7  136 *****  97.4  98.0   75.8 ***** *****
 STD%      3.3   2.5   6.7   31.3   60 *****   7.4  11.9   60.5 ***** *****
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80424 W121N/TI002 (4E13) W079 00 000
SOL8            AM1: PO=91.60MW/CM©2  NO AR COATING

ID      ISC   VOC   IP    LOG(IO)  N      R    FF    Eff    OCD    PCDa   PCDb

2R*    21.90 .558 19.95  -6.845 1.80   -.87 .755   9.75    .00    .00    .00
1B*    19.80 .530 17.26  -5.191 2.54 -1.55 .693   7.69   1.30    .00    .00
2B     21.50 .553 19.79  -7.836 1.50    .07 .754   9.48   5.85    .00    .00
3B     21.40 .539 19.04  -6.212 1.98    .27 .694   8.46   3.90    .00    .00
4B     21.40 .541 19.03  -6.122 2.03    .03 .697   8.54   3.90    .00    .00
5B     21.20 .540 19.01  -6.535 1.86    .30 .705   8.54   4.29    .00    .00
1C     19.70 .517 16.51  -4.463 3.13 -1.61 .641   6.90   1.17    .00    .00
2C     19.50 .524 16.68  -4.673 2.95 -2.33 .676   7.31   1.17    .00    .00
3C     19.70 .524 17.09  -5.171 2.53 -1.12 .680   7.42   1.69    .00    .00
4C     19.70 .512 16.39  -4.363 3.22 -1.57 .631   6.73    .91    .00    .00
5C     19.60 .526 17.24  -5.665 2.22   -.50 .690   7.52   1.95    .00    .00
6C     19.50 .523 17.00  -5.394 2.37   -.66 .679   7.33   1.30    .00    .00
7C     20.00 .521 16.95  -4.558 3.04 -2.00 .661   7.28   1.30    .00    .00
8C     19.60 .521 17.11  -5.507 2.29   -.35 .677   7.31   1.69    .00    .00
9C     21.50 .538 18.76  -5.444 2.38   -.37 .677   8.28   3.25    .00    .00
10C    19.90 .525 17.44  -5.535 2.29   -.59 .686   7.58   1.69    .00    .00
11C    19.70 .526 17.64  -6.356 1.89   -.19 .712   7.80   2.08    .00    .00
1S     19.90 .530 17.81  -6.330 1.91   -.16 .711   7.93   2.60    .00    .00
2S     19.90 .532 17.71  -5.925 2.10   -.87 .714   7.99   2.47    .00    .00
3S     19.70 .526 17.23  -5.440 2.35   -.82 .687   7.53   1.95    .00    .00
4S     19.80 .525 17.44  -5.653 2.22   -.71 .696   7.65   1.95    .00    .00
5S     19.80 .521 16.63  -4.320 3.32 -2.72 .658   7.17   1.04    .00    .00
6S     20.00 .525 17.50  -5.406 2.37   -.94 .689   7.65   2.08    .00    .00
1T     19.80 .519 16.44  -4.260 3.39 -2.11 .636   6.91   1.04    .00    .00
2T     20.30 .536 18.46  -6.954 1.70   -.41 .742   8.54   1.30    .00    .00
3T     19.90 .526 17.41  -5.393 2.38 -1.01 .690   7.64   1.69    .00    .00
4T     19.90 .523 17.23  -5.106 2.57 -1.18 .678   7.46   1.30    .00    .00
5T     19.70 .522 17.01  -5.051 2.61 -1.22 .675   7.34   1.56    .00    .00

AVERAGES: 80424  BASELINE W079 00 000
       21.38 .543 19.22  -6.676 1.84    .17 .713   8.76   4.49    .00    .00
  STD    .11 .006   .33    .687  .21    .12 .024    .42    .80     *      *
          80424 W121N/TI002 (7E13)
       19.87 .525 17.26  -5.317 2.51 -1.07 .681   7.51   1.69    .00    .00
  STD    .40 .006   .58    .688  .46    .70 .026    .42    .56     *      *
PERCENT OF BASELINE
       93.0  96.6  89.8  120.4  136 *****  95.6   85.8   37.7 ***** *****
 STD%   2.3   2.1   4.6   19.6   44 *****   7.0    9.1   21.6 ***** *****
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80425 W122TI007 (8.4E13)W097 0 000  (Fast Growth)
SOL8            AM1: PO=91.60MW/CM©2  NO AR COATING

ID         ISC   VOC   IP     LOG(IO)  N     R     FF    Eff    OCD    PCDa   PCDb

2R*       21.90 .557 19.85  -6.482 1.93 -1.20 .752  9.70   .00    .00    .00
1B        22.20 .551 20.12  -6.638 1.85  -.67 .742  9.59  5.20    .00    .00
2B.       22.30 .546 19.91  -5.840 2.18 -1.28 .728  9.37  4.42    .00    .00
3D        22.20 .548 19.94  -6.150 2.04  -.97 .732  9.42  4.16    .00    .00
4B*       22.30 .543 19.38  -4.995 2.71 -1.78 .695  8.90  2.99    .00    .00
5B.*      22.30 .549 19.89  -5.828 2.20 -1.25 .726  9.40  4.55    .00    .00
1C        14.10 .468 12.09  -5.214 2.32  -.55 .654  4.56   .52    .00    .00
2C        13.90 .468 12.12  -5.730 2.02   .10 .669  4.60   .52    .00    .00
3C        13.90 .469 12.23  -6.018 1.88   .31 .678  4.68   .65    .00    .00
4C        13.90 .470 12.25  -6.042 1.88   .11 .684  4.72   .78    .00    .00
5C        13.90 .467 12.26  -6.117 1.83   .36 .681  4.68   .65    .00    .00
6C        14.30 .469 12.63  -6.154 1.82   .36 .684  4.85   .91    .00    .00
7C        14.00 .462 12.07  -5.392 2.18  -.20 .657  4.49   .65    .00    .00
8C        13.80 .465 12.10  -5.934 1.91   .37 .673  4.56   .65    .00    .00
9C        14.00 .469 12.20  -5.702 2.04   .02 .669  4.65   .78    .00    .00
10C       13.70 .468 12.09  -6.112 1.84   .29 .683  4.63   .78    .00    .00
11C       13.90 .459 11.83  -5.086 2.37  -.46 .643  4.34   .39    .00    .00
1S        14.20 .472 12.55  -6.145 1.83   .24 .686  4.86   .78    .00    .00
2S        14.20 .470 12.47  -5.935 1.92   .20 .677  4.78   .78    .00    .00
3S        14.10 .469 12.43  -6.063 1.86   .20 .683  4.78   .78    .00    .00
4S        14.10 .469 12.48  -6.309 1.76   .73 .681  4.77   .91    .00    .00
5S        14.20 .467 12.36  -5.603 2.08  -.26 .671  4.70   .78    .00    .00
6S        14.20 .470 12.49  -6.020 1.88   .32 .678  4.79   .91    .00    .00
1T        13.90 .468 12.01  -5.391 2.21  -.49 .663  4.56   .91    .00    .00
2T        14.00 .464 12.00  -5.216 2.31  -.48 .652  4.48   .91    .00    .00
3T        13.80 .466 12.11  -5.892 1.93   .08 .677  4.61   .91    .00    .00
4T        13.90 .457 11.69  -4.822 2.57  -.86 .633  4.25   .65    .00    .00

AVERAGES: 80425  BASELINE W097 0 000
          22.20 .550 20.03  -6.394 1.94  -.82 .737  9.50  4.68    .00    .00
  STD       .00 .002   .09    .244  .09   .15 .005   .09   .52     *      *
            80425 W122TI007 (3E14)
          14.00 .467 12.21  -5.757 2.02   .02 .670  4.64   .74    .00    .00
  STD       .16 .004   .24    .406  .22   .39 .014   .15   .15     *      *
PERCENT OF BASELINE
          63.1  85.0  61.0  110.0  104 202.3  91.0  48.8  15.9 ***** *****
 STD%       .7    .9   1.5   10.0   17  56.7   2.6   2.1   5.2 ***** *****
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80427 W123TI008 (1.05E14) W097 00 000 (Slow Growth)
SOL8  8 /13/78    AM1: P0=91.60MW/CM©2   NO AR COATING

ID        ISC   VOC   IP     LOG(IO)   N      R     FF    Eff    OCD    PCDa   PCDb

2R*       21.90 .555 19.76   -6.233 2.03 -1.39 .748   9.61    .00    .00    .00
1B        22.20 .549 19.46   -5.191 2.59 -1.79 .707   9.11   4.16    .00    .00
2B        22.10 .546 19.76   -5.988 2.10 -1.01 .726   9.26   3.90    .00    .00
3B*       22.20 .536 18.84   -4.466 3.18 -2.21 .667   8.40   2.86    .00    .00
4B*       22.30 .536 19.19   -5.129 2.57  -.25 .657   8.30   4.16    .00    .00
5B*       22.30 .536 18.75   -4.221 3.48 -2.87 .664   8.40   3.25    .00    .00
2C        14.80 .468 12.99   -5.930 1.91   .33 .674   4.94    .78    .00    .00
3C        14.40 .469 12.65   -5.924 1.92   .12 .679   4.85    .91    .00    .00
4C        14.40 .464 12.42   -5.437 2.16   .04 .655   4.63    .65    .00    .00
5C        14.40 .470 12.69   -6.071 1.86   .31 .681   4.87    .78    .00    .00
6C        14.30 .468 12.71   -6.478 1.69   .85 .685   4.85    .91    .00    .00
7C        14.50 .466 12.63   -5.764 1.98   .53 .661   4.72    .78    .00    .00
8C        14.60 .462 12.58   -5.454 2.13   .27 .651   4.64    .91    .00    .00
9C        14.10 .464 12.30   -5.837 1.94   .55 .664   4.59    .91    .00    .00
10C       14.30 .464 12.33   -5.505 2.12   .39 .651   4.56    .65    .00    .00
11C       14.40 .466 12.55   -5.722 2.01   .18 .667   4.73    .91    .00    .00
12C       14.50 .468 12.72   -6.035 1.86   .78 .668   4.80    .39    .00    .00
1S        14.70 .479 13.07   -6.425 1.74   .63 .689   5.13    .39    .00    .00
2S        14.10 .474 12.67   -7.013 1.53  1.19 .697   4.93    .65    .00    .00
3S        14.30 .475 12.77   -6.716 1.63  1.03 .690   4.96    .78    .00    .00
4S        14.40 .474 12.79   -6.450 1.72   .83 .685   4.94    .65    .00    .00
5S        14.40 .470 12.57   -5.780 1.99   .32 .667   4.77    .78    .00    .00
6S        14.40 .473 12.64   -6.348 1.75  1.97 .654   4.71    .78    .00    .00
1T        14.20 .473 12.34   -5.699 2.05   .40 .661   4.69    .91    .00    .00
2T        14.20 .470 12.29   -5.473 2.17  -.26 .663   4.68    .91    .00    .00
3T        14.20 .468 12.29   -5.421 2.19  -.53 .667   4.68    .78    .00    .00
4T        14.30 .466 12.52   -5.937 1.90   .62 .667   4.70    .65    .00    .00
5T        14.30 .467 12.40   -5.548 2.11   .01 .662   4.67    .65    .00    .00

AVERAGES: 80427  BASELINE W097 00 000
          22.15 .548 19.61   -5.590 2.35 -1.40 .716   9.19   4.03    .00    .00
  STD       .05 .002   .15     .398  .24   .39 .009    .07    .13     *      *
            80427 W123TI008 (1.88E14)
          14.37 .469 12.59   -5.953 1.93   .48 .670   4.78    .75    .00    .00
  STD       .17 .004   .21     .438  .18   .51 .013    .14    .15     *      *
PERCENT OF BASELINE
          64.9  85.7  64.2     93.5   82 234.3  93.5   52.0   18.6 ***** *****
 STD%       .9   1.0   1.6     16.0   17  56.3   3.1    1.9    4.5 ***** *****
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80531 W124M0003 W097 00 000  (4.6 E10)
SOL9              AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP     LOG(IO)   N      R     FF    Eff    OCD    PCDa   PCDb

2R*      21.90 .556 19.84   -6.498 1.92 -1.11 .750   9.65    .00    .00    .00
1B.*     22.00 .549 19.67   -6.016 2.10  -.91 .723   9.24   3.77    .00    .00
2B       21.70 .546 19.67   -6.743 1.80  -.39 .736   9.22   3.64    .00    .00
3B*      22.10 .540 18.88   -4.699 2.96 -1.57 .666   8.41   2.21    .00    .00
4B*      20.40 .544 18.05   -5.612 2.32 -1.34 .712   8.36   3.25    .00    .00
5B.*     22.10 .546 19.52   -5.483 2.38 -1.42 .713   9.10   3.51    .00    .00
1C       21.60 .546 19.77   -7.303 1.62  -.32 .752   9.38   3.25    .00    .00
2C       21.50 .538 18.46   -4.756 2.91 -1.87 .678   8.29   1.95    .00    .00
3C       21.70 .542 19.29   -5.774 2.20 -1.09 .717   8.92   2.21    .00    .00
4C       21.90 .546 19.72   -6.340 1.95  -.74 .732   9.25   2.86    .00    .00
5C       21.90 .540 19.44   -5.752 2.20  -.95 .712   8.91   2.86    .00    .00
7C       21.50 .543 19.64   -7.157 1.65  -.42 .750   9.27   3.38    .00    .00
8C       21.80 .542 19.30   -5.588 2.31 -1.33 .715   8.94   2.99    .00    .00
9C       21.80 .538 18.99   -5.100 2.61 -1.57 .694   8.61   2.86    .00    .00
10C      21.80 .538 18.56   -4.591 3.07 -1.89 .666   8.27   1.95    .00    .00
11C      21.50 .540 18.98   -5.502 2.35 -1.39 .712   8.74   2.99    .00    .00
12C      21.60 .541 19.54   -6.546 1.85  -.72 .739   9.13   3.25    .00    .00
1S       21.40 .544 18.87   -5.415 2.43 -1.65 .714   8.79   3.25    .00    .00
2S       21.30 .543 19.02   -5.930 2.13 -1.09 .724   8.85   3.12    .00    .00
3S       21.50 .545 19.50   -6.701 1.81  -.66 .743   9.20   3.64    .00    .00
4S       21.70 .539 18.88   -5.011 2.69 -1.90 .698   8.63   2.60    .00    .00
5S       21.60 .542 19.08   -5.498 2.36 -1.44 .713   8.83   3.25    .00    .00
1T       21.60 .547 19.59   -6.776 1.79  -.45 .739   9.23   4.16    .00    .00
2T       21.60 .544 19.49   -6.427 1.91  -.76 .735   9.14   3.64    .00    .00
3T       21.70 .546 19.90   -7.511 1.56  -.11 .751   9.41   3.90    .00    .00
4T       21.40 .540 19.03   -5.797 2.19 -1.10 .718   8.77   2.86    .00    .00
5T       21.70 .533 18.39   -4.559 3.07 -1.68 .658   8.04   1.69    .00    .00

AVERAGES: 80531   BASELINE W097 00 000
         21.70 .546 19.67   -6.743 1.80  -.39 .736   9.22   3.64    .00    .00
  STD      .00 .000   .00     .000  .00   .00 .000    .00    .00     *      *
           80531 W124M0003
         21.62 .542 19.21   -5.906 2.22 -1.10 .717   8.89   2.98    .00    .00
  STD      .16 .003   .43     .856  .45   .54 .026    .36    .62     *      *
PERCENT OF BASELINE
         99.6  99.2  97.7   112.4   124 -79.9  97.5   96.4   82.0  *****  *****
 STD%      .7    .6   2.2    12.7    25 136.3   3.6    4.0   17.1  *****  *****
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80601 W125M0004 W097 00 000   (6E11)
SOL9               AM1: P0=91.60MW/CM©2  NO AR COATING

ID        ISC    VOC   IP      LOG(IO)  N       R      FF     Eff     OCD     PCDa    PCDb

2R*       21.90 .558 20.18   -7.719 1.54    -.34 .765    9.88     .00     .00     .00
1B        22.00 .549 20.00   -6.925 1.74    -.28 .739    9.43    3.25     .00     .00
2B        22.10 .549 20.11   -7.045 1.70    -.11 .737    9.46    3.90     .00     .00
3B        21.90 .548 19.73   -6.501 1.89    -.31 .724    9.19    3.90     .00     .00
4B        22.10 .548 20.09   -6.875 1.75    -.42 .742    9.50    3.77     .00     .00
5B        22.00 .549 19.72   -6.199 2.02    -.59 .721    9.21    3.64     .00     .00
1C        21.20 .535 18.49   -5.128 2.59  -1.66 .697    8.36    1.56     .00     .00
2C        20.80 .536 18.59   -5.965 2.09  -1.15 .726    8.56    1.95     .00     .00
3C        21.30 .535 19.02   -6.016 2.06    -.83 .720    8.67    1.82     .00     .00
4C        21.20 .538 19.23   -6.742 1.77    -.57 .741    8.94    2.08     .00     .00
5C        21.20 .538 18.82   -5.693 2.24  -1.30 .718    8.66    2.08     .00     .00
6C        21.00 .534 17.97   -4.626 3.02  -2.37 .680    8.06    1.30     .00     .00
7C        21.00 .536 18.48   -5.420 2.39  -1.42 .707    8.41    1.82     .00     .00
8C        21.10 .535 18.85   -6.043 2.05    -.81 .720    8.59    1.56     .00     .00
9C        21.00 .535 18.75   -5.972 2.08    -.99 .722    8.58    2.08     .00     .00
10C       21.10 .534 18.87   -6.071 2.03    -.84 .722    8.61    1.95     .00     .00
11C       20.90 .533 18.40   -5.400 2.39  -1.53 .709    8.35    1.69     .00     .00
12C       21.00 .522 17.64   -4.611 2.97    -.71 .632    7.33     .91     .00     .00
1S        21.10 .536 18.97   -6.344 1.92    -.62 .727    8.69    2.21     .00     .00
2S        21.20 .535 18.80   -5.736 2.20  -1.01 .712    8.54    1.95     .00     .00
3S        21.10 .535 18.95   -6.241 1.96    -.77 .727    8.68    1.95     .00     .00
4S        21.20 .529 18.40   -5.060 2.61  -1.49 .688    8.16    1.30     .00     .00
5S        21.10 .538 18.98   -6.306 1.94    -.80 .731    8.78    2.47     .00     .00
6S        21.00 .536 18.73   -5.948 2.10    -.95 .720    8.57    1.95     .00     .00
1T        20.80 .536 18.39   -5.554 2.31  -1.39 .713    8.40    1.95     .00     .00
2T        20.70 .535 18.18   -5.302 2.47  -1.78 .709    8.31    1.69     .00     .00
3T        20.80 .524 17.66   -4.612 2.99  -1.70 .660    7.61     .91     .00     .00
4T        20.90 .523 18.26   -5.013 2.62  -2.42 .712    8.23    1.56     .00     .00
5T        20.80 .535 18.57   -5.928 2.10  -1.16 .725    8.53    2.34     .00     .00

AVERAGES: 80601  BASELINE W097 00 000
          22.02 .549 19.93   -6.709 1.82    -.34 .732    9.36    3.69     .00     .00
  STD       .07 .000   .17     .313  .12     .16 .008     .13     .24      *       *
            80601 W125M0004
          21.02 .534 18.57   -5.640 2.30  -1.23 .709    8.42    1.79     .00     .00
  STD       .16 .004   .41     .581  .35     .50 .024     .36     .39      *       *
PERCENT  OF BASELINE
          95.5  97.3   93.2   115.9    126 *****   96.9    90.0    48.4  *****   *****
 STD%      1.1    .9    2.9    13.0     29 387.9    4.4     5.1    14.5  *****   *****
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80602 W126MULTI001 W097 00 000
SOL9              AM1: PO=91.60MW/CM©2  NO AR COATING

ID        ISC    VOC   IP      LOG(IO)   N      R     FF     Eff    OCD    PCDa   PCDb

2R*      21.90 .558 20.06   -7.244 1.67   -.55 .758   9.79    .00    .00    .00
1B*      21.60 .545 19.29   -6.001 2.10   -.86 .720   8.96   3.64    .00    .00
2B       21.90 .548 19.90   -6.893 1.75   -.36 .740   9.39   4.68    .00    .00
3B*      21.70 .550 19.65   -7.019 1.72    .42 .719   9.07   4.55    .00    .00
4B       21.60 .550 19.85   -7.604 1.55   -.18 .756   9.50   4.94    .00    .00
1C       19.30 .532 17.37   -6.566 1.83   -.14 .719   7.80   1.30    .00    .00
2C       19.90 .530 17.78   -6.217 1.96   -.34 .711   7.93   1.30    .00    .00
3C       19.70 .528 17.43   -5.870 2.12   -.38 .697   7.66   1.04    .00    .00
4C       19.50 .530 17.63   -6.783 1.75   -.10 .726   7.93   1.30    .00    .00
5C       19.90 .525 17.29   -5.220 2.49  -1.02 .680   7.52    .91    .00    .00
6C       19.90 .529 17.72   -6.028 2.04   -.59 .710   7.91   1.30    .00    .00
7C       19.70 .529 17.63   -6.135 1.99   -.87 .723   7.97   1.30    .00    .00
8C       19.70 .532 17.65   -6.217 1.97   -.67 .721   7.99   1.30    .00    .00
9C       19.60 .529 17.47   -5.968 2.07   -.94 .717   7.86   1.30    .00    .00
10C      19.90 .529 17.75   -6.013 2.05   -.83 .717   7.98   1.17    .00    .00
11C      19.90 .529 17.86   -6.387 1.89   -.33 .718   7.99   1.30    .00    .00
12C      19.60 .523 16.98   -5.089 2.58  -1.38 .681   7.38    .91    .00    .00
13C      19.50 .525 17.02   -5.340 2.42  -1.06 .687   7.44    .91    .00    .00
1S       20.00 .533 17.59   -5.485 2.35  -1.21 .701   7.90   1.30    .00    .00
2S       20.00 .532 17.91   -6.218 1.97   -.62 .720   8.10   1.56    .00    .00
3S       19.90 .532 17.76   -6.038 2.05   -.83 .718   8.04   1.56    .00    .00
4S       20.00 .530 17.63   -5.582 2.28  -1.06 .702   7.87   1.30    .00    .00
5S       20.20 .530 17.93   -5.857 2.13   -.80 .709   8.03   1.30    .00    .00
1T       19.40 .532 17.53   -6.689 1.79   -.30 .728   7.95   1.43    .00    .00
2T       19.50 .528 17.23   -5.679 2.22  -1.01 .705   7.67   1.04    .00    .00
3T       19.20 .530 16.95   -5.873 2.13   -.18 .690   7.43   1.17    .00    .00
4T       19.50 .526 17.10   -5.389 2.39  -1.38 .699   7.59   1.04    .00    .00
5T       19.30 .525 16.89   -5.383 2.39  -1.18 .693   7.42    .91    .00    .00

AVERAGES: 80602  BASELINE W097 00 000
         21.75 .549 19.88   -7.249 1.65   -.27 .748   9.45   4.81    .00    .00
  STD      .15 .001   .02     .356  .10    .09 .008    .05    .13     *      *
          80602 W126MULTI001
         19.70 .529 17.48   -5.914 2.12   -.75 .708   7.80   1.22    .00    .00
  STD      .26 .003   .32     .456  .23    .39 .014    .23    .19     *      *
PERCENT OF BASELINE
         90.6  96.4  88.0   118.4   129  -75.8  94.6   82.6   25.3 ***** *****
 STD%     1.8    .7   1.7    10.6    22  276.9   2.9    2.9    4.7 ***** *****
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80530 W127FZ/TI001                                  W101 00 000 (4E13)
SOL9  8 /13/78   AM1: P0=91.60MW/CM©2  NO AR COATING

ID       ISC   VOC   IP    LOG(IO)   N     R     FF     Eff    OCD   PCDa   PCDb

2R*      21.90 .556 19.95  -6.826 1.80   -.87 .754   9.71    .00   .00    .00
1B       22.30 .545 19.87  -5.844 2.17  -1.07 .721   9.27   3.64   .00    .00
2B*      22.30 .539 19.00  -4.465 3.20  -2.59 .679   8.63   2.47   .00    .00
3B       22.30 .546 19.76  -5.580 2.32  -1.36 .717   9.23   3.64   .00    .00
4B*      21.70 .535 18.34  -4.358 3.32  -2.62 .667   8.19   2.08   .00    .00
5B*      22.30 .541 19.40  -4.990 2.71  -1.91 .699   8.91   3.25   .00    .00
1CB      22.60 .547 20.05  -5.722 2.24   -.97 .712   9.31   3.51   .00    .00
2CB      22.60 .547 20.53  -6.833 1.76   -.39 .740   9.67   4.42   .00    .00
3CB      22.80 .548 20.51  -6.300 1.97   -.65 .729   9.63   3.77   .00    .00
4CB      22.60 .546 20.11  -5.765 2.21  -1.12 .719   9.39   4.42   .00    .00
5CB*     22.90 .543 19.67  -4.692 2.97  -2.01 .682   8.97   2.99   .00    .00
1C       14.20 .466 12.40  -5.835 1.95    .43 .667   4.67    .65   .00    .00
2C       14.10 .463 12.29  -5.746 1.99    .26 .666   4.60    .39   .00    .00
3C       14.40 .464 12.57  -5.703 2.01   -.13 .673   4.76    .65   .00    .00
4C       14.30 .463 12.56  -5.949 1.88    .27 .676   4.73    .52   .00    .00
5C       14.20 .462 12.46  -5.949 1.88    .32 .675   4.68    .91   .00    .00
6C       14.30 .462 12.58  -6.032 1.84    .39 .677   4.73    .78   .00    .00
7C       14.20 .459 12.38  -5.713 1.98    .12 .668   4.60    .78   .00    .00
8C       14.20 .460 12.46  -5.931 1.88    .32 .674   4.66    .78   .00    .00
1S       14.30 .462 12.45  -5.702 2.00    .25 .664   4.64    .52   .00    .00
2S       14.30 .463 12.48  -5.759 1.98    .22 .668   4.68    .65   .00    .00
3S       14.20 .463 12.44  -5.941 1.89    .51 .670   4.66    .78   .00    .00
4S       14.20 .460 12.41  -5.800 1.94    .24 .669   4.62    .78   .00    .00
5S       14.50 .460 12.54  -5.520 2.09    .15 .657   4.64    .65   .00    .00
1T       14.00 .460 12.23  -5.831 1.93    .34 .668   4.55   2.21   .00    .00
2T       14.30 .462 12.45  -5.702 2.00    .25 .664   4.64    .78   .00    .00
3T       14.40 .462 12.57  -5.789 1.95    .35 .667   4.69    .65   .00    .00
4T       14.30 .459 12.41  -5.569 2.06   -.03 .664   4.61    .78   .00    .00

AVERAGES: 80530  BASELINE W101 00 000
         22.53 .547 20.14  -6.007 2.11   -.93 .723   9.42   3.90   .00    .00
  STD      .18 .001   .29    .431  .19    .32 .009    .17    .38   *      *
               80530 W127FZ/TI001 WITH CZ BASES ADDED CB
         14.26 .462 12.45  -5.792 1.96    .25 .669   4.66    .78   .00    .00
  STD      .11 .002   .09    .135  .06    .15 .005    .05    .38   *      *
PERCENT OF BASELINE
         63.3  84.5  61.8  103.6    93  227.0  92.5   49.4   20.0 ***** *****
 STD%     1.0    .5   1.4    9.3    12   31.2   1.9    1.5   12.6 ***** *****
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80603 W128TA002 W097 00 000 (8E11)
SOL9  8 /10/78    AM1: PO=91.60MW/CM©2  NO AR COATING

ID        ISC   VOC   IP    LOG(IO)  N      R      FF     Eff    OCD    PCDa   PCDb

2R*       21.90 .556 19.87   -6.535 1.90 -1.15 .752    9.69    .00    .00    .00
1B        21.80 .550 19.93   -7.124 1.68  -.60 .755    9.58   4.16    .00    .00
2B.*      21.90 .547 19.37   -5.513 2.37 -1.49 .716    9.07   3.38    .00    .00
3B*       16.10 .185 11.02  -12.761  .28  7.29 .356    1.12    .00    .00    .00
4B.*      21.90 .543 19.02   -4.924 2.78 -2.13 .699    8.79   2.86    .00    .00
5B        22.10 .549 20.18   -6.960 1.73  -.80 .757    9.72   4.42    .00    .00
1C        21.60 .547 19.71   -7.122 1.67  -.37 .748    9.34   2.99    .00    .00
2C        21.10 .546 18.76   -5.704 2.26 -1.44 .722    8.80   3.12    .00    .00
3C        21.30 .546 19.15   -6.292 1.97  -.70 .730    8.98   2.99    .00    .00
4C        21.50 .547 19.66   -7.277 1.63  -.23 .748    9.30   3.51    .00    .00
5C        21.40 .546 19.55   -7.163 1.66  -.39 .750    9.26   3.51    .00    .00
6C        21.30 .546 19.30   -6.711 1.81  -.51 .738    9.08   3.51    .00    .00
7C        21.30 .546 19.33   -6.794 1.78  -.46 .739    9.09   3.51    .00    .00
8C        21.50 .544 19.39   -6.371 1.93  -.91 .738    9.12   3.25    .00    .00
9C        21.40 .546 19.44   -6.894 1.75  -.36 .739    9.14   2.60    .00    .00
10C       21.40 .537 18.21   -4.542 3.12 -2.21 .670    8.14   3.38    .00    .00
11C       21.40 .540 19.18   -6.185 2.00  -.72 .724    8.85   1.82    .00    .00
12C       21.50 .545 19.13   -5.802 2.20 -1.16 .720    8.92   2.60    .00    .00
1S        21.30 .550 19.38   -6.917 1.75  -.47 .744    9.21   3.51    .00    .00
2S        21.30 .544 18.42   -4.833 2.87 -2.25 .693    8.49   2.86    .00    .00
3S        21.40 .546 18.93   -5.554 2.35 -1.42 .715    8.83   2.99    .00    .00
4S        21.40 .548 19.36   -6.573 1.87  -.67 .738    9.15   3.12    .00    .00
5S        21.50 .546 19.42   -6.510 1.88  -.67 .736    9.13   3.12    .00    .00
1T        21.30 .547 18.40   -5.093 2.67  -.86 .670    8.26   2.60    .00    .00
2T        21.20 .549 19.43   -7.394 1.60  -.33 .755    9.29   3.25    .00    .00
3T        21.30 .546 18.88   -5.652 2.29 -1.28 .715    8.80   1.56    .00    .00
4T        21.60 .537 18.56   -4.834 2.83 -1.53 .674    8.26   3.25    .00    .00
5T        21.40 .547 19.43   -6.781 1.79  -.54 .741    9.18   2.99    .00    .00

AVERAGES: 80603   BASELINE W097 00 000
          21.95 .550 20.05   -7.042 1.71  -.70 .756    9.65   4.29    .00    .00
 STD        .15 .001   .12     .082  .02   .10 .001     .07    .13     *      *
          80603 W128TA002
          21.38 .545 19.14   -6.227 2.08  -.89 .725    8.94   3.00    .00    .00
 STD        .12 .003   .42     .837  .43   .57 .025     .35    .51     *      *
PERCENT  OF BASELINE
          97.4  99.2  95.4    111.6  122  72.9  95.8    92.6   70.0 ***** *****
 STD%      1.2    .7   2.7     13.0   28 112.2   3.5     4.3   14.3 ***** *****
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