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# ANALYSIS AND EVALUATION IN THE PRODUCTION PROCESS AND EQUIPMENT AREA OF THE LOW-COST SOLAR ARRAY PROJECT

Quarterly Report for January—April 1979



By
H. Goldman
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June 1979

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# U.S. Department of Energy

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# ANALYSIS AND EVALUATION IN THE PRODUCTION PROCESS AND EQUIPMENT AREA of the LOW-COST SOLAR ARRAY PROJECT



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The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DoE.

## ABSTRACT

Significant economic and technical data on the current front junction formation processes of Spectrolab's gaseous diffusion, and of involving the Varian-Extrion 200-1000 implanter were tabulated, and were used to judge the feasibility of diffusion proposals by Motorola and RCA and ion implantation proposals by Lockheed, Motorola, RCA, and Spire to meet future LSA-JPL guidelines. Cost calculations, consistent with the SAMICS methodology, were performed for the junction formation processes studied.

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# INTRODUCTION

The manufacturing methods for photovoltaic solar energy utilization systems consist, in complete generality, of a sequence of individual processes. This process sequence has been, for convenience, logically segmented into five major "work areas": Reduction and purification of the semiconductor material, sheet or film generation, device generation, module assembly and encapsulation, and system completion, including installation of the array and the other subsystems. For silicon solar arrays, each work area has been divided into 10 generalized "processes" in which certain required modifications of the work-in-process are performed. In general, more than one method is known by which such modifications can be carried out. The various methods for each individual process are identified as proces "options". This system of processes and options forms a two-dimensional array, which is here called the "process matrix".

In the search to achieve improved process sequences for producing silicon solar cell modules, numerous options have been proposed and/or developed, and will still be proposed and developed in the future. It is a near necessity to be able to evaluate such proposals for the technical merits relative to other known approaches, for their economic benefits, and for other techno-economic attributes such as energy consumption, generation and disposal of waste by-products, etc. Such evaluations have to be as objective as possible in light of the available information, or the lack thereof, and have to be periodically updated as development progresses and new information becomes available. Since each individual process option has to fit into a process sequence, technical interfaces between consecutive processes must be compatible. This places emphasis on the specifications for the work-in-process entering into and emanating from a particular process option.

The objective of this project is to accumulate the necessary information as input for such evaluations, to develop appropriate methodologies for the performance of such techno-economic analyses, and to perform such evaluations at various levels. The first application of this developing methodology was made to the Czochralski's crystal pulling process.

Previously, the reduction of quartzite to metallurgical grade silicon was examined, and comparative evaluations of competing Czochralski techniques for growing single crystal, cylindrical ingots, and of slicing processes to produce single crystal, silicon wafers were perfromed. The next "work area" for producing solar arrays is the fabrication of the silicon wafers to solar cells. This process involves many steps with one of them being front junction formation. One of the major current junction forming processes, gaseous diffusion, was examined. In addition, future proposals, which include modifying gaseous diffusion and using ion implantation, to decrease the cost of junction formation, in order to meet future LSA-JPL price goals, were studied.

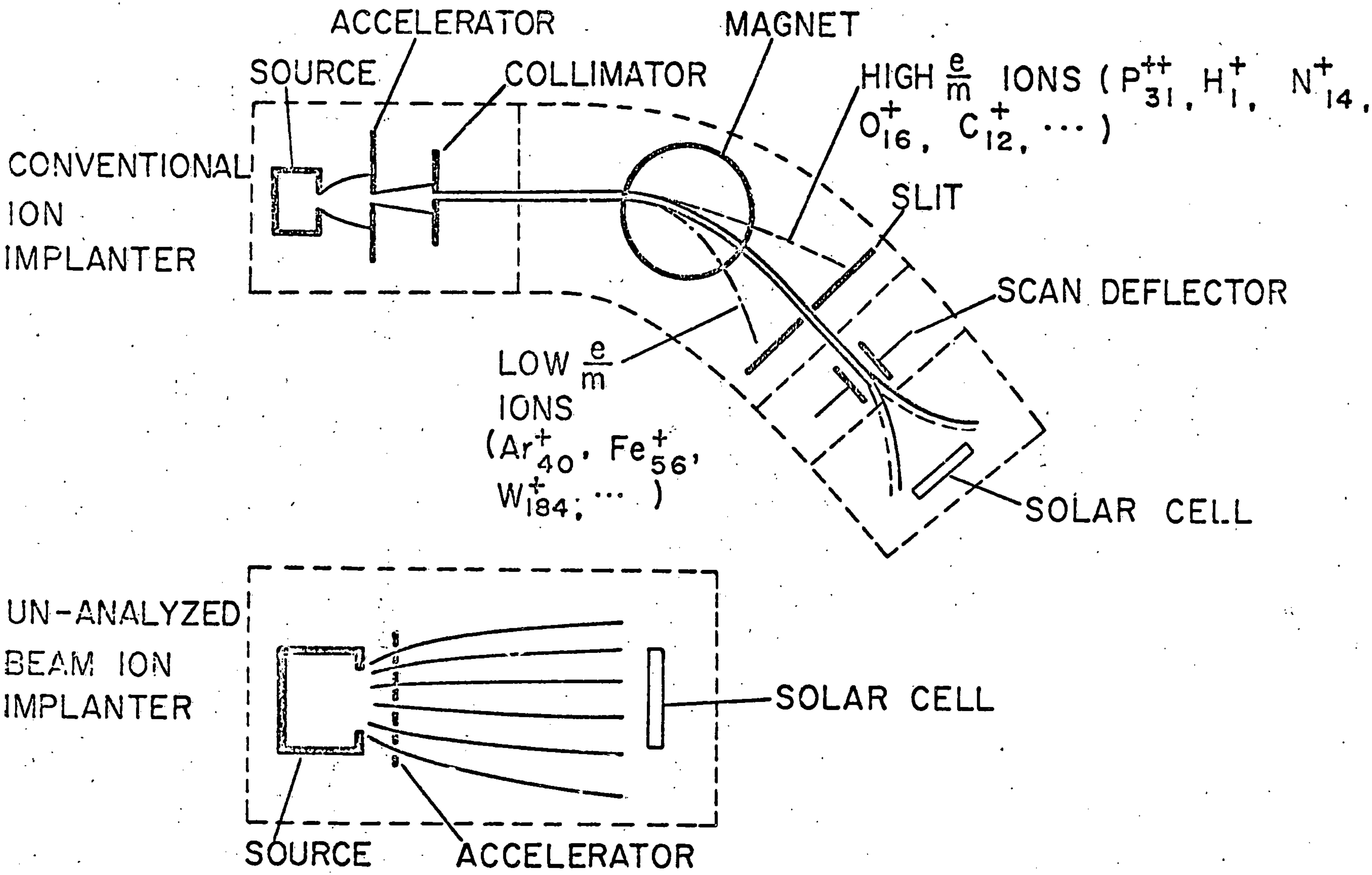
As with our crystal growing and slicing studies the evaluations were started with the current methods of gaseous diffusion, and ion implantation for which a large amount of the needed information is available. Nevertheless, substantial gaps or uncertainties were found in important information required for both technical and economical evaluation of the currently practiced processes. In proceeding to the evaluation of processes which are still in the developmental or even conceptual stage, the gaps in needed information become very large. In these cases, it is necessary to fill the gaps more extensively with estimates based on extrapolations or analogies. Such estimates always leave some doubt on the accuracy of the evaluations, and it will be necessary to also make "probable error" estimates to reduce decision mistakes based on early evaluations. Nevertheless, collecting the information and carrying our evaluations at the earliest possible time provides not only a planning tool, but also aids in uncovering the deciding attributes about which information ought to be obtained at an early stage of the development process.

For the gaseous diffusion process, we have tabulated production experience data from Spectrolab [1] and projections made by Motorola[2] and RCA.[3] In our studies of of ion implantation of PN junctions, experimental data from Spire [4] using a modified Varian-Extrion machine along with material, labor, and capital projections made by Lockheed [5], Motorola,[6] and Spire[4] for their proposed machines were examined.

A. Principals and Application of Ion Implantation

Ion implantation is a method for introducing dopant material below the semiconductor surface to form PN or high/low junctions. In the common type of ion implantation machine, the source material, usually a chemical compound containing the dopant, is broken down and ionized under electron bombardment in the ionization chamber, the ions are extracted from this chamber by an electric field and further accelerated and collimated, purified using a mass spectrometer, and then scanned either electrically, magnetically, or mechanically while impinging on the semiconductor wafer to be implanted. The top portion of Figure 1 shows a schematic presentation of such an ion implanter with a magnetic analyzer. In simpler machines, as shown in the bottom part of Figure 1, functions such as beam collimation, mass analysis, or scanning may be omitted.

In the machine shown in the top part of Figure 1, the source material can be ionized in a number of ways, the principal ones of which are: heating and electron bombardment of the source material from a high temperature emitter, called the "hot cathode source"; electron discharge from a low work function emitter, such as barium, under the influence of a strong electric field, into the vaporized source material to form a plasma (cold cathode source); or by microwave discharge. In any of the mentioned sources, a magnetic field can be applied to concentrate the plasma density and increase the




PRINCIPLES OF ION IMPLANTER DESIGN

FIGURE 1

efficiency of ionization. This will also result, though, in lower source lifetime and a larger energy spread of the ions.

Three principal types of hot cathode ion sources are used in the implanters mentioned in this report. In all, the current density from a metal surface at temperature T with a work function of $\Phi$ is principally described by:

$$j_e = AT^2 e^{-e\Phi/kT} \tag{2.1}$$

However, at adequately high emission rates, the current density $j_e$ is usually reduced below the value given by Eq. (2.1) because of space-charge effects, in which the mutual repulsion of the electrons crowding the space near the filament inhibits further emission. The electron density then becomes:

$$j_e = \frac{V^{2/3}}{9\pi d^2 \ (m/2e)^{1/2}} \tag{2.2}$$

where V is the voltage between the cathode and anode, d is the thickness of the electron sheath and m/e is the electron's mass to charge ratio. The production of positive ions in the source chamber tends to neutralize this "electron cloud" and reduce the space charge effects. The cathode current thus increases in the presence of positive ions.

In the "Freeman source", the heated wire cathode has its terminals on opposite sides of the "extraction gap" through which the ions leave. In the "Chavet source", the filament wire is looped so that its electrodes are on the same side of the extraction gap. The Chavet filament configuration was designed to increase the filament's lifetime by decreasing its exposure to the back-streaming ions and thus reduce the sputtering caused by them. Another thermionic source is the hollow cathode in which the interior of a cylindrical cavity is coated with a low work function material, such as barium oxide. Upon introduction of the vaporized source material, an arc discharge takes place between the cathode and anode so that the source material is ionized. As a result of applied high voltage, the ions are extracted through a hole in the cathode. Vaporized atoms also pass through this aperture. They are subsequently ionized by the accelerated electrons. One configuration of a cold cathode source known as the "Penning source", has an anode that is also cylindrical in shape with the end plates forming the cathode. In addition, a magnetic field is applied parallel to the cylindrical axis of the "Penning source" to force electrons from the cathode to form helical trajectories, thus increasing their path length and enhancing the ionization efficiency.

After the ion beam is extracted from the source chamber, it is accelerated through a potential drop. For small acceleration energies ($<30$ keV), a single gap electrode could be used. The accelerated ion beam is then subjected to a magnetic field for mass separation. A singly charged ion of atomic mass M (AMU's) moving through a magnetic field with strength B (in gauss) will be deflected into a circular path with the radius of curvature equal to

$$R = \frac{143.95}{B} (MV)^{1/2} \text{ cm}, \qquad (2.3)$$

where V is the acceleration voltage. The dispersion between ions of two different masses is

$$D_M = \frac{\Delta M}{M} R \text{ cm} . \qquad (2.4)$$

In order to achieve good mass resolution, power supplies to the acceleration and magnet regions must have stabilities of 1 part in 10,000.

To form the junction, the analyzed beam is then scanned, with one of the techniques mentioned previously, on the silicon substrate. Overscanning is necessary because of the tails in the Gaussion distribution of the ion concentration in the beam.

Junction formation using ion implantation offers several potential advantages over the diffusion process. It is a dry, vacuum process, thus avoiding potential contamination from impurities contained in spin-on or gaseous vehicles for the dopants used in some varieties of the diffusion process. Where selective introduction of the dopant is wanted, this may be accomplished without application of masking and subsequent stripping, and without back-surface etching because of double-sided impurity penetrations. Thus, ion implantation can involve fewer handling or transferring operations than the diffusion process, and consequently can result in labor savings and increased yields. However, ion implantation requires an annealing step, which will be further discussed later on. It has been suggested[8] to use ion implantation as an integral part of a total vacuum process sequence for fabricating solar cells after wafer or sheet generation. Such a sequence, although high in capital costs, could result in labor savings and high yields.

The charge on the dopant ions allows for mass-spectroscopic separation using magnetic fields, and for accurate measurement of the ion flux entering the deposition region, as long as neutral and doubly charged particles are handled correctly. The ion beam currents can be readily measured by placing a Faraday cup in the beam's path, but this requires a preceding calibration to determine the fraction of uncharged and doubly charged ions. The mass analysis and ion current measurement features of the ion implantation process can provide better control over the quantity and quality of the dopant than other processes, and can therefore be applied to obtain better process uniformity and repeatability. Dose uniformities of $\pm$ 5% ($2\sigma$) are achievable[9].

Since ion implantation can be performed at or near room temperature, low energy implantations can result in original dopant penetration of less than 100Å, shallower than can be achieved in most high temperature source deposition steps in the diffusion process.

Upon entering the substrate, the dominant interactions of the ion are with the electrons of the lattice, which slow the ion down through kinetic energy transfer. After this initial slow-down to sufficiently low energies, i.e., ion velocity less than $Z_i e^2/\hbar$, collisions of the ion take place with the nuclei which completely stop the ion. In most cases, the stopped ion rests interstially in the crystal lattice. The largest impurity concentration is thus found at a penetration distance, "$x_p$", from the surface. As a first approximation in the region where nuclear collisions dominate, the penetration depth is proportional to the square root of the ion beam energy. This penetration depth is described by:

$$x_p = \frac{0.7\ (Z_I^{2/3} + Z_{Si}^{2/3})}{Z_I Z_{Si}} \cdot \frac{M_I + M_{Si}}{M_I} E_I\ (\text{Å}). \quad (2.5)$$

$E_I$ is the energy of the ion beam in eV, Z and M refer to the atomic number and atomic weight, respectively, while the subscripts I and Si refer to the ion and to Si, respectively. The concentration varies from the penetration distance approximately according to a Gaussian distribution and the impurity distribution can be described by the empirical relationship,

$$C(x) = C_p \exp\ (-(x-x_p)^2/2\ \sigma_R^2). \quad (2.6)$$

$C_p$ is the concentration at the penetration distance, and $\sigma_R$ is called the standard deviation of the concentration function, or the distance from $x_p$ at which the concentration is equal to $C_p/\sqrt{e}$. The peak concentration depends upon the ion beam current (i) and the implantation time (t) or

$$C_p = \frac{10^{16} i \cdot t}{4\ \sigma_R}\ \text{cm}^{-2}. \qquad (2.7)$$

The unit of i is mA, that of t is seconds, and $\sigma_R$ is is given in μm.

The penetration distance can be calculated from electron and nuclear ionic collisions only if "channeling" does not occur. Channeling is the name given to the considerably enhanced penetration distance of ions which are aligned in low index crystallographic directions, and therefore travel parallel to and in between high atomic density crystal planes. Since ions travelling this path experience relatively fewer collisions with silicon atoms, they can travel further into the silicon. To avoid channeling, the beam must be oriented at a slight angle (~7°) from the orientation of the low index crystallographic axes. This increases the apparent distribution of atoms in the crystal plane normal to the ion beam's path, and thus increases the probability of ion-nucleur collisions.

The implantation process results in the displacement of the silicon atoms from their normal lattice sites by the ion collisions, thus creating "vacancies" and "interstitials". The implanted impurity atoms, predominately located at interstitial sites, and are not electrically active. Thus few impurity atoms which take up substitutional positions, tend to compensate the originally present impurity atoms of opposite dopant type, and thus to shift the Fermi level of the silicon towards the center of the energy gap. Annealing of the ion implanted wafers is thus required both to reduce the mentioned crystal structure damage resulting from the implantation process, some of which is electrically active (recombination and trapping centers), and to electrically "activate" the dopant impurity by moving its implanted atoms from interstitial to substitutional sites.

Even though thermal annealing broadens the impurity profile as far or more than obtained by use of relatively low temperature, short time diffusion as used for solar cell production, it is the only annealing process reported so far that produces ion implanted cells with efficiencies equivalent to those prepared using diffusion. A thermal annealing cycle of 1h at 450°C and 0.5h at 850°C has been found to result in performance-wise competitive silicon solar cells.[10] This, in part, negates the potential advantage of ion implantation, which exists in being able to control the dopant profile at will by changing the implantation energy and dosage together. Such "designed profiles" could lead to higher efficiency solar cells. Electron and laser beam annealing have therefore been and are being investigated because of this as well as several other anticipated advantages. These have, however, so far not been realized, and cells with efficiencies comparable to those obtained by the oven annealing process have so far not been reported. If a suitable annealing process could be found that would limit the junction movement of ion implanted cells and simultaneously provide good impurity activation and healing of implantation-induced crystal damage, so that ion implanted solar cells might attain higher efficiencies than cells prepared by diffusion processes, then ion implantation would become a most interesting process option, even at a possibly somewhat higher process cost than diffusion.

With an efficiency advantage of the ion implanted solar cells not yet achieved over the diffusion produced cells, the potential application of ion implantation, as part of a LSA solar cell sequence will be primarily determined by the degree of cost reductions that can ultimately be attained. Currently, the high capital costs, the low reliability, and the low throughput rate of ion implantation machines, make junction formation with them too costly to be used for large scale solar cell production. Large cost reductions are, however, expected to be accomplished in the future (1986) by several approaches. Approaches to this end include the introduction of large throughput machines with high current, hot cathode ion beam sources incorporating an analyzer and more automated operation through computer control [7], and the development of ion implanters with unanalyzed or roughly analyzed ion beams [6,11] using hollow cathode sources. Some current and future applications of ion implantation are listed in Table I along with the conditions contingent to the two potential advantages of lower cost and higher efficiency.

## EVALUATION OF ION IMPLANTATION FOR LSA PRODUCTION

| APPLICATION | STATUS | PRINCIPAL ALTERNATE PROCESSES |
|---|---|---|
| PN JUNCTION FORMATION | PROVEN; PERFORMANCE EQUAL DIFF'D JCTN. | DIFFUSION<br>CVD/ EPI |
| BSF OR BACK HI/LO JCTN. | CONCEPTUAL | THICK FILM/ALLOYING ; DIFFUSION; CVD/ EPI |
| FSF OR FRONT HI/LO JCTN | EFFECTIVENESS NOT YET PROVEN | DIFUSSION<br>CVD/EPI |
| CONTACT METALLIZATION | CONCEPTUAL | THICK FILM<br>ELECTROLESS PLATING<br>VACUUM EVAPOR'N<br>SPUTTERING |

## ION IMPLANTATION FOR PN-JUNCTION FORMATION

| CONCEIVED ADVANTAGES | CONDITIONS | STATUS |
|---|---|---|
| LOWER COST | LIKELY ONLY IN SEQUENCE WITH OTHER VACUUM PROCESSES | TECHNOLOGY ADVANCEMENTS REQUIRED. |
| HIGHER CELL PERFORMANCE THAN ACHIEVABLE BY ALTERNATE PROCESSES | DEPENDS ON SUPERIOR IMPURITY PROFILE, FEWER CRYSTAL DEFECTS | STILL TO BE DEMONSTRATED |

Table I

B. Appraisal of Present-day Ion Implanters

Ion implantation is currently used in semi-conductor industry production activities for implanting, in solid state devices, impurities of low dosage and relatively deep penetration (high energy). In order to gather information on the current state of production line ion implantation, we visited, among others, RCA-Somerville, where a Varian-Extrion 200-1000 ion implanter is used for integrated circuit manufacture, as well as for solar cell[12] fabrication in pilot operations. Implantations are routinely performed at beam currents ranging from 0.1 μA to 1.5 mA, at voltages up to 100 kV, alternatingly with $P^+$, $B^+$ and $As^+$ ions, in a 24 hour-a-day schedule of 5 to 7 days-a-week.

The Varian-Extrion 200-1000 ion implanter is available with a semi-automatic cassette wafer feeding mechanism that allows continuous processing, increasing its output rate to 300, 7.62-cm round wafers per hour. In order to achieve this output rate, the ion implanter also has to be modified to operate in a high current (4 mA), low voltage (<25 keV) mode. These options are included in a Varion-Extrion 200-1000 implanter in operation at Spire.[2] Additional options provide an off-axis beam tilt to minimize channeling. To achieve dose uniformity and avoid shadowing from a tilted beam on a texture-etched surface, the wafer is rotated about its axis at 1 rev/sec.

The cost of such a machine is approximately $315,000 and it requires one full-time operator. To achieve acceptable machine operation, the RCA personnel have found it necessary to have a skilled technician stationed within the immediate vicinity of their ion implanter at all times, and to make adjustments in the machine operating parameters quasi-continuously. They believe that computer controlled functions, similar to those proposed by Spire[7] in their ion implanter design, could considerably reduce the need for continuous skilled attendance. They mentioned, however, that designing adequate computer controls might be difficult since, so far, adequate sensing of the status of all parts of the machine and of the parameters affecting its operation does not exist. Thus, correctly operating the ion implanter is still more of an art than a science and requires the adjustment of many functionally interrelated controls. Similar statements were variously heard, summarized by Varian-Extrion personnel in the remark that successful machine operation depends very heavily on the operator, and that wide variations are experienced among the various users. RCA personnel has found that leakage from the high voltage machine elements, in part due to condensed source material, tends to interfere with the sensitive dose rate measurements and the machine control. Other problems resulted from persistent leakage of cooling fluid which could be reduced by the use of freon in lieu of the more common deionized water, albeit at significantly higher costs for the make-up fluid.

One of the major problems mentioned at RCA and elsewhere, is the deposition on many parts of the machine of atoms of the implanted species as well as of material sputtered off the various parts of the source. Arsenic is especially troublesome in this respect because of its relatively low vapor pressure compared to other implanted species. This deposition occasionally results in electrical malfunctions, such as shorting of insulators and arcing, which occasionally has led to power supply or logic board damage. The machine, therefore, requires frequent thorough cleaning of the affected regions. Phosphorus also condenses on the machine's interior, and we have heard of short phosphorous fires upon opening the machine.

Much of the unscheduled maintenance is performed under service contracts. RCA personnel mentioned that such a service contract with Varian-Extrion has an annual cost of $13,000. This contract provides the so-far extensive on-location servicing by Varian-Extrion personnel and replacement of failed parts, frequently circuit boards. RCA personnel estimates that about two-thirds of this money covers time and expenses of the service personnel, and the remainder replacement parts. RCA has recently introduced regular scheduled maintenance of their Varian-Extrion 200-1000 "high current" implanter for which 4 hours per week are allocated. During these maintenance periods, the machine interior is cleaned, filaments, if needed, are replaced, vacuum pump oils are changed, the machine inspected, and potentially unreliable parts identified and replaced. Since this institution of preventive maintenance, the previously frequent machine breakdowns have decreased to a tolerable level. At RCA, the experienced filament lifetime, as plotted on Figure 2, is in the 60 to 120 h range for an average ion beam current of around 0.75 mA, although much implantating is done with a 1 mA beam current.[12]

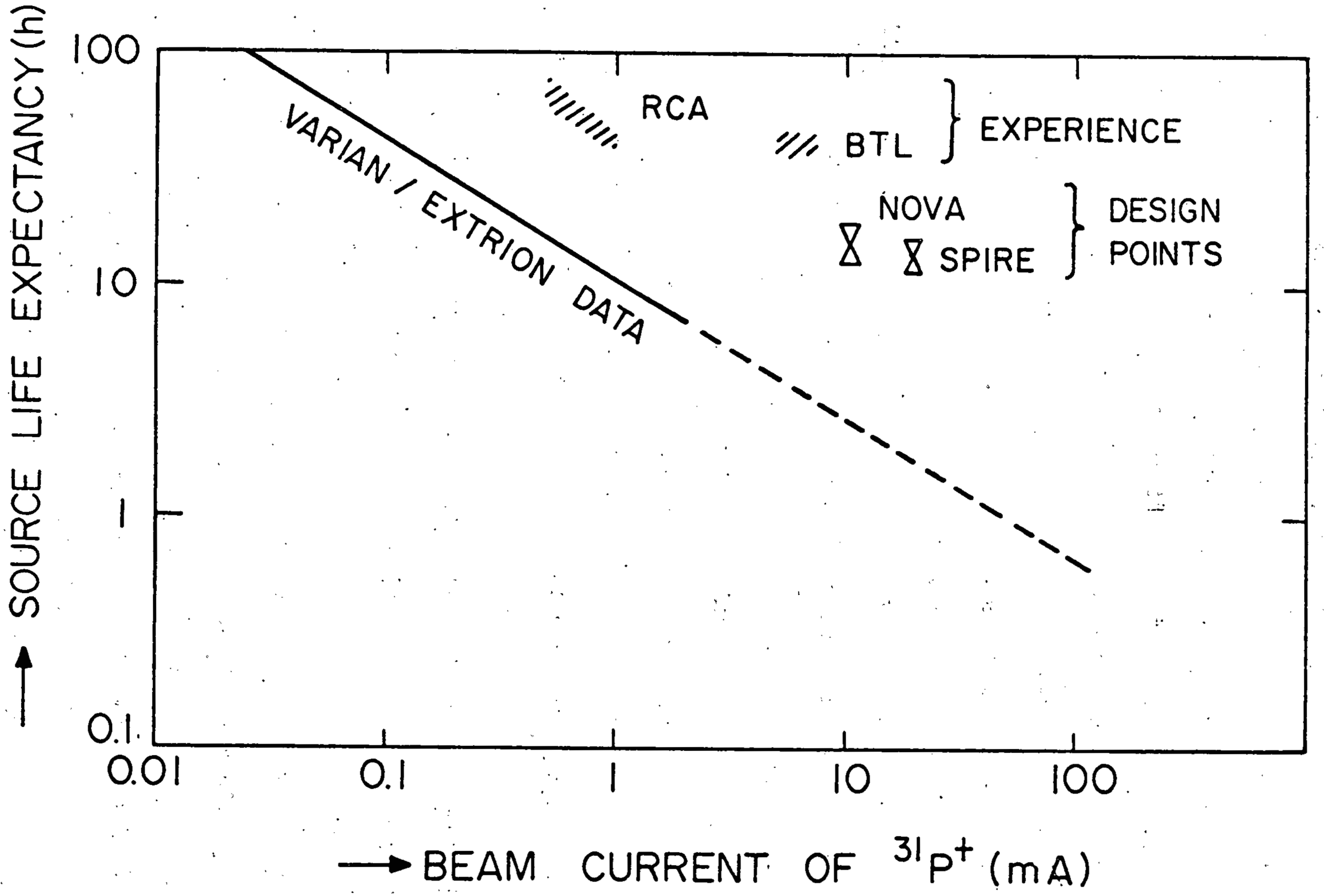

SOURCE LIFE EXPECTANCY (h)
100
10
1
0.1
0.01
0.1
1
10
100
BEAM CURRENT OF $^{31}P^{+}$ (mA)
VARIAN / EXTRION DATA
RCA
BTL
EXPERIENCE
NOVA
SPIRE
DESIGN POINTS

FIGURE 2

Because of the relatively frequent machine breakdowns of ion implanters, RCA's personnel have found it necessary to keep an extensive spare parts inventory, so that bad or suspicious parts can be replaced with minimal machine down time, in order to maintain production schedules and to reduce the impact on operating costs which are heavily influenced by the high cost of the equipment.

An ion implanter has been in operation at Western Electric since 1974 in a production line, high throughput mode. This implanter, called the PR-30, has an output rate of 450, 7.62-cm diameter wafers/h at a dosage of $1 \times 10^{15}$ ions/$cm^2$.(13) The machine can accomodate either a hot cathode, Freeman-type source, or a cold cathode (Penning) source. It operates in a low voltage (30keV) mode. In the case of the cold cathode source, a phosphorus current of 5 mA is obtained, with a source lifetime of 40 h.(14) The wafers (7.62-cm diameter) are placed on a disk, 30 at a time. The disk is mounted horizontally in the ion implanter. After pump down to $10^{-5}$ torr, which takes approximately 3 minutes, the disk is rotated at 900 rpm while the underside of the wafers is exposed to the fixed ion beam. The total time of each run is approximately 4 min.

The PR-30 is physically, a relatively small machine. The implantation unit, without controls, occupies a floor area of 1.8m x 2.1m. Two standard instrument racks house the control units. The PR-30 is used only in Western Electric factories, and it is not sold on the open market. We have been given an estimated price for this machine, if it could be marketed, of less than \$300,000.[15]

A high current (10 mA) and low voltage (10-50 keV) ion implanter, designated NV-10, is currently being readied by Nova Associates for introduction into the marketplace. The machine uses a Freeman, hot cathode source, with an expected lifetime of 16 h at 10 mA. The machine costs approximately \$410,000.[16] Its output rate for a $2 \times 10^{15}$ ions/cm$^2$ dosage of 270 wafers per hour of 7.62-cm diameter is limited by the wafer feed mechanism. If a faster feed mechanism could be installed, the output could be increased to 3-4 times the present one, to take better advantage of the machine's high beam current. The wafers are mounted, 18 at a time, in a disk that is rotated in a near vertical plane during implantation. The stationary beam is approximately 1cm x 2-3cm. As with the Western Electric implanter, wafer rotation eliminates the need for magnetic or electrical beam scanning.

An add-on process price of \$38.96/m$^{-2}$ for implanting phosphorus with a $1\text{-}2 \times 10^{15}$ ions/cm$^2$ dose was calculated for the modified Varian-Extrion 200-1000 machine. This price includes the cost of the silicon sheet lost-in-process. The sheet price used applies to silicon wafers which have been texture etched on one side. The slicing cost was taken from our previous study[17] of current production slicing costs (HAMCO ID data). The details of the price calculation for ion this process are shown in a UPPC format attached in the Appendix. The add-on process price for ion-implantation using the modified Varion-Extrion 200-1000 is low compared to other prices calculated for currently used ion implanters. For instance, the calculated add-on process price for the Varian-Extrion 200-20 A machine is $\$303.42/m^2$ (4) This high price is due to the machines's low throughput rate as it was designed for high voltage, low current (under 0.2 mA) operation. Its hourly output rate therefore is only 10 cells of 12-cm diameter.

It should be noted that the given add-on price calculation for the modified Varian-Extrion 200-1000 implanter is based on experimental, not production line data. Therefore, this value does not reflect the breakdown or maintenance problems experienced by ion implanters in production operations. However, reliable detail data are not yet available for the cost components of regular production ion implantation, since this process was only rather recently introduced as a production process. Still, if such data would be available, they would not represent the ultimately achievable costs, after machine and process maturity have been attained. While efforts are in progress to adapt the ion implanters better to production line operation by increasing their throughput rate, mechanizing their operation and improving their reliability, it will be some time before the process will be a mature production operation with similar costs experienced by the various users.

C. Ion Implantation and Diffusion

The application of ion implantation for PN or high/low junction formation in process sequences for future large scale LSA manufacture depends on the fulfillment of either of two conditions: 1.) its costs are equal to or lower than those for PN junction formation using diffusion or high/low junction formation using alloying or diffusion, possibly in combination with each other or with other process steps; or 2.) the performance of the solar cells fabricated by use of ion implantation is adequately higher than those prepared by other processes and is adequately higher to justify a higher price.

As diffusion is a major competitive process, we have examined the attributes and costs of present and projected future diffusion processes. In their current production operation, Spectrolab uses open-tube diffusion of phosphine diluted heavily in hydrogen to form a PN junction. Thanks to the data supplied generously by R. Oliver and E.L. Ralph of Spectrolab, (1) we have been able to make a detailed analysis of the present diffusion process as a baseline case, the results of which are contained in a UPPC format attached to the Appendix. The diffusion process takes approximately 35 minutes for a run containing 75 wafers of 7.62-cm diameter. We have observed that the process as performed by Spectrolab is very labor intensive. The reason is that only two diffusion furnaces are needed to handle the entire production, but one operator is needed to attend the process. Thus, this operator devotes most of his/her time to manually loading and unloading wafers onto and from the quartz diffusion boat, which could be done mechanically. If one assumes automatic wafer feeding, the operator's time could easily be reduced to 10 minutes per run, and the processing add-on price would be reduced to approximately $\$9.50/m^2$ from the present value of $\$12.74/m^2$ (SAMICS methodology).

Another significant cost contributor, and one that has been ignored in most projections for future diffusion processes, is that for cleaning the quartz furnace tubes and boats, which is usually done with a $HF-HNO_3-H_2O$ solution, as often as twice a day. Frequent quartzware cleaning has been found instrumental to maintaining high cell efficiency, but it contributes $\$2.23/m^2$ to the diffusion add-on price in the Spectrolab process. This price contribution was calculated assuming that the quartz cleaning operation requires 1 h/work day of labor, and a tube cleaning tower which costs $15,000 including installation, and which is shared between the two furnaces. About half of this cleaning cost contribution is due to equipment costs, with the remainder, listed in decreasing magnitude, shared between labor, facility, and material costs.

Future diffusion price projections, such as for Motorola's phosphine ($PH_3$) process,[2] also detailed in a UPPC format in the Appendix, are about a factor of four lower than present calculated prices ($\$3.10/m^2$ compared to

$\$12.74/m^2$). The Motorola process which has approximately the same wafer throughput rate as Spectrolab's current process, is applied to 12-cm diameter wafers, rather than 7.62-cm wafers in the Spectrolab process.

The 12-cm wafers have an area that is nearly 2.5 times larger than that of the 7.62-cm wafer, accounting for most of the cost difference between Motorola's and Spectrolab's diffusion processes. The rest of the cost difference can be attributed to the more automated nature of the Motorola process, requiring half-as-much labor as Spectrolab requires, and the lack of inclusion, by Motorola, for cleaning of the quartzware. On the other hand, notable are Motorola's projected use of significantly more energy and direct material (phosphine) than Spectrolab is consuming now.

Currently, the PN junction formation process by diffusion is not a large cost-contributing factor in cell processing. In application of the diffusion process, a separate annealing step is not required, at least not beyond a somewhat slowed cooling rate from diffusion temperature. A separate post-annealing step is, however, required after the ion implantation process to reduce the crystal damage resulting from implantation, and to activate the impurity species. Therefore, the annealing cost must be included in any cost analysis of ion implantation. Using a Thermco eight-tube diffusion furnace, which has an output rate of 1,000 12-cm diameter wafers/h, an add-on price of $\$1.18/m^2$

was calculated for the annealing process step. (For details, see the UPPC format attached in the Appendix.) If ion implantation is to replace diffusion, it may be able to become cost competitive only as part of a more extended sequence of vacuum processes, or by producing cells of significantly higher performance than achievable by the diffusion process.

D. Technology Development for Future Ion Implantation Machines

The realization of the 1986 cost projections for ion implantation is contingent on several improvements in the technology of ion implantation machines. For one, the ion beam current has to be increased significantly to achieve economically acceptable throughput rates. Also needed to be increased is the lifetime of the source, in terms of mAh's, to avoid excessive costs from changing and rebuilding the sources, as well as machine downtime. To reduce skilled labor requirements, the implanter's controls should be as automatic as possible. In addition, continuous or semicontinuous wafer feed, along with appropriate vacuum pumping mechanisms have to be employed. Also, care has to be taken in the mass analyses and the control of large current/small voltage ion-beams needed for solar cell fabrication, because space charge effects make those operations difficult. In some LSA process sequences, ribbon material is planned to be the substrate. Since rotation of elongated rectangular workpieces about their axis is impractical, other procedures to achieve uniform deposition have to be utilized in the future implanter, e.g., magnetic or mechanical beam scanning.

As mentioned previously, at present, PN junction formation using open tube diffusion is a small cost contributor to the solar cell module cost, constituting approximately 1%.[(18)] A replacement process for diffusions in future LSA process sequences would require lower costs, or yield higher performing cells, or offer a simplified fabrication sequence. Implantation costs are expected to be lowered dramatically by increasing the ion implanter's throughput rate from about 2 $m^2/h$ to nearly 200 $m^2/h$. To accomplish this, the total ion beam current, flux rate of ions impinging on the silicon, is expected to be increased from 4 mA to 100 mA. If multiple sources are used, then the ion beam current per source needs to be increased by a factor of 4 to 5. Increasing the beam current will, in general, increase the implanter's output rate in the same ratio. But, as shown on Figure 3, the increase in the machine's cost per unit beam current decreases with beam current. In Figure 3, the experienced machine cost per unit beam current is plotted as a function of the beam current together with an extrapolation to the future. The first four open circles reflect the costs of ion implantation machines that are in operation and the solid circles reflect projected data from the listed organizations.

In addition to larger ion sources, future implanters would have to be more reliable than current ones. The high capital cost of ion implanters necessitates their utilization rate to be as high as possible. Proposed future machines (Lockheed, RCA, Spire) have been projected to have utilization rates between 85-95% as opposed to today's 80%. For Motorola's unanalyzed ion beam implanter, the uptime fraction is not as significant because of its relatively low cost. The Motorola machine is expected to cost $85,000 as opposed to at least $500,000 for any of the other three proposed machines which employ analyzing magnets. One reliability

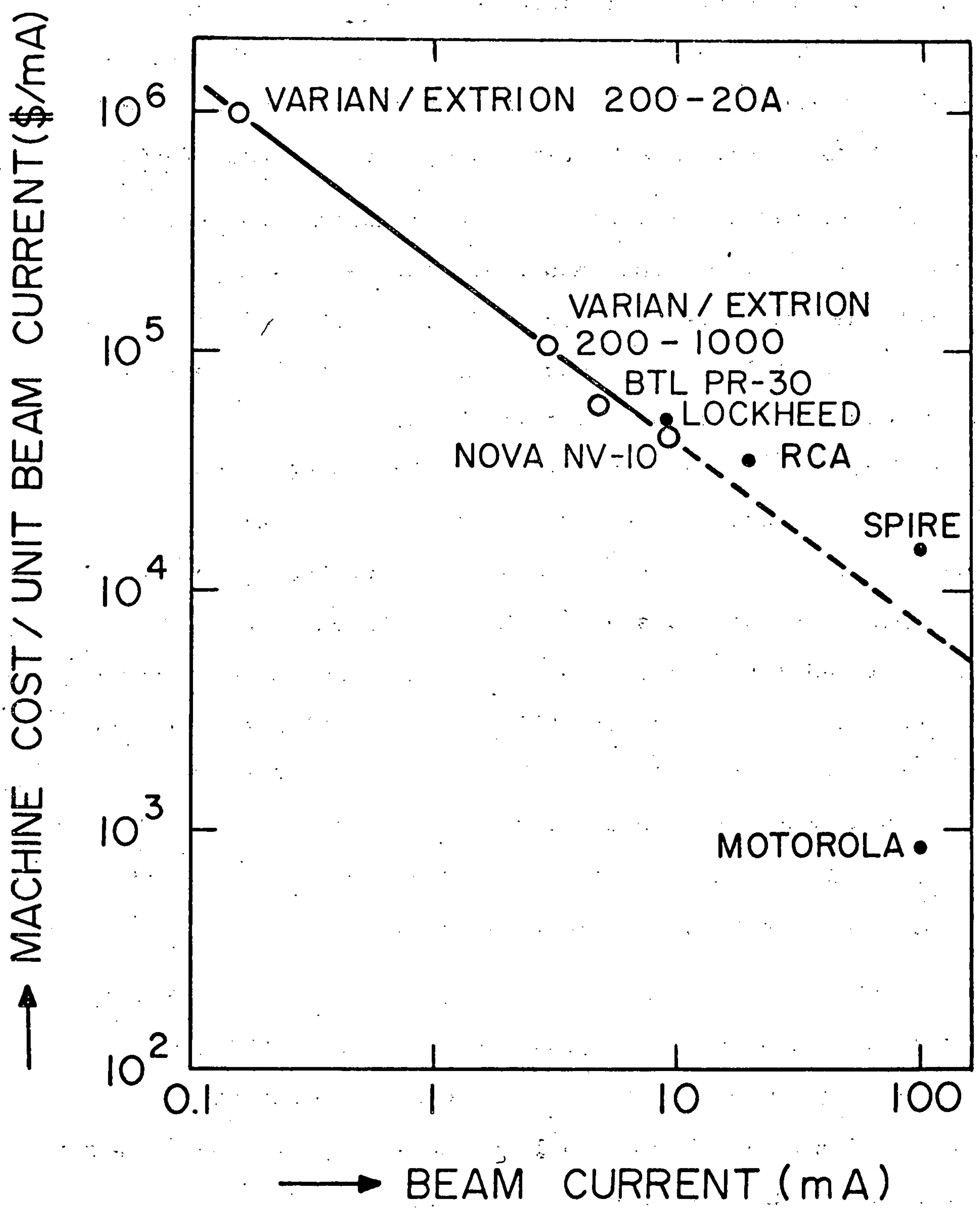

VARIAN / EXTRION 200-20A
VARIAN / EXTRION 200 - 1000
BTL PR-30
LOCKHEED
NOVA NV-10
RCA
SPIRE
MOTOROLA
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.1
1
10
100
MACHINE COST / UNIT BEAM CURRENT ($/mA)
BEAM CURRENT (mA)

FIGURE 3

improvement is expected from increasing the source lifetime in terms of mAh's with beam current. However, although the source life expectancy decreases as beam current output increases, as shown in Figure 2, the product of source current and lifetime increases with increasing output. Therefore more silicon can be processed between filament changes. In one proposal[7], multiple and spare sources are employed so that they could be replaced while the machine is operating. As listed on Table II, the source lifetime (mAh) is expected to increase in the future by a factor of ten.

Another projected improvement is the reduced dependence of the ion implanter's performance on operator skill. At present a skilled operator needs to monitor the operating ion implanter continuously to achieve optimum output rates. These skilled labor requirements are expected to be decreased, in future implanters, by simplifying the machine's operation,[6] by larger batch loads,[3,5] or by using microprocessors.[4] It is thus hoped that future implanters could be operated with unskilled labor with skilled labor called upon only occasionally for mechanical and electrical servicing.

Since annealing is an integral part of the implantation process, studies are being conducted in the JPL-LSA program on an optimum process.[19] Processes studied include thermal, electron pulse, and laser annealing with only thermal annealing yielding solar cells of comparable efficiency to those produced from diffusion. Thermal annealing costs, as mentioned previously are significant compared to those

## TECHNOLOGY PROBLEMS TO BE RESOLVED FOR SUCCESSFUL LOW COST ION-IMPLANTATION

5-FOLD INCREASE OF BEAM CURRENT PER SOURCE (4 mA → 20 mA)

10-FOLD INCREASE OF SOURCE FILAMENT LIFE (25 mAh → 280 mAh)

REDUCED RELIANCE ON OPERATOR INFLUENCE FOR EFFICIENT MACHINE PERFORMANCE

REDUCED FREON LOSSES FROM COOLING SYSTEM (HIGH VOLTAGE.)

EASIER CLEANING OF SPURIOUS MATERIAL DEPOSITED IN SYSTEM. (DEPOSITION PROBABLY NOT AVOIDABLE.)

UNIFORM DEPOSITION W/O WORKPIECE ROTATION

REDUCED CAPITAL COST (CURRENT SINGLE SOURCE, 2 mA MACHINES CAPABLE OF 200 WAFERS/H COST ~$0.5 MILL.)

IMPROVED ANNEALING METHODS (PULSE ANNEALING?)

REDUCED ENERGY CONSUMPTION.

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ALTERNATE TECHNOLOGIES:

COLD CATHODE, SOLID SOURCES (SIMPLER SYSTEM. BUT: FASTER SOURCE EROSION? MORE SPURIOUS DEPOSITION IN SYSTEM THAN FROM GASEOUS SOURCES?)

OMISSION OF ANALYZING MAGNET (CAPITAL COST AND ENERGY SAVINGS. BUT: IMPURITY PROFILE ACCEPTABLE? SPURIOUS IMPURITIES CONTROLLABLE?)

Table II

for future ion implantation processes. Also thermal annealing decreases the potential efficiency of ion implanted cells. The shallow implanted PN junction depth that can be obtained from implanting with low energy ions has the potential of yielding better performing cells than those from the diffusion process, because of greater UV-response. However, the thermal anneal cycle broadens the shallow implanted junctions depth, making it comparable to that obtained using gaseous diffusion.

For an effective use of the ion implantation process, an extended, automated, vacuum, production sequence has been proposed by Spire. For this sequence to be practical, the annealing process has to be performed in a short time interval. Since conveyor belt, in the Spire sequence, moves at a rate of 30 cm/sec, a thermal annealing cycle of only 5 minutes would require an effective furnace length of 90 m. Electron or laser beam annealing would be compatible with a rapid production line, since they can be performed in fractions of seconds.[19,20] However, solar cells annealed with either of these two techniques show a decreased performance. A summary of some other technical problems that need to be solved for the successful implementation of ion implantation for future solar cell manufacturing processes is listed in Table II. These problems include uniform deposition of ribbon-shaped wafers, more effective coolant usage and convenient removal of deposited source material.

The importance of beam current size to implantation output is shown by the expression for the unit area ion implantation time:

$$t_p = k \frac{\left[1.602 \times 10^{-19} \text{ (a·sec/ion)}\right] \cdot \left[\text{ion flux (ions/cm}^2\text{)}\right]}{\text{Ion beam (amps)}} \text{ sec/cm}^2 \tag{2.8}$$

The proportionality constant, k, is $\leq$ 1 and depends on the degree of overscan and the beam utilization. Therefore, as a first approximation, the throughput rate of an ion implanter is proportional to its beam current. Because the implantation process is capital intensive, lowering the machine cost per unit beam current will lower the implantation cost in about the same ratio. As can be observed in Figure 3, the machine costs normalized to their beam current are expected to decrease approximately proportionally with increased beam current. For future ion implanters, a large capital cost decrease per unit of output is anticipated by increasing the beam current without proportional increases in machine costs.

There are several approaches for increasing the ion beam current. One approach, proposed by Spire, is to increase the size and number of the hot cathode sources to 20 mA and 10, respectively.[7] The source current lifetime is increased by changing from a Freeman to a Chavet type filament. Higher currents are tolerable in the latter source, because the Chavet filament is looped and therefore is not as heavily degraded by the back ion bombardment. Although source lifetime does decrease with increasing currents, as shown in Figure 2, this decrease is less than the increase in current. In another approach, a hollow cathode source, similar to that used in ion beam thrusters, is proposed.[6] This source is expected to yield a current of 100 mA, but because of the non-collimated, large crossection nature of the beam it cannot be mass-analyzed. In an ion implanter proposed by RCA, two 10 mA ion beams are used simultaneously. One is used to implant the front of the wafer with phosphorus at a $1 \times 10^{15}$ $cm^{-2}$ dosage while the other implants boron with a dose of $5 \times 10^{14}$ $cm^{-2}$.[3] The Lockheed proposal has one 10 mA beam that can process about one 7.62-cm diameter wafer/second.[5] The wafers are loaded and unloaded to and from 4 side chambers which surround the central implant chamber.

In the proposed Spire machine, 7 of the 10 sources are operated simultaneously with six running at a current of 16 mA, and the seventh at 4 mA. The ion beam from each source passes through a collimator with a slit geometry of 2 x 75 mm to provide mass analysis. The larger six sources are broken into two sets with an analyzing magnet for each set. Three ion beams strike the moving silicon wafers at $+15^{\circ}$ to the normal and three at $-15^{\circ}$. The wafers are transported on 20x20 cm carriers on a belt moving at a rate of 30 cm/sec. The seventh and smaller ion beam is used for a final dose control. The three remaining sources are used as spares. As plotted in Figure 2, it is expected, by Spire, that the average source lifetime can be increased to 24h, or approximately 400 mAh. This would mean, on average, a source replacement every 4 h with each replacement requiring 10-15 min. labor. A "dead" source is expected to be ready for replacement within 24 h. The implantation energy is designed to be 10 keV, dose uniformity to be ± 10%, and analysis to ± 0.5 AMU. In order not to enhance the space charge effect of the large beams, electric fields after the extraction gap are avoided in the Spire machine design. The scanning deflector, shown in Fig. 1, is operated magnetically.

The narrow width of the 16 mA ion beams makes them analyable since the radius of curvature of the ion beams caused by the magnetic field can be made larger than the beam's width. The radius of curvature is given by:

$$r = (^m/e) \times {}^v/B \qquad (2.9)$$

where (m/e) is the ion's mass to charge ratio, v is the ion velocity, and B is the magnetic field strength (in gauss). If a linear magnetic field is assumed, then the deflection angle is $\sin^{-1}\left[(e/m) \times (B/v)\ \ell\right]$, where $\ell$ is the length of the magnet. As seen in the top drawing of Figure 1, therefore, the angle of deflection depends on the (e/m) ratio. A slit in the ion path placed preceding the beam selects the desired ion.

A large, transient temperature increase ($\sim 800^{\circ}C$) can cause considerable stress in the silicon wafer, and make substrate movement and handling difficult. The energy flux density J, of a 10 keV ion beam at a density of $1 \times 10^{-15}$ ions/$cm^2$, is 1.602 j/$cm^2$. With the proposed output of the Spire implanter of 180 $m^2$/h, the implantation time is 0.002 sec/$cm^2$. The temperature rise of implanted wafers is given by,

$$\Delta T = J/C_p \rho (2D\,t_p)^{1/2} \quad {}^{\circ}C, \qquad (2.10)$$

where $C_p$ is the specific heat of silicon (0.71 j/g$^{\circ}$C)[21] at RT, and $\rho$ is the silicon density (2.34 $g/cm^3$). D is known as the heat diffusivity which is equal to $k/C_p\rho$, where k is the thermal conductivity of silicon (1.47 j/sec·cm °C).[22] The expression $\sqrt{2Dt_p}$ is the thermal diffusion length and cannot exceed the wafer's thickness. Equation 2.10 is valid when the implanted junction depth is small compared to $\sqrt{2Dt_p}$ or the thickness of wafer. This condition is satisfied for NP solar cell NP junction formation. The junction depth is normally approximately 0.2 μm and the implantation time is sufficiently long to make the diffusion length several hundred microns. For implanting a 200 μm thick wafer, with the porposed Spire machine, the temperature increase over the environment is expected to be 48°C.

In Motorola's proposal, shown in the bottom drawing of Figure 1, a large ion current beam (100 mA) is obtained from a hollow-cathode source derived from ion thruster technology. Ion thrusters, using ionization of mercury, have very large beam currents (several amps), and lifetimes of thousands of hours. It is thought not to be difficult to modify the thruster to ionize phosphorus or other suitable dopants.[11] However, the ion thruster beam can not be mass-analyzed because of its circular cross-section and large diameter. The dispersion caused by a magnetic field would be less than the beam's diameter. In addition, the energy spread of ions emitted from a ion thruster type source hinders good magnetic separation, since the curvature radius of ions under the influence of a magnetic field is directly proportional to its velocity. The effect on solar cell efficiency of implanting with an unanalyzed or a "roughly" analyzed beam is not yet known and investigations have just been initiated.[23] The proposed Motorola ion implanter is fairly simple in design; the wafers are transported (past the ion beam) by a belt through differentially pumped vacuum chambers. Dose uniformity might be a problem, because of the Gaussian distribution of the beam's intensity and an individual wafer might be exposed to only a selected portion of the ion beam. It takes less than 0.75 sec. to implant a 12-cm diameter wafer with a $2 \times 10^{15}$ $cm^{-2}$ dosage of phosphorus with a 100 mA beam. The low capital cost of this implanter, makes the Motorola proposed ion implanted process the lowest cost one studied in this report. Details of this cost calculation are contained in a UPPC format attached to the Appendix.

In the RCA and Lockheed proposed machines, hot cathode ion sources are employed. In the RCA-proposed machine,[3] both the PN and PP+ junctions are formed simultaneously by using two separate 10 mA beams. One beam is used for phosphorus and the other for boron. This machine can process approximately 100 $cm^2$/sec, and allowing time for beam scanning and beam loss at edges, the machine's throughput is 2000, 7.62-cm diameter wafers per hour. The wafers are transferred automatically from 500 wafer cartridges to 50 wafer cassettes from which they are then removed to a holder for implantation. The high capital cost of the RCA implanter relative to its output, makes the RCA process the most expensive of the future implantation process projections.

The Lockheed proposed machine uses a 10 mA beam, and can implant 3000 wafers/h (7.62-cm diameter).[5] The wafers, which are batch-loaded, are held in 1200 ring-shaped trays or carousels (50 wafers/tray) that are stacked and distributed among 4 cylindrical vacuum chambers adjacent to the implantation chamber. During the implantation process, the trays are transferred to the central chamber where they are rotated such that each wafer is scanned on its underside by the ion beam. This is repeated 4 times for each tray to assure dose uniformity. The ion beam is kept constant at $7^{\circ}$ to the normal while the wafers are rotated. This eliminates the need for electrical or magnetic beam scanning. After all the wafers in the machine have been scanned, vacuum in the implantation system is broken and the wafer loading cylindrical chambers are replaced. It takes approximately 20 hours for the completion of one run: 2 hours for loading, 16 hours for processing, and 2 hours for unloading. The Lockheed process employs phosphorous pentaflouride ($PF_5$) as the source gas, instead of $PH_3$ or P. Phosphorous pentaflouride is very expensive and is a large cost contributor (about 16%) to the add-on process price as shown in the UPPC format attached to the Appendix.

## E. Junction Formation Cost Structures

The costs of present and future junction formation processes, broken up into their material, labor, capital, overhead, and return-on-equity components, are summarized in Table III. The cost calculations are based on the SAMICS methodology [24] and are detailed in UPPC formats attached in the Appendix. Also listed in Table III is the throughput rate, in terms of number of wafers processed per hour and their diameter.

The cost of the wafers, which are reflected in the lost-in-process cost, are taken from our previous studies of slicing processes [17], and the 1986 silicon and sheet value goals listed in JPL-LSA's price allocation guidelines.[25] In addition to slicing, the cost of one-sided texture etching is included in the current and future wafer prices. The etching is performed by applying etch stop in the form of wax on one surface, texture etching with 30% NaOH at 90°C, and removing the wax with plasma etching. The etching step costs have been derived from information published by Motorola,[26] and add up to approximately \$3.09/m$^2$. The calculated prepared wafer prices are \$350.98/m$^2$ and \$41.21/m$^2$ for 1978 and 1986, respectively. The specific process for the current wafer price is slicing 10.16-cm diameter wafers with a HAMCO ID saw.

The first two columns of Table III refer to current implantation and diffusion techniques, while the other columns

## III. Technical and Economic Comparison of Present and Proposed

### Junction Formation Processes

Add-on Cost Components ($\$/m^2$)

| ORGANIZATION | Varian-Extrion 200-1000 WF (Spire) (1978) | Spectrolab $PH_3$ diffusion (1978) | Motorola $PH_3$ diffusion (1986) | Motorola 5-step diffusion process (1986) | RCA 2-side ion implantation w/annealing (1986) | Lockheed $PF_5$ Implantation (1986) | Motorola Activation annealing (1986) | Motorola Unanalyzed beam implanter (1986) | Spire High thruput ion implanter (1986) |
|---|---|---|---|---|---|---|---|---|---|
| Throughput/rate (no.$h^{-1}$/dia.(cm)) | 240/7.6-cm | 129/7.6-cm | 1000/12-cm | 1000/12-cm | 2000/7.6-cm | 3,000/7.62-cm | 2000/12-cm | 4800/12-cm | 18,000/10-cm |
| 1. Direct Materials | 0.01 | 0.02 | 0.29 | 2.26 | 0.25 | 0.86 | -- | 0.03 | 0.07 |
| 2. Indirect Materials | 0.75 | 0.19 | 0.20 | 0.25 | 0.69 | 0.68 | 0.03 | 0.07 | 0.02 |
| 3. Expendible tooling | 2.63 | 0.28 | 0.11 | 0.16 | 0.27 | | 0.05 | 0.00 | 0.06 |
| 4. Electrical Energy | 0.65 | 0.08 | 0.22 | 0.44 | 0.22 | 0.02 | 0.10 | 0.02 | 0.08 |
| 5. Total Materials (1.0526* (1.+2.+3.+4.)) | 4.26 | 0.59 | 0.86 | 3.27 | 1.51 | 1.63 | 0.19 | 0.13 | 0.24 |
| 6. Direct Labor | 4.84 | 4.65 | 0.52 | 1.68 | 0.42 | 0.55 | 0.24 | 0.12 | 0.06 |
| 7. Maintenance Labor | 1.36 | -- | 0.08 | 0.37 | 0.14 | | -- | 0.02 | 0.02 |
| 8. Indirect Labor (0.25*(6.+ 7.)) | 1.55 | 1.17 | 0.15 | 0.51 | 0.14 | 0.14 | 0.06 | 0.03 | 0.02 |
| 9. Total Labor (1.3158 * (6.+ 7.)) | 8.19 | 6.12 | 0.78 | 2.72 | 0.73 | 0.73 | 0.32 | 0.18 | 0.1 |
| 10. Equipment | 7.42 | 1.15 | 0.17 | 0.79 | 2.45 | 0.99 | 0.08 | 0.05 | 0.36 |
| 11. Facility | 0.39 | 0.30 | 0.05 | 0.19 | 0.26 | 0.23 | 0.03 | 0.02 | 0.01 |
| 12. Capital (10.+ 11.) | 7.81 | 1.45 | 0.22 | 0.98 | 2.71 | 1.22 | 0.10 | 0.07 | 0.37 |
| 13. Overhead | 0.48 | 0.10 | 0.02 | 0.05 | 0.17 | 0.08 | 0.01 | 0.005 | 0.02 |
| 14. Return-on-equity | 13.27 | 4.12 | 0.77 | 2.96 | 4.68 | 2.76 | 0.31 | 0.21 | 0.58 |
| 15. Add-on price of process | 34.01 | 12.38 | 2.65 | 9.98 | 9.90 | 6.42 | 0.95 | 0.60 | 1.31 |
| 16. Yield (%) | 99 | 99.9 | 99 | -- | -- | 99.2 | 99.4 | 99.8 | 99.9 |
| 17. Yielded add-on process price | 34.36 | 12.39 | 2.68 | 9.98 | 9.90 | 6.47 | 0.95 | 0.60 | 1.31 |
| 18. Cost of silicon lost-in-process | 3.51 | 0.35 | 0.42 | 1.78 | 0.84 | 0.32 | 0.25 | 0.08 | 0.04 |
| 19. Add-on price | 37.86 | 12.74 | 3.10 | 11.76 | 10.74 | 6.79 | 1.20 | 0.68 | 1.35 |

detail the costs of proposed processes. Two multi-step sequences for producing front and BSF cells are also shown on Table III. The 5-step Motorola diffusion process, which is detailed in Table IV, consists of protecting the front surface by spinning-on-silica, diffusion of the BSF using $BCl_3$, a spin-on silica protection of the back surface, phosphine diffusion, and stripping of silica from both surfaces with a 4:1 $NH_4OH$:HF solution. The result is an $N^+PP^+$ wafer with no silica coating, ready for metallization or AR-coating. The other multi-step process consists of RCA's double-sided ion implantation followed by thermal annealing. The RCA 2-step process yields wafers equivalent to Motorola's 5-step wet chemical sequence.

The cost components for activation annealing are included in Table III because it is presently a necessary step after ion implantation to achieve state-of-the-art performing cells. Annealing costs are significant compared to those derived using the high throughput implanters proposed by Motorola and Spire.

The major cost components from Table III are graphically represented on Figure 4. In addition, Figure 4 includes the cost of RCA's proposed gaseous diffusion using $POCl_3$. This diffusion process takes approximately one hour and has an output rate of 2,000 7.62-cm diameter wafers per hour. Additional details of the RCA $POCl_3$ diffusion process are contained in a UPPC format attached to the Appendix.

The prices for the proposed $PH_3$ and $POCl_3$ diffusion processes are \$3.01/m$^2$ and \$3.86/m$^2$, respectively. These two processes should be available for near term production sequences; no major technical problems need to be solved for their applicability.

Table IV

Yielded Add-on Cost Components for Motorola's 5-Step Wet Chemical Front Junction and BSF Sequence ($\$/m^2$)

| Process Step | Step Yield (%) | Cumulative Yield (%) | Materials | Labor | Capital | Return-on Equity | Lost Si (1986) | Subtotal |
|---|---|---|---|---|---|---|---|---|
| 1. Spin-on silica (front surface) | 99.0 | 95.9 | 1.06 | 0.50 | 0.28 | 0.72 | 0.43 | 2.99 |
| 2. BSF diffusion with $BCl_3$ | 99.0 | 96.8 | 0.33 | 0.81 | 0.24 | 0.69 | 0.43 | 2.50 |
| 3. Spin-on silica (back surface) | 99.0 | 97.8 | 1.04 | 0.49 | 0.28 | 0.71 | 0.42 | 2.94 |
| 4. Phosphine diffusion for front junction | 99.0 | 98.8 | 0.79 | 0.79 | 0.24 | 0.78 | 0.42 | 3.02 |
| 5. Stripping of silica with 4:1 $NH_4OH$:HF solution | 99.8 | 99.8 | 0.06 | 0.15 | 0.01 | 0.05 | 0.08 | 0.35 |
| Totals | | | 3.28 | 2.74 | 1.05 | 2.95 | 1.78 | 11.80 |

# JUNCTION FORMATION ADD-ON PRICES

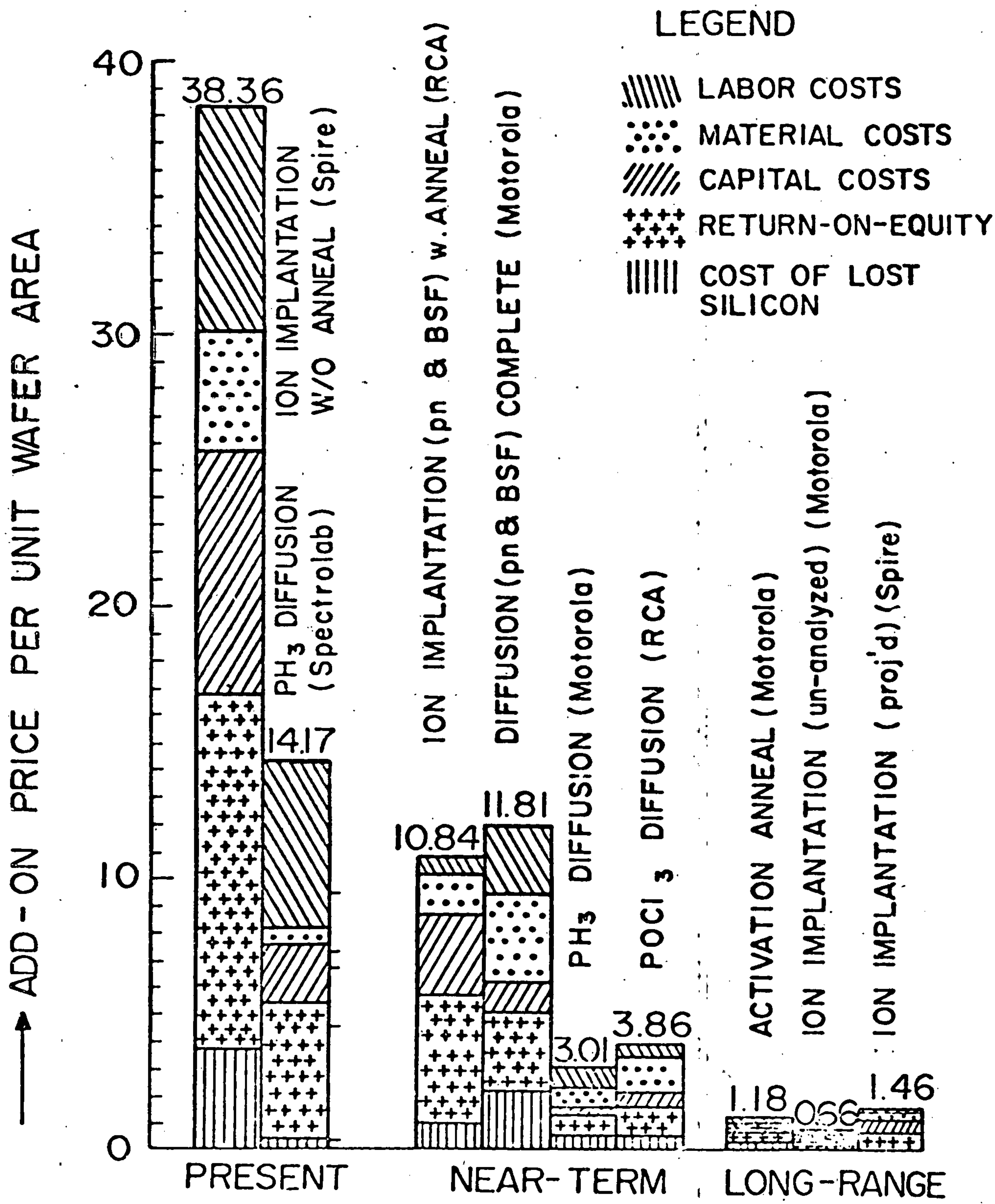


FIGURE 4

The cost decreases for the diffusion processes are about a factor of four lower from current ones, and for the most part, depend upon throughput increases. The higher output rate for Motorola's diffusion process, as compared to Spectrolab's, is based on processing larger wafers (12-cm) at the same rate as smaller ones (7.62-cm). The larger area (2.48x) of the 12-cm diameter wafers accounts for the higher throughput rates of Motorola's process. RCA proposes to automatically transfer wafers from cassettes to furnace boats, and load/unload the boats from the furnace, to increase output rates. The loading and transferring machines add to the capital cost of the RCA process, but increase output sufficiently to lower unit area costs.

The RCA 2-sided implantation process, which is included on Figure 4 with annealing, and the Lockheed implantation proposal, should be ready for near-term production (1982-1984). Both these machines have 10 mA ion beams. The RCA implanter actually has two 10 mA beams but only one is used for the front junction formation. This beam size is only twice as large as some machines in operation and a 10 mA machine, the NV-10, by Nova Associates, should be introduced into the marketplace shortly.

The processing costs from employing the high current (100 mA) machines by Motorola and Spire are the lowest ones listed on Table III for junction formation. However, a longer time than for the other options discussed above will be needed before these machines are suitable for production use, because of larger extrapolations of ion currents and throughput rates. In addition, the Morotola 100 mA proposal has reductions in labor, and capital costs because of its greatly simplified operation. It employs an unanalyzed beam from a hollow cathode source, thus eliminating the need for any acceleration, magnetic, and scanning capabilities. The hollow cathode source originally designed for space propulsion use in ion thrusters, should give the high currents and lifetimes necessary for a low-cost, high throughput operation, needed in solar cell manufacturing. But, the effects on cell performance by implanting with an unanalyzed beam are unknown, although investigations have recently been initiated.(23) Spire expects their implanter to have a 100-fold increase in output rate over current machines. This is to accomplished, for the most part, by increasing the beam current to 100 mA, by having a continuously pumped, belt system, feed mechanism, and by increases in machine reliability by extensive use of microprocessors and redundant beam sources.

3. Conclusions

In order for the front junction formation processes involving gaseous diffusion and ion implantation to fit into future (1986) low-cost solar cell fabrication sequences their costs will have to decrease by factors of approximately four and ten, respectively. At present, the phosphorus diffusion process cost is $12.74/m^2$ while the ion implantation of phosphorus costs $37.86/m^2$. It is anticipated that the future cost contribution for front junction formation would be less than $3.20/m^2$.

The costs in the long term ion implantation projections by themselves seem significantly lower than those of the diffusion processes, but adding the cost of the necessary activation annealing, makes the costs comparable. For combined front and BSF sequences, the cost difference between a wet-chemical process (the 5-step Motorola sequence) and an equivalent multi-step process employing ion implantation, is about $1/m^2$. The closeness of these two projections makes it difficult to judge which would be economically advantageous in 1986. From our calculations, it would appear that ion implantation and diffusion could be competitive.

Future junction formation processes will have to fit well into high volume process sequences. Even though currently, gaseous diffusion is an inexpensive step in manufacturing solar cells, its costs have to be reduced even more to fit into the future LSA framework. Cost reductions depend upon larger throughput rates to be achieved by processing larger diameter wafers, and by automatic wafer transfer. Wafer transferring could be accomplished using specifically designed machines, which would increase the capital cost of gaseous diffusion. Another cost reduction for diffusion is related to quartzware (boats and tube liners) cleaning using mild chemical etching. The cleaning is necessary to minimize wafer contamination and is currently a significant cost contributor to the diffusion process. The required cleaning frequency and alternative cleaning procedures should be investigated.

Ion implantation has recently been introduced into production activities, and its state-of-the-art performance is rapidly changing. During the last decade, ion beam current (and consequently the throughput rate) has increased by a factor of 1,000 - from a few microamps to, soon to be introduced 10 mA. For low-cost solar cell junction formation, the implanter's beam current would have to increase by an additional order of magnitude and its cost reduced by approximately a factor of 20. The feasibility of achieving these goals cannot, at this time, be assured. But certainly, activity in this area should be continued.

If ion implantation's cost reductions could be accomplished through larger throughput rates and greater reliability, and if a compatible annealing process could be perfected, then ion implantation would be a strong candidate for junction formation in future LSA process sequences.

The cost reductions required for gaseous diffusion to meet the LSA future price goals are not as dramatic as those needed for ion implantation, and are not as dependent on technical development. However, studies should be continued in automatic wafer handling and in quartzware cleaning methods, because these are potential add-on price reduction areas for diffusion.

## 4. NEW TECHNOLOGY

No new technology developed during this quarter.

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# APPENDIX

## The University of Pennsylvania Characterization Formats for Gaseous Diffusion and Ion Implantation Junction Formation Processes

Note: The time units used in these formats refer to plant operating hours.

Process No. 3 . 1 . 0 1 - 0 1

Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Device Fabrication

Subprocess: Junction Formation

Option: Ion implantation (n-layer, phosphorus) using a modified Varian-Extrion 200-1000F)

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Form 2

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Revision -1 Date 4/9/79

Process No. 3 . 1 . 01 - 01

| 0.1 Value Added: | $/ |
|---|---|

Process Description: Ion implantation of phosphorous, using 5% phosphine in $H_2$ with a modified Varian-Extrion 200-1000 implanter with cassette loader, operating at an ion beam current of 2-4 ma. at 10 KeV Using 3" dia. wafers (45.6 $cm^2$), a cassette load (25 wafers) is processed in average operating time of 5 min., for a throughput rate of 1.368 $m^2$/h. Machine utilization is 0.8 oper'g hours per calendar hour, for an effective throughput rate of 240 wafers/calend. hour.

1. Input Specification:

Name of Item: Prepared water on sheet material as specified

Dimensions: 7.62-cm diameter, 240 wafers/h

Material: Solar grade silicon

Other Specifications:

1.1 Quantity Required: 1.094 $m^2$ / h Unit Cost: 351 $/ $m^2$

| 1.2 Input Value: | $/ |
|---|---|
| 1.3 Input Cost: | 384.13 $/ h |

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 3 . 1 . 0 1 - 0 1

Form 3

Page 1 of 1

2.1 Direct Materials:

Revision 1 Date 4/9/79

2.1_1 Type: 5% phosphine in hydrogen;

Specification: Only used when machine is operating. Consumption rate is 3.5 x $10^{-4}$ $ft^3$/min; cost is \$0.82/$ft^3$ (SAMICS No. E1472D).

Quantity Required: 0.476 ℓ /h; Unit Cost: 0.029 \$/ℓ; Cost: 0.0138 \$/h

2.1_ Type: ;

Specification: ;

Quantity Required: ___ /___; Unit Cost: ___ \$/___; Cost: ___ \$/___

2.1_ Type: ;

Specification: ;

Quantity Required: ___ /___; Unit Cost: ___ \$/___; Cost: ___ \$/___

2.1 Subtotal Direct Materials: 0.014 \$/h

Process No. 3 . 1 . 0 1 - 0 1

Form 4



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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Cooling Water;

Specification: Needed continuously to cool diffusion pumps. (SAMICS No. C1128D)

Quantity Required: 0.48 kW /; Unit Cost: 0.566 \$/ kWh; Cost: 0.272 \$/ h

2.2.2 Type: Liquid $N_2$

Specification: Needed continuously for vacuum traps. Consumption rate is 0.096 $ft^3/h$. Unit cost is \$5.66/$ft^3$, (SAMICS No. C1080D).

Quantity Required: 2.69 ℓ / h; Unit Cost: 0.202 \$/ℓ; Cost: 0.543 \$/ h

2.2_ Type:

Specification:

Quantity Required: /; Unit Cost: \$/; Cost: \$/

| 2.2 Subtotal Indirect Materials: | 0.82 \$/ h |
|---|---|

Process No. 3 . 1 . 01 - 01

Form 5



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2.3 Expendable Tooling:

| | | Unit Cost | Cost |
|---|---|---|---|
| 2.3 1 | Type: Spare parts ( e.g. tungsten filaments, vacuum seals, pump oils). | | |
| | Quantity Required: 48 min / h | 0.06 $/ min | 2.88 $/ h |
| 2.3 _ | Type: | | |
| | Quantity Required: / | $/ | $/ |
| 2.3 _ | Type: | | |
| | Quantity Required: / | $/ | $/ |
| 2.3 _ | Type: | | |
| | Quantity Required: / | $/ | $/ |
| 2.3 | Subtotal Expendable Tooling: | | 2.88 $/ h |

2.4 Energy

| | | Unit Cost | Cost |
|---|---|---|---|
| 2.4 1 | Type: Electricity, 25 kW, (usage during non-operating time is 12.5 kW) | | |
| | Quantity Required: 22.5 kW / min | 0.0319 $/kWh | 0.718 $/ h |
| 2.4 _ | Type: | | |
| | Quantity Required: | $/ | $/ |
| 2.4 | Subtotal Energy Costs: | | 0.718 $/ h |
| 2.5 | Subtotal 2.1 to 2.4: | | 4.43 $/ h |
| 2.6 | Handling Charge: 5.26 % of item 2.5 | | 0.23 $/ h |
| 2.7 | Subtotal Materials and Supplies: (2.5 + 2.6) | | 4.66 $/ h |

Process No. 3 . 1 . 0 1 - 0 1

Form 6
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Revision 1 Date 4/9/79

3.1 Direct Labor:

3.1_1 Category: Semiconductor Assembler (SAMICS No. B3096D) Activity: Machine operation
Amount Required: 1 h/ 1 ; Rate: $ 3.894 /h; Load 36.0 %; Cost: 5.296 $/ h

3.1_2 Category: Electronics Technician (SAMICS No. B3736D) Activity: Machine adjustments
Amount Required: 0.1 h/ h ; Rate: $ 5.29 /h; Load 36.0 %; Cost: 0.719 $/ h

3.1_3 Category: Maintenance Mechanic (SAMICS No. B3704D) Activity: Service and repair
Amount Required: 0.1 h/ h ; Rate: $ 5.67 /h; Load 36.0 %; Cost: 0.771 $/ h

3.1 Direct Labor Subtotal: 6.79 $/ h

3.2 Indirect Labor: 25% of direct

3.2_ Category: ________ Activity: ________
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ h

3.2_ Category: ________ Activity: ________
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ________ Activity: ________
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 1.70 $/ h

| | | |
|---|---|---|
| 3.3 Subtotal 3.1 and 3.2 | 8.49 | $/ h |
| 3.4 Overhead on Labor: 5.26 % | 0.47 | $/ h |
| 3.5 Subtotal Labor | 8.96 | $/ h |

Process No. 3 . 1 . 0 1 - 0 1

Form 7
Page 1 of 1
Revision 1 Date 4/9/79

4.1 Equipment

4.1_1 Type: Varian-Extrion 200-1000F ion implanter

Cost: 315,000 $; Installation Cost: 5,000 $; Throughput: 1.368 $m^2$ /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 80 %; Machine Oper'g Time ______ h/y

Servicing Costs: Labor -- h/y at -- $/h; Parts or Outside Service: -- $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 67,253 $/y | 8.12 $/ h

4.1_ Type: ______

Cost: ______ $; Installation Cost: ______ $; Throughput: ______ /h;

Plant Oper'g Time ______ h/y; Machine Avail'ty: ______ %; Machine Oper'g Time ______ h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: ______ $/y

Useful Life: ______ y; Charge Rate: ______ % of Cost/y; Capital Cost: ______ $/y | ______ $/ ______

4.1_ Type: ______

Cost: ______ $; Installation Cost: ______ $; Throughput: ______ /h;

Plant Oper'g Time ______ h/y; Machine Avail'ty: ______ %; Machine Oper'g Time ______ h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: ______ $/y

Useful Life: ______ y; Charge Rate: ______ % of Cost/y; Capital Cost: ______ $/y | ______ $/ ______

| 4.1 Subtotal Equipment Cost: | 8.12 $/h |
|---|---|

Process No. 3 . 1 . 0 1 - 0 1

Form 8
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## 4.2 Facilities:

**4.21** Type: Machine area Floor Area: 19.51 $m^2$; Throughput: 9062 $m^2$/y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

| | | | | |
|---|---|---|---|---|
| Heating | /y at | $/ | | |
| Air Cond'g | /y at | $/ | | |
| Lighting | /y at | $/ | | |

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: 3495 $/y — 0.42 $/h

**4.2_** Type: ____ Floor Area: ____ $m^2$; Throughput: ____ ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

| | | | | |
|---|---|---|---|---|
| Heating | /y at | $/ | | |
| Air Cond'g | /y at | $/ | | |
| Lighting | /y at | $/ | | |

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

**4.2_** Type: ____ Floor Area: ____ $m^2$; Throughput: ____ ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

| | | | | |
|---|---|---|---|---|
| Heating | /y at | $/ | | |
| Air Cond'g | /y at | $/ | | |
| Lighting | /y at | $/ | | |

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

| | |
|---|---|
| 4.2 Subtotal Facilities: | 0.42 $/h |
| 4.3 Equipment and Facilities Subtotal : | 8.54 $/h |

* Includes energy use

Form 9-1

Page 1 of 1

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Process No. 3 . 1 . 01 – 01

| | | | |
|---|---|---|---|
| 5. | Salvaged Material (Work-in-process) | | |
| 5.1 | Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit) | 1.0835 $m^2$ / h | |
| 5.21 | Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1) | 0.0109 $m^2$ / h | |
| 5.22 | Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐ | – / – | |
| 5.23 | Credit for 5.22 at the Market Value of ______$/______: | – $/ – | |
| 5.24 | Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ______$/______: | – $/ – | |
| 5.25 | Net Credit for 5.22 (5.23 minus 5.24): | | ______$/______ |
| 5.26 | Material of Type 1. Lost in Process (5.21 minus 5.22) | 0.0109 $m^2$ / h | |
| 5.3 | Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1) | | 3.84 $/ h |
| 5.4 | Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1) | | 380.29 $/ h |

Salvaged Materials Summary:

| | | |
|---|---|---|
| 5.8 | Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76) | ______$/______ |

Process No. 3 . 1 . 01 - 01

Form 10
Page 1 of 1

Revision 1 Date 4/9/79

6. Byproducts and Wastes

6.1 Solid Byproducts/Wastes

6.1_ Type (Composition): ______ Quantity Produced: ______/______

Physical Shape/Size: ______ Energy Content: ______ kWh/______

Density: ______ $g/cm^3$; Water Solubility: ______ g/l at ______ °C; pH: ______

Toxicity: ______ Biodegradable: ______ Other Remarks: ______

Type of Disposal: ______

Input Material for: ______ Cost/(Credit) ______ $/______; Cost: ______ $/______

6.2 Liquid Byproducts/Wastes (inorganic):

6.21 Type (Composition): From cleaning cassettes Quantity Produced: ? /______

Density: ______ $g/cm^3$; Suspended Solids: ______ Amount: ______ mg/l pH: ______

Toxicity: ______ Heavy Metal Content: ______ mg/l Other Remarks: ______

Type of Disposal: ______

Input Material for: ______ Cost/(Credit) ______ $/______ Cost: ______ $/______

Carry: ______ $/______

Revision 1 Date 4/9/79

Process No. 3 . 1 . 0 1 - 0 1

| 6.3 Liquid Byproducts/Wastes (organic) | Carry from Form 10 | ______$/______ |
|---|---|---|

6.3_ Type (Composition):____________ Quantity Produced:______/______

Density:________g/cm$^3$; Toxicity:________ COD:________mg/l; BOD:________mg/l

Ignition Point:_____°C; Explosive Mixture in Air:___% to ___%; Other Remarks:________

________________________________________

Type of Disposal:________________________________________

Input Material for:________________Cost(Credit)____$/_____; Cost: ______$/______

6.4 Fumes, Gaseous Byproducts/Wastes

6.4_1 Type (Composition): fumes or exhuast gases Quantity Produced: 1400 ft$^3$/min

Energy Content (Combustion):______kWh/______; Explosive Mixture in Air ___% to ___%.

Ignition Point:______°C; Aerosol ☐ Precipitates in _____ minutes pH______

Toxicity______________ Requires Scrubbing ☐ Type of Scrubber:______________

(enter scrubber under 4.1, 4.2, scrubber effluent under 6.1 to 6.3)

Other remarks: Fumes composed of air, $N_2$, $H_2$ and $PH_3$

________________________________________

Type of Disposal: Power of fan taken from Motorola, (0.46 kW/1000 ft$^3$/min).

Operating Costs: 180 $/ y ; Cost: 0.02 $/h

| 6. Subtotal: Byproduct/Waste Disposal Cost: | 0.02 $/h |
|---|---|

Process No. 3 . 1 . 01 — 01

Revision 1 Date 4/9/79

7. Process Cost Computation

| | |
|---|---|
| 7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.) | 22.18 \$/ h |
| 7.22 Other Indirect Costs: ______ % of 7.11 (0.059*(4.1)+0.108 *(4.2)) | 0.52 \$/ h |
| 7.21 Total Operating Add-on Costs of Process: | 22.70 \$/ h |
| 7.22 G & A ______ % of 7.21 | \$/ |
| 7.31 Total Gross Add-On Cost of Process | 22.70 \$/ h |
| 7.32 Credit for Salvaged Material (5.8) | -- \$/ |
| 7.33 Cost of Work-in-Process Lost (5.3) | 3.84 \$/ h |
| 7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32) | 26.54 \$/ h |
| 7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4) | 380.29 \$/ h |
| 7.36 Loading on Item 7.35 at Rate ______ % | \$/ |
| 7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36) | 406.83 \$/ h |

| | |
|---|---|
| 7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units) | 1.094 $m^2$ / h |
| 7.42 Practical Yield | 99 % |
| 7.43 Effective Yield (7.41 x 7.42) | ______ / ______ |
| 7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35 | 1.083 $m^2$ / h |

| | |
|---|---|
| 7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44) | 375.65 \$/ $m^2$ |
| 7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44) | 24.51 \$/ $m^2$ |

Process No. 3.1.01-01

Form 13-2
Page 1 of 1

Revision 1 Date 4/9/79

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

| | | | |
|---|---|---|---|
| 0.9274* 8.12 $/ h | from Subtotal 4.1 = | 7.53 $/ h | |
| 1.946* 0.42 $/ h | from Subtotal 4.2 = | 0.82 $/ h | |
| | Subtotal = | 8.35 $/ h | |

8.22 Costs of Amortization of the One-Time Cost:

| | | | |
|---|---|---|---|
| 0.192* 4.66 $/ h | from Subtotal 2.7 = | 0.89 $/ h | |
| 0.192* 8.96 $/ h | from Subtotal 3.5 = | 1.72 $/ h | |
| 0.2958* 8.12 $/ h | from Subtotal 4.1 = | 2.40 $/ h | |
| 2.77* 0.42 $/ h | from Subtotal 4.2 = | 1.16 $/ h | |
| | Subtotal = | 6.17 $/ h | |

8.23 Total Net Cost of Equity (8.21 + 8.22): 14.52 $/ h

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 1.083 $m^2$ / h from 7.44)

13.41 $/ $m^2$

8.25 Price of Process (7.52 + 8.24) 37.92 $/ $m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 388.06 $/ $m^2$

Process No. 3 . 1 . 0 1 - 0 1

Form 15
Page 1 of 1

Revision 1 Date 4/9/79

0. Output Specification:

Name of item: Wafers with PN-junctions (phosphorus implanted)

Dimensions: 7.62-cm diameter

Material: Solar grade silicon

Other Specifications:

Process No. 3 . 1 . 0 2 - 0 2 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Device Fabrication

Subprocess: Formation of Potential Barrier

Option: Open tube n-type diffusion using phosphine gas (Spectrolab)

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Process No. 3 . 1 . 0 2 - 0 2

| | |
|---|---|
| 0.1 Value Added: | $/ |

Process Description: Open tube n-type diffusion using 0.05% phosphine in nitrogen. One run contains 75 wafers, 7.62-cm dia. each. Total cycle time is 35 minutes, phosphine flows for 5-10 minutes. Two 1-tube furnaces are used, handled by 1 operator, 1.5 shift operation. Most time is spent manually loading and unloading diffusion boats. Calculation made on 3 shift basis.

1. Input Specification:

Name of Item: Silicon wafers, texture-etched.

Dimensions: 7.62-cm diameter

Material: Cz grown silicon, (100) orientation

Other Specifications:

1.1 Quantity Required: 0.34203 $m^2$ / run Unit Cost: 351 $/ $m^2$

| | |
|---|---|
| 1.2 Input Value: | 120.05 $/ run |
| 1.3 Input Cost: | $/ |

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 3 . 1 . 0 2 - 0 2

Form 3

Page 1 of 1

2.1 Direct Materials:

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2.1_1 Type: Phospine gas in nitrogen;

Specification: 500 ppm of $PH_3$

Cost of gas tank is \$60 and it contains approximately 1.4 $m^3$

Flow rate is 20 mℓ/min/furnace tube. 7.5 minutes/run;

Quantity Required: 150 mℓ /run; Unit Cost: 42.86 \$/ $m^3$; Cost: 0.006 \$/ run

2.1_ Type: ____;

Specification: ____;

Quantity Required: ____ /____; Unit Cost: ____ \$/____; Cost: ____ \$/____

2.1_ Type: ____;

Specification: ____;

Quantity Required: ____ /____; Unit Cost: ____ \$/____; Cost: ____ \$/____.

2.1 Subtotal Direct Materials: 0.006 \$/ run

Process No. 3 . 1 . 02 - 02

Form 4

Page 1 of 1

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Nitrogen gas;

Specification: From liquid nitrogen (One liter of $LN_2$ yields about 500 ℓ of gas). Gas flow rate is 1 ℓ/min/tube. Cost of liquid $LN_2$ is $15.66/ft^3$ (SAMICS C1080D).

Quantity Required: 35 ℓ /run; Unit Cost: 0.00040 $/ℓ; Cost: 0.014 $/run

2.2.2 Type: Oxygen gas

Specification:

Quantity Required: Minimal /; Unit Cost: $/; Cost: $/

2.2.3 Type: 1:3:5 wt. ratio of $HF:HNO_3:H_2O$

Specification: Used for cleaning the quartz ware (tube and boats). Consumption is 2 ℓ/day (2 cleanings).

Quantity Required: 0.05 ℓ/run; Unit Cost: 1.00 $/ℓ; Cost: 0.05 $/run

| 2.2 Subtotal Indirect Materials: | 0.064 $/run |
|---|---|

Process No. 3 . 1 . 0 2 – 0 2



2.3 Expendable Tooling:

2.3 1 Type: Quartz boats - replacements for each furnace tube

Quantity Required: 7 boats / y : Unit Cost: 50 $/boat Cost: 0.025 $/ run

2.3 2 Type: Furnace tubes

Quantity Required: 2 tubes / y : Unit Cost: 500 $/tube Cost: 0.07 $/ run

2.3 _ Type: ____

Quantity Required: ____ / ____ : Unit Cost: ____ $/ ____ Cost: ____ $/ ____

2.3 _ Type: ____

Quantity Required: ____ / ____ : Unit Cost: ____ $/ ____ Cost: ____ $/ ____

| | | |
|---|---|---|
| 2.3 | Subtotal Expendable Tooling: | 0.095 $/ run |

2.4 Energy

2.4 1 Type: Electricity, 8 kW/tube, 17.5 % duty cycle

Quantity Required: 0.817 kWh/run : Unit Cost: 0.0319 $/kWh Cost: 0.026 $/ run

2.4 _ Type: ____

Quantity Required: ____ ____ : Unit Cost: ____ $/ ____ Cost: ____ $/ ____

| | |
|---|---|
| 2.4 Subtotal Energy Costs: | 0.026 $/ run |
| 2.5 Subtotal 2.1 to 2.4: | 0.191 $/ run |
| 2.6 Handling Charge: 5.26 % of item 2.5 | 0.01 $/ run |
| 2.7 Subtotal Materials and Supplies: (2.5 + 2.6) | 0.201 $/ run |

Process No. 3 . 1 . 0 2 - 0 2

Form 6
Page 1 of 1
Revision 4/79 Date 1/79

3.1 Direct Labor:

3.1 1 Category: Semiconductor assembler (SAMICS No. B3096D) Activity: Furnace load/unload, control, clean quartz
Amount Required: 0.3 h/ run ; Rate: $ 3.89 /h; Load 36 %; Cost: 1.59 $/ run

3.1_ Category:________ Activity:________
Amount Required:____ h/____ ; Rate: $____ /h; Load____ %; Cost: ____ $/____

3.1_ Category:________ Activity:________
Amount Required:____ h/____ ; Rate: $____ /h; Load____ %; Cost: ____ $/____

3.1 Direct Labor Subtotal: 1.59 $/ run

3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category:________ Activity:________
Amount Required:____ h/____ ; Rate: $____ /h; Load____ %; Cost: ____ $/____

3.2_ Category:________ Activity:________
Amount Required:____ h/____ ; Rate: $____ /h; Load____ %; Cost: ____ $/____

3.2_ Category:________ Activity:________
Amount Required:____ h/____ ; Rate: $____ /h; Load____ %; Cost: ____ $/____

3.2 Indirect Labor Subtotal: 0.40 $/ run

| | | |
|---|---|---|
| 3.3 Subtotal 3.1 and 3.2 | 1.99 | $/ run |
| 3.4 Overhead on Labor: 5.26 % | 0.105 | $/ run |
| 3.5 Subtotal Labor | 2.09 | $/ run |

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Process No. 3 . 1 . 0 2 - 0 2

4.1 Equipment

4.1_1 Type: 2 Furnaces with 1 tube each, incl. temperature and gas flow controls

Cost: ea. 15,000 $; Installation Cost: included $; Throughput: 3.4 runs /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 99.8%; Machine Oper'g Time 8260 h/y

Servicing Costs: Labor 20 h/y at 8.12 $/h; Parts or Outside Service: -- $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 6730 $/y | 0.240 $/run

4.1_2 Type: Exhaust system for furnace - shared between two furnaces

Cost: 5,000 $; Installation Cost: included $; Throughput: 3.4 runs /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 99.8%; Machine Oper'g Time 8260 h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 1,065 $/y | 0.038 $/run

4.1_3 Type: Tube cleaning tower - shared between two furnaces

Cost: 10,000 $; Installation Cost: 5,000 $; Throughput: 3.4 runs /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: 99.8%; Machine Oper'g Time 8260 h/y

Servicing Costs: Labor -- h/y at -- $/h; Parts or Outside Service: -- $/y

Useful Life: 7 y; Charge Rate: 21.35% of Cost/y; Capital Cost: 3,200 $/y | 0.114 $/run

| 4.1 Subtotal Equipment Cost: | 0.392 $/run |
|---|---|

Process No. 3 . 1 . 02 - 02

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4.2 Facilities:

4.2 1 Type: Area for 2 furnaces Floor Area: 13 $m^2$; Throughput: 28,000 runs /y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: 2320 $/y — 0.083 $/run

4.2 2 Type: Cleaning tower area Floor Area: 3.3 $m^2$; Throughput: 28,000 runs /y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: 600 $/y — 0.021 $/run

4.2_ Type: ______ Floor Area: ______ $m^2$; Throughput: ______ ______/y

Charge Rate: ______ $/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: ______$/y — ______$/______

4.2 Subtotal Facilities: 0.104 $/run

4.3 Equipment and Facilities Subtotal: 0.496 $/run

*Includes energy use

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Process No. 3 . 1 . 02 - 02

5. Salvaged Material (Work-in-process)

| | | | |
|---|---|---|---|
| 5.1 | Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit) | 0.999 run / run | |
| 5.21 | Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1) | 0.001 run / run | |
| 5.22 | Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ - ☐☐ | ____ ____ / ____ | |
| 5.23 | Credit for 5.22 at the Market Value of ____ $/____ : | ____ $/ ____ | |
| 5.24 | Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ____ $/____ : | ____ $/ ____ | |
| 5.25 | Net Credit for 5.22 (5.23 minus 5.24): | | ____ $/ ____ |
| 5.26 | Material of Type 1. Lost in Process (5.21 minus 5.22) | 0.001 run / run | |
| 5.3 | Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1) Not contained in Good Output Work-In-Process (Amount 5.21 Times Unit Cost 1.1) | | 0.12 $/run |
| 5.4 | Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount ~~5.8~~ 5.1 Times Unit Cost from 1.1) | | 119.88 $/run |

Salvaged Materials Summary:

| | | |
|---|---|---|
| 5.8 | Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76) | ____ $/ ____ |

Process No. 3 . 1 . 0 2 – 0 2

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6. Byproducts and Wastes

6.1 Solid Byproducts/Wastes

6.1_ Type (Composition): ______ Quantity Produced: ______/______

Physical Shape/Size: ______ Energy Content: ______ kWh/______

Density: ______ $g/cm^3$; Water Solubility: ______ g/l at ______ °C: pH: ______

Toxicity: ______ Biodegradable: ______ Other Remarks: ______

______

Type of Disposal: ______

Input Material for: ______ Cost/(Credit) ______ $/______; Cost: ______ $/______

6.2 Liquid Byproducts/Wastes (inorganic):

6.2_1 Type (Composition): Contaminated acid Quantity Produced: 1 ℓ / d

Density: ______ $g/cm^3$; Suspended Solids: ______ Amount: ______ mg/l pH: ______

Toxicity: ______ Heavy Metal Content: ______ mg/l Other Remarks: ______

______

Type of Disposal: ______

Input Material for: ______ Cost/(Credit) ______ $/______ Cost: ______ $/______

Carry: ______ $/______

Process No. 3 . 1 . 0 2 - 0 2

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6.3 Liquid Byproducts/Wastes (organic)

| Carry from Form 10 | _____$/_____ |
|---|---|

6.3_ Type (Composition): __________ Quantity Produced: ____/____

Density: _____ $g/cm^3$; Toxicity: _____ COD: _____ mg/l; BOD: _____ mg/l

Ignition Point: ____ °C; Explosive Mixture in Air: ___% to ___%; Other Remarks: _____

____________________

Type of Disposal: ____________________

Input Material for: __________ Cost(Credit) ____$/____; Cost: _____$/_____

6.4 Fumes, Gaseous Byproducts/Wastes

6.4_1 Type (Composition): $N_2$ with $PH_3$ Quantity Produced: 1 ℓ / min./ furnace

Energy Content (Combustion): -- kWh/____; Explosive Mixture in Air --% to --%.

Ignition Point: -- °C; Aerosol ☐ Precipitates in ____ minutes pH _____

Toxicity ? Requires Scrubbing ☐ Type of Scrubber: __________

(enter scrubber under 4.1, 4.2, scrubber effluent under 6.1 to 6.3)

Other remarks: ____________________

____________________

Type of Disposal: ____________________

Operating Costs: ______$/_____; Cost: _____$/_____

| 6. Subtotal: Byproduct/Waste Disposal Cost: | |
|---|---|

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Process No. 3 . 1 . 02 – 02

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7. Process Cost Computation

| | |
|---|---|
| 7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.2, 6.) | 2.787 $/run |
| 7.22 Other Indirect Costs: (0.059*(4.1)+0.108*(4.2)) % of 7.11 | 0.034 $/run |
| 7.21 Total Operating Add-on Costs of Process: | 2.822 $/run |
| 7.22 G & A ____ % of 7.21 | $/ |
| 7.31 Total Gross Add-On Cost of Process | 2.822 $/run |
| 7.32 Credit for Salvaged Material (5.8) | $/ |
| 7.33 Cost of Work-in-Process Lost (5.3) | 0.12 $/ |
| 7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32) | 2.942 $/run |
| 7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4) | 119.88 $/ |
| 7.36 Loading on Item 7.35 at Rate -- % | -- $/ |
| 7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36) | 122.82 $/ |

| | |
|---|---|
| 7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units) | 0.34203 $m^2$ / run |
| 7.42 Practical Yield | 99.9 % |
| 7.43 Effective Yield (7.41 x 7.42) | 0.34169 $m^2$/ run |
| 7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35 | 0.34169 $m^2$ / run |

| | |
|---|---|
| 7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44) | 359.45 $/ $m^2$ |
| 7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44) | 8.61 $/ $m^2$ |

Process No. 3 . 1 . 02 - 02

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Page 1 of 1

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8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

| | | | | |
|---|---|---|---|---|
| 0.9274* 0.392 $/ run | from Subtotal 4.1 | = | 0.364 $/ run | |
| 1.946* 0.104 $/ run | from Subtotal 4.2 | = | 0.202 $/ run | |
| | Subtotal | = | 0.57 $/ run | |

8.22 Costs of Amortization of the One-Time Cost:

| | | | | |
|---|---|---|---|---|
| 0.192* 0.201 $/ run | from Subtotal 2.7 | = | 0.039 $/ run | |
| 0.192* 2.09 $/ run | from Subtotal 3.5 | = | 0.401 $/ run | |
| 0.2958* 0.392 $/ run | from Subtotal 4.1 | = | 0.116 $/ run | |
| 2.77* 0.104 $/ run | from Subtotal 4.2 | = | 0.288 $/ run | |
| | Subtotal | = | 0.844 $/ run | |

8.23 Total Net Cost of Equity (8.21 + 8.22): 1.410 $/ run

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 0.3417 $m^2$ / run from 7.44)

4.13 $/ $m^2$

8.25 Price of Process (7.52 + 8.24) 12.74 $/ $m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 363.58 $/ $m^2$

Process No. 3 . 1 . 0 1 - 0 2



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0. Output Specification:

Name of item: Silicon wafers with PN-junction

Dimensions: 7.62-cm diameter

Material: high purity silicon

Other Specifications:

Process No. 3 . 1 . 0 1 - 0 2 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Device Fabrication

Subprocess: Formation of potential barrier

Option: Phosphorus diffusion using phosphine ($PH_3$) in argon (Motorola)

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Process No. 3.1.01-02

| | |
|---|---|
| 0.1 Value Added: | ________$/________ |

Process Description: Open tube n-type diffusion using phosphine in argon. An 8-tube furnace module is used, handled by 1 operator in 3 shift operation. 1 run contains 125 wafers per tube, requiring 1 h process time.

1. Input Specification:

Name of Item: Silicon wafers with boron $p^+$ back layer

Dimensions: 12-cm diameter

Material: High purity single crystal silicon with B dopant

Other Specifications: Wafers have been diffused with $BCl_3$, etch-step applied to back surface, oxide removed, etched on front surface, centrifuge-rinsed/dried, plasma cleaned, texture-etched, and centrifuge-rinsed/dried again. 1 run contains 125 wafers of 1.4137 $m^2$. 8 tubes operate simultaneously. At 90% equipment availability, production rate is 10.18 $m^2$/h.

1.1 Quantity Required: 10.18 $m^2$ / h    Unit Cost: 41.21 $/ $m^2$

| | |
|---|---|
| 1.2 Input Value: | 419.52 $/ h |
| 1.3 Input Cost: | ________$/________ |

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 3 . 1 . 0 1 - 0 2

Form 3

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**2.1 Direct Materials:**

2.1.1 Type: Phosphine gas;

Specification: Cost of the phosphine is 828.07/$ft^3$ (Motorola). Consumption is 0.1164 $ft^3/h$ (for 8 tubes). Flowing only during machine availability.;

Quantity Required: 3.0 ℓ / h; Unit Cost: 0.991 $/ℓ; Cost: 2.94 $/h

2.1_ Type: ______;

Specification: ______;

Quantity Required: ______ /____; Unit Cost: ______ $/______; Cost: ______ $/______

2.1_ Type: ______;

Specification: ______;

Quantity Required: ______ /____; Unit Cost: ______ $/______; Cost: ______ $/______

| 2.1 | Subtotal Direct Materials: | 2.94 $/h |
|---|---|---|

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.21 Type: Argon gas;

Specification: Used as the carrier gas for phosphine. Cost is \$0.14/ft$^3$ (SAMICS E1112D). Consumption is 14.8 ft$^3$/h (for 8 tubes) during 0.95 of time.

Quantity Required: 398 ℓ /h; Unit Cost: 0.005 \$/ℓ; Cost: 1.99 \$/h

2.2_ Type:

Specification:

Quantity Required: /; Unit Cost: \$/; Cost: \$/

2.2_ Type:

Specification:

Quantity Required: /; Unit Cost: \$/; Cost: \$/

2.2 Subtotal Indirect Materials: 1.99 \$/h

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2.3 Expendable Tooling:

2.3 1 Type: Quartzware (tubes and boats) replaced annually.

Quantity Required: 1 tube set /5400 h: Unit Cost: 769 $/tube incl. boats Cost: 1.14 $/h

2.3 _ Type:

Quantity Required: / : Unit Cost: $/ Cost: $/

2.3 _ Type:

Quantity Required: / : Unit Cost: $/ Cost: $/

2.3 _ Type:

Quantity Required: / : Unit Cost: $/ Cost: $/

| | | |
|---|---|---|
| 2.3 | Subtotal Expendable Tooling: | 1.14 $/h |

2.4 Energy

2.4 1 Type: Electricity, 140 kW name-plate rating, 50% duty cycle, incl. using off hours.

Quantity Required: 70 kW : Unit Cost: 0.0319 $/kWh Cost: 2.233 $/h

2.4 _ Type:

Quantity Required: : Unit Cost: $/ Cost: $/

| | | |
|---|---|---|
| 2.4 | Subtotal Energy Costs: | 2.233 $/h |
| 2.5 | Subtotal 2.1 to 2.4: | 8.30 $/h |
| 2.6 | Handling Charge: 5.26 % of item 2.5 | 0.44 $/h |
| 2.7 | Subtotal Materials and Supplies: (2.5 + 2.6) | 8.74 $/h |

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3.1 Direct Labor:

3.1_1 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Machine operator
Amount Required: 1 h/ h ; Rate: $ 3.89 /h; Load 36.0 %; Cost: 5.29 $/h

3.1_2 Category: Maintenance Mechanic (SAMICS B3736D) Activity: Service and repair
Amount Required: 0.1 h/ h ; Rate: $ 5.67 /h; Load 36.0 %; Cost: 0.77 $/h

3.1_ Category: ____ Activity: ____
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.1 Direct Labor Subtotal: 6.06 $/h

3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 1.52 $/h

3.3 Subtotal 3.1 and 3.2: 7.58 $/h

3.4 Overhead on Labor: 5.26 % 0.40 $/h

3.5 Subtotal Labor: 7.98 $/h

Process No. 3 . 1 . 0 1 - 0 2

Form 7
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4.1 Equipment

4.11 Type: Thermco eight-tube diffusion furnace, type 4000 572 per spec 19000

Cost: 49,271 $; Installation Cost: -- $; Throughput: 10.18 $m^2$ /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 90 %; Machine Oper'g Time 7450 h/y

Servicing Costs: Labor -- h/y at -- $/h; Parts or Outside Service: ____ $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 10,520 $/y | 1.27 $/ h

4.12 Type: Eight process controllers for above furnace

Cost: 16,000 $; Installation Cost: ____ $; Throughput: 10.18 $m^2$ /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 90 %; Machine Oper'g Time 7450 h/y

Servicing Costs: Labor -- h/y at -- $/h; Parts or Outside Service: -- $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 3416 $/y | 0.413 $/ h

4.13 Type: Exhaust system

Cost: n.a. $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: -- %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y | ____ $/ ____

| 4.1 Subtotal Equipment Cost: | 1.68 $/ run |
|---|---|

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## 4.2 Facilities:

**4.21** Type: Machine area    Floor Area: 25.55 $m^2$; Throughput: 84290 $m^2$ /y

Charge Rate: 179.13 $/($m^2$·y);

Energy Use:

| | | | | |
|---|---|---|---|---|
| Heating | } included | /y at | $/ | |
| Air Cond'g | } included | /y at | $/ | |
| Lighting | } included | /y at | $/ | |

Maintenance Costs:

- Labor: ______ h/y at ______ $/h
- Supplies: included $/y
- Outside Services: ______ $/y

Total Cost: 4580 $/y    0.553 $/h

**4.2_** Type: ______ Floor Area: ______ $m^2$; Throughput: ______ /y

Charge Rate: ______ $/($m^2$·y);

Energy Use:

| | | | | |
|---|---|---|---|---|
| Heating | | /y at | $/ | |
| Air Cond'g | | /y at | $/ | |
| Lighting | | /y at | $/ | |

Maintenance Costs:

- Labor: ______ h/y at ______ $/h
- Supplies: ______ $/y
- Outside Services: ______ $/y

Total Cost: ______ $/y    ______ $/______

**4.2_** Type: ______ Floor Area: ______ $m^2$; Throughput: ______ /y

Charge Rate: ______ $/($m^2$·y);

Energy Use:

| | | | | |
|---|---|---|---|---|
| Heating | | /y at | $/ | |
| Air Cond'g | | /y at | $/ | |
| Lighting | | /y at | $/ | |

Maintenance Costs:

- Labor: ______ h/y at ______ $/h
- Supplies: ______ $/y
- Outside Services: ______ $/y

Total Cost: ______ $/y    ______ $/______

| | |
|---|---|
| 4.2 Subtotal Facilities: | 0.553 $/h |
| 4.3 Equipment and Facilities Subtotal : | 2.24 $/h |

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Process No. 3 . 1 . 01 – 02

5. Salvaged Material (Work-in-process)

| | | | |
|---|---|---|---|
| 5.1 | Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit) | 10.08 $m^2$ / h | |
| 5.21 | Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1) | 0.10 $m^2$ / h | |
| 5.22 | Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐ | ____ ____/____ | |
| 5.23 | Credit for 5.22 at the Market Value of ____$/____: | ____$/____ | |
| 5.24 | Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ____$/____: | ____$/____ | |
| 5.25 | Net Credit for 5.22 (5.23 minus 5.24): | | -- $/ -- |
| 5.26 | Material of Type 1. Lost in Process (5.21 minus 5.22) | 0.10 $m^2$ / h | |
| 5.3 | Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1) | | 4.20 $/ h |
| 5.4 | Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1) | | 415.40 $/ h |

Salvaged Materials Summary:

| | | |
|---|---|---|
| 5.8 | Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76) | ____$/____ |

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Page 1 of 1

Process No. 3 . 1 . 0 1 - 0 2

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6.3 Liquid Byproducts/Wastes (organic)

| Carry from Form 10 | _____\$/_____ |
|---|---|

6.3_ Type (Composition): _____ Quantity Produced: _____/_____

Density: _____ $g/cm^3$; Toxicity: _____ COD: _____ mg/l; BOD: _____ mg/l

Ignition Point: _____ °C; Explosive Mixture in Air: ___ % to ___ %; Other Remarks: _____

Type of Disposal: _____

Input Material for: _____ Cost(Credit) _____\$/_____; Cost: _____\$/_____

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6.4 Fumes, Gaseous Byproducts/Wastes

6.4 1 Type (Composition): $PH_3$, argon, air Quantity Produced: 125 $ft^3$ min

Energy Content (Combustion): _____ kWh/_____; Explosive Mixture in Air ___ % to ___ %.

Ignition Point: _____ °C; Aerosol ☐ Precipitates in _____ minutes pH _____

Toxicity _____ Requires Scrubbing ☐ Type of Scrubber: _____

(enter scrubber under 4.1, 4.2, scrubber effluent under 6.1 to 6.3)

Other remarks: Fumes from furnace. Exhaust fan operates continuously, Electrical consumption is 0.46 kW/1000 CFM

Type of Disposal: Exhausted into atmosphere

Operating Costs: 16.08 \$/ y ; Cost: 0.002 \$/ h

| 6. Subtotal: Byproduct/Waste Disposal Cost: | 0.002 \$/ h |
|---|---|

Process No. 3 . 1 . 01 — 02

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7. Process Cost Computation

| | |
|---|---|
| 7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.) | 18.96 $/ h |
| 7.22 Other Indirect Costs: (0.059*(4.1)+0.108*(4.2)) % of 7.11 | 0.16 $/ h |
| 7.21 Total Operating Add-on Costs of Process: | 19.12 $/ h |
| 7.22 G & A ____ % of 7.21 | $/ |
| 7.31 Total Gross Add-On Cost of Process | 19.12 $/ h |
| 7.32 Credit for Salvaged Material (5.8) | $/ |
| 7.33 Cost of Work-in-Process Lost (5.3) | 4.20 $/ h |
| 7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32) | 23.32 $/ h |
| 7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4) | 415.40 $/ h |
| 7.36 Loading on Item 7.35 at Rate ____ % | $/ |
| 7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36) | 438.72 $/h |

| | |
|---|---|
| 7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units) | 10.18 $m^2$ / h |
| 7.42 Practical Yield | 99 % |
| 7.43 Effective Yield (7.41 x 7.42) | / |
| 7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35 | 10.08 $m^2$ / h |

| | |
|---|---|
| 7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44) | 43.53 $/ $m^2$ |
| 7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44) | 2.32 $/ $m^2$ |

Process No. 3.1.01-02

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8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

| | | | | |
|---|---|---|---|---|
| 0.9274* | 1.68 $/h | from Subtotal 4.1 | = | 1.56 $/h |
| 1.946* | 0.553 $/h | from Subtotal 4.2 | = | 1.08 $/h |
| | | Subtotal | = | 2.64 $/h |

8.22 Costs of Amortization of the One-Time Cost:

| | | | | |
|---|---|---|---|---|
| 0.192* | 8.74 $/h | from Subtotal 2.7 | = | 1.68 $/h |
| 0.192* | 7.98 $/h | from Subtotal 3.5 | = | 1.53 $/h |
| 0.2958* | 1.68 $/h | from Subtotal 4.1 | = | 0.50 $/h |
| 2.77* | 0.553 $/h | from Subtotal 4.2 | = | 1.53 $/ |
| | | Subtotal | = | 5.24 $/h |

8.23 Total Net Cost of Equity (8.21 + 8.22): 7.88 $/h

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 10.08 $m^2$ / h from 7.44)

0.78 $/$m^2$

8.25 Price of Process (7.52 + 8.24) 3.10 $/$m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 44.31 $/$m^2$

Process No. 3 . 1 . 0 1 - 0 2

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0. Output Specification:

Name of item: Silicon wafers with PN -junctions

Dimensions: 12-cm diameter

Material: high purity silicon

Other Specifications:

Process No. 3 . 1 . 0 1 - 0 2 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Device generation

Subprocess: Junction formation

Option: Formation of front-junction by open-tube diffusion with $POCl_3$ (RCA)

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Form 2

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Process No. 3 . 1 . 0 1 - 0 2

**0.1 Value Added:** ______ $/ ______

Process Description: Dopant is introduced by decomposition of $POCl_3$ in diffusion furnace. There is a 10-minute pre-heat cycle in nitrogen, 45-minute cycle for diffusion and a 10 minute cool down cycle with a 90:10 $N_2:O_2$ mixture.

1. Input Specification:

Name of Item: Silicon wafers, with back-surface junction

Dimensions: 7.62-cm diameter

Material: High purity silicon

Other Specifications: Output rate is 2000 wafers/h or 9.12 $m^2$/h and machine availability is 85% for an effective output rate of 7.75 $m^2$/h.

Wafer is p-type with a resistivity of 1-5 ohm-cm and its orientation is [[100]].

Back side of wafer is protected with silica

1.1 Quantity Required: 7.75 $m^2$/h  Unit Cost: 41.21 $/ $m^2$

**1.2 Input Value:** ______ $/ ______

**1.3 Input Cost:** 319.49 $/ h

**Note to Item 1.3: Use price, if input produced in own plant.**

Process No. 3 . 1 . 01 - 02

Form 3

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2.1 Direct Materials:

2.1 1 Type: $POCl_3$ (Phosphorus oxychloride);

Specification: 0.21 g per wafer needed

Cost is \$9.26/lb, (SAMICS E1504D).

;

Quantity Required: 357 g / h; Unit Cost: 0.02 \$/ g; Cost: 7.14 \$/h

2.1_ Type: ;

Specification: ;

Quantity Required: ____ ___/___; Unit Cost: ____\$/____; Cost: ____\$/____

2.1_ Type: ;

Specification:

;

Quantity Required: ____ ___/___; Unit Cost: ____\$/____; Cost: ____\$/____

| 2.1 Subtotal Direct Materials: | 7.14 \$/h |
|---|---|

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Nitrogen;

Specification: 1360 $cm^3$ required per wafer.

Obtained from liquid nitrogen (SAMICS C1080D)

Quantity Required: 2312 ℓ / h; Unit Cost: 0.0004 $/ ℓ; Cost: 0.92 $/ h

2.2.2 Type: Oxygen

Specification: 33 $cm^3$ required per wafer

Cost is 0.0052 $/ft^3$ (SAMICS E1448D).

Quantity Required: 56.1 ℓ / h; Unit Cost: 0.000184 $/ ℓ; Cost: 0.01 $/ h

2.2 _ Type:

Specification:

Quantity Required: ____ / ____; Unit Cost: ____ $/ ____; Cost: ____ $/ ____

| 2.2 Subtotal Indirect Materials: | 0.93 $/ h |
|---|---|

Process No. 3 . 1 . 0 1 – 0 2



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2.3 Expendable Tooling:

2.3 1 Type: Silicon boats, 76-cm long

Quantity Required: 4 boats/y : Unit Cost: 1350 $/boat Cost: 0.65 $/h

2.3 _ Type:

Quantity Required: ____ /____ : Unit Cost: ____ $/____ Cost: ____ $/____

2.3 _ Type:

Quantity Required: ____ /____ : Unit Cost: ____ $/____ Cost: ____ $/____

2.3 _ Type:

Quantity Required: ____ /____ : Unit Cost: ____ $/____ Cost: ____ $/____

| | | |
|---|---|---|
| 2.3 | Subtotal Expendable Tooling: | 0.65 $/h |

2.4 Energy

2.4 1 Type: Power requirements are 40 kW and usage fraction is 85%

Quantity Required: 34 kW : Unit Cost: 0.0319 $/kWh Cost: 1.08 $/h

2.4 _ Type:

Quantity Required: ____ : Unit Cost: ____ $/____ Cost: ____ $/____

| | | |
|---|---|---|
| 2.4 | Subtotal Energy Costs: | 1.08 $/h |
| 2.5 | Subtotal 2.1 to 2.4: | 9.81 $/h |
| 2.6 | Handling Charge: 5.26 % of item 2.5 | 1.12 $/h |
| 2.7 | Subtotal Materials and Supplies: (2.5 + 2.6) | 10.33 $/h |

Process No. 3.1.01-02

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Revision ______ Date ______

3.1 Direct Labor:

3.1 1 Category: Semiconductor assembler (SAMICS B3096D) Activity: Machine operation and attendance

Amount Required: 0.35 h/ h ; Rate: $ 3.894 /h; Load 36.0 %; Cost: 1.85 $/h

3.1 2 Category: Maintenance mechanic (SAMICS B3736D) Activity: Service and repair of furnace

Amount Required: 0.15 h/ h ; Rate: $ 5.67 /h; Load 36.0 %; Cost: 1.16 $/h

3.1_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.1 Direct Labor Subtotal: 3.01 $/h

3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2 Indirect Labor Subtotal: 0.75 $/h

| | | |
|---|---|---|
| 3.3 Subtotal 3.1 and 3.2 | 3.76 | $/h |
| 3.4 Overhead on Labor: 5.26 % | 0.20 | $/h |
| 3.5 Subtotal Labor | 3.96 | $/h |

Process No. 3 . 1 . 0 1 - 0 2

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4.1 Equipment

4.11 Type: $POCl_3$ diffusion furnace (Thermco SPARTAN furnace)

Cost: 66,600 $; Installation Cost: ________ $; Throughput: 9.12 $m^2$ /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 85 %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 14,200 $/y — 1.72 $/h

4.12 Type: Furnace liners, paddles and heat coil

Cost: 21,600 $; Installation Cost: ________ $; Throughput: 9.12 $m^2$ /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 85 %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 4,600 $/y — 0.56 $/h

4.13 Type: Clam shell unloader and cassette stacker

Cost: 18,000 $; Installation Cost: ________ $; Throughput: 9.12 $m^2$ /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 85 %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 3,800 $/y — 0.46 $/h

| 4.1 Subtotal Equipment Cost: | 2.74 $/h |
|---|---|

Process No. 3 . 1 . 0 1 – 0 2

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4.2 Facilities:

4.2.1 Type: Furnace area Floor Area: 25.55 $m^2$; Throughput: 64,200 $m^2$/y

Charge Rate: 179.13* $/($m^2$·y);

| Energy Use: | | | Maintenance Costs: | |
|---|---|---|---|---|
| Heating | ____ ____/y at | ____$/____ | Labor: | ____h/y at ____$/h |
| Air Cond'g | ____ ____/y at | ____$/____ | Supplies: | ____$/y |
| Lighting | ____ ____/y at | ____$/____ | Outside Services: | ____$/y |
| | | | Total Cost: | 4,600 $/y |

0.55 $/h

4.2_ Type: ____ Floor Area: ____ $m^2$; Throughput: ____ ____/y

Charge Rate: ____ $/($m^2$·y);

| Energy Use: | | | Maintenance Costs: | |
|---|---|---|---|---|
| Heating | ____ ____/y at | ____$/____ | Labor: | ____h/y at ____$/h |
| Air Cond'g | ____ ____/y at | ____$/____ | Supplies: | ____$/y |
| Lighting | ____ ____/y at | ____$/____ | Outside Services: | ____$/y |
| | | | Total Cost: | ____$/y |

____$/____

4.2_ Type: ____ Floor Area: ____ $m^2$; Throughput: ____ ____/y

Charge Rate: ____ $/($m^2$·y);

| Energy Use: | | | Maintenance Costs: | |
|---|---|---|---|---|
| Heating | ____ ____/y at | ____$/____ | Labor: | ____h/y at ____$/h |
| Air Cond'g | ____ ____/y at | ____$/____ | Supplies: | ____$/y |
| Lighting | ____ ____/y at | ____$/____ | Outside Services: | ____$/y |
| | | | Total Cost: | ____$/y |

____$/____

*Includes energy use

| | |
|---|---|
| 4.2 Subtotal Facilities: | 0.55 $/h |
| 4.3 Equipment and Facilities Subtotal : | 3.29 $/h |

Form 9-1

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Process No. 3 . 1 . 01 – 02

5. Salvaged Material (Work-in-process)

| | | | |
|---|---|---|---|
| 5.1 | Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit) | 7.675 $m^2$ / h | |
| 5.21 | Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1) | 0.0775 $m^2$ / h | |
| 5.22 | Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐ | ______ ______ / ______ | |
| 5.23 | Credit for 5.22 at the Market Value of ______ $/ ______ : | ______ $/ ______ | |
| 5.24 | Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ______ $/ ______ : | ______ $/ ______ | |
| 5.25 | Net Credit for 5.22 (5.23 minus 5.24): | | ______ $/ ______ |
| 5.26 | Material of Type 1. Lost in Process (5.21 minus 5.22) | 0.0775 $m^2$ / h | |
| 5.3 | Cost of Work-in-Process Not Contained in Good Output Work-in-Process (Amount 5.21 Times Unit Cost 1.1) | | 3.19 $/ h |
| 5.4 | Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.1 Times Unit Cost from 1.1) | | 316.29 $/ h |

Salvaged Materials Summary:

| | | |
|---|---|---|
| 5.8 | Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76) | ______ $/ ______ |

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Process No. 3 . 1 . 0 1 — 0 2 Revision ______ Date 3/79

7. Process Cost Computation

| | |
|---|---|
| 7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.) | 17.58 $/h |
| 7.22 Other Indirect Costs: (0.059*4.1+0.108*4.2) ______% of 7.11 | 0.22 $/h |
| 7.21 Total Operating Add-on Costs of Process: | 17.80 $/h |
| 7.22 G & A ______% of 7.21 | ______ $/______ |
| 7.31 Total Gross Add-On Cost of Process | 17.80 $/h |
| 7.32 Credit for Salvaged Material (5.8) | ______ $/______ |
| 7.33 Cost of Work-in-Process Lost (5.3) | 3.19 $/h |
| 7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32) | 20.99 $/h |
| 7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4) | 316.29 $/h |
| 7.36 Loading on Item 7.35 at Rate ______% | ______ $/______ |
| 7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36) | 337.28 $/h |

| | |
|---|---|
| 7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units) | 7.753 $m^2$ / h |
| 7.42 Practical Yield | 99.0 % |
| 7.43 Effective Yield (7.41 x 7.42) | ______ / ______ |
| 7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35 | 7.675 $m^2$ / h |

| | |
|---|---|
| 7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44) | 43.94 $/ $m^2$ |
| 7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44) | 2.73 $/ $m^2$ |

Process No. 3.1.01-02

Form 13-2
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Revision ______ Date ______

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

| | | | | |
|---|---|---|---|---|
| 0.9274* 2.74 $/ h | from Subtotal 4.1 = | 2.54 $/ h | | |
| 1.946* 0.55 $/ h | from Subtotal 4.2 = | 1.08 $/ h | | |
| | Subtotal = | 3.62 $/ h | | |

8.22 Costs of Amortization of the One-Time Cost:

| | | | | |
|---|---|---|---|---|
| 0.192* 10.33 $/ h | from Subtotal 2.7 = | 1.98 $/ h | | |
| 0.192* 3.96 $/ h | from Subtotal 3.5 = | 0.76 $/ h | | |
| 0.2958* 2.74 $/ h | from Subtotal 4.1 = | 0.81 $/ h | | |
| 2.77* 0.55 $/ h | from Subtotal 4.2 = | 1.53 $/ h | | |
| | Subtotal = | 5.08 $/ h | | |

8.23 Total Net Cost of Equity (8.21 + 8.22): 8.70 $/h

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 7.675 $m^2$ / h from 7.44)

1.13 $/ $m^2$

8.25 Price of Process (7.52 + 8.24) 3.86 $/ $m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 45.07 $/ $m^2$

Process No. 3.1.01-02

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0. Output Specification:

Name of item: Wafer with NP-junction

Dimensions: 7.62-cm diameter

Material: High purity silicon

Other Specifications: Wafers are contained in 500 sheet cassettes.

Process No. 3 . 1 . 0 1 — 0 1 Form 1

3 . 1 - 0 1 - 0 7

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Device Fabrication

Subprocess: Junction Formation

Option: Projected Ion Implantation (both sides) (RCA)

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Form 2



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Process No. 3 . 1 . 0 1 – 0 1

| 0.1 Value Added: | ______ $/ ______ |
|---|---|

Process Description: Ion implantation of phosphorous and boron ions to form wafer with a $npp^+$ junction. Output of machine is 2000 3" cells/h (both sides) but machine availability is 85% for an effective output rate of 1700 cells/h. Cell output is 0.717 watts. Machine current is 10 mA per ion beam. Front junction dosage of phosphorous is $1 \times 10^{15}$ ions/$m^2$ and the boron dosage is $5 \times 10^{14}$ ions/$cm^2$.

1. Input Specification:

Name of Item: Wafers that are cleaned by the Z-wafer cleaning process

Dimensions: 3" (7.62-cm diameter)

Material: SeG-Si

Other Specifications: Cleaning process is a hot Caro's acid immersion followed by three cascade rinses in deionized water and spin-drying. Output rate of 1700 wafers/h is equal to 7.753 $m^2$/h.

1.1 Quantity Required: 7.753 $m^2$ / h    Unit Cost: 41.21 $/ $m^2$

| 1.2 Input Value: | ______ $/ ______ |
|---|---|
| 1.3 Input Cost: | 319.50 $/ h |

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 3 . 1 . 01 - 01

Form 3

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2.1 Direct Materials:

2.11 Type: Ion source gas;

Specification: Cost is 2.28 $/h and is only needed when machine is operating.

Quantity Required: 0.85 ___/___; Unit Cost: 2.28 $/ h; Cost: 1.94 $/ h

2.1_ Type: ______;

Specification: ______;

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: ______ $/______

2.1_ Type: ______;

Specification: ______;

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: ______ $/______

| | |
|---|---|
| 2.1 Subtotal Direct Materials: | 1.94 $/ h |

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Cooling water;

Specification: Usage is 2400 ℓ/h machine (used continuously). Cost is $8480/150,000 $ft^3$ (SAMICS Catalog No. C1016B).

Quantity Required: 2400 ℓ/h; Unit Cost: 0.000113 $/ℓ; Cost: 0.27 $/h

2.2.2 Type: Liquid $N_2$

Specification: Quantity required is 10 ℓ/h and usage fraction is 0.925. Cost is $5.66/$ft^3$ (SAMICS No. C1080D).

Quantity Required: 9.25 ℓ/h; Unit Cost: 0.20 $/ℓ; Cost: 1.85 $/h

2.2._ Type:

Specification:

Quantity Required: ____/____; Unit Cost: ____$/____; Cost: ____$/____

| 2.2 Subtotal Indirect Materials: | 2.12 $/h |
|---|---|

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**2.3 Expendable Tooling:**

| | | | | |
|---|---|---|---|---|
| 2.3 1 Type: Spare parts; cost is $8,000/y/machine | | | | |
| Quantity Required: 0.97 | $ / h | Unit Cost: ___ $/ ___ | Cost: | 0.97 $/ h |
| 2.3 _ Type: | | | | |
| Quantity Required: | ___/___ | Unit Cost: ___ $/ ___ | Cost: | ___ $/ ___ |
| 2.3 _ Type: | | | | |
| Quantity Required: | ___/___ | Unit Cost: ___ $/ ___ | Cost: | ___ $/ ___ |
| 2.3 _ Type: | | | | |
| Quantity Required: | ___/___ | Unit Cost: ___ $/ ___ | Cost: | ___ $/ ___ |
| | | 2.3 | Subtotal Expendable Tooling: | 0.97 $/ h |



**2.4 Energy**

| | | | | |
|---|---|---|---|---|
| 2.4 1 Type: Electricity 40 kWh/machine and usage fraction is 0.925 | | | | |
| Quantity Required: 37 kW | | Unit Cost: 0.0319 $/ kWh | Cost: | 1.18 $/h |
| 2.4 _ Type: | | | | |
| Quantity Required: | | Unit Cost: ___ $/ ___ | Cost: | ___ $/ ___ |
| | | 2.4 | Subtotal Energy Costs: | 6.20 $/h |

| | |
|---|---|
| 2.5 Subtotal 2.1 to 2.4: | 6.20 $/h |
| 2.6 Handling Charge: 5.26 % of item 2.5 | 0.33 $/h |
| 2.7 Subtotal Materials and Supplies: (2.5 + 2.6) | 6.53 $/h |

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Form 4

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Cooling water;

Specification: Usage is 2400 ℓ/h machine (used continuously). Cost is $8480/150,000 $ft^3$ (SAMICS Catalog No. C1016B).

Quantity Required: 2400 ℓ / h; Unit Cost: 0.000113 $/ℓ; Cost: 0.27 $/h

2.2.2 Type: Liquid $N_2$

Specification: Quantity required is 10 ℓ/h and usage fraction is 0.925. Cost is $5.66/$ft^3$ (SAMICS No. C1080D).

Quantity Required: 9.25 ℓ/ h; Unit Cost: 0.20 $/ℓ; Cost: 1.85 $/h

2.2._ Type: ______

Specification: ______

Quantity Required: ______ /______; Unit Cost: ______ $/______; Cost: ______ $/______

2.2 Subtotal Indirect Materials: 2.12 $/h

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2.3 Expendable Tooling:

2.3 1 Type: Spare parts; cost is $8,000/y/machine

Quantity Required: 0.97 $ / h : Unit Cost: ____ $/ ____ Cost: 0.97 $/ h

2.3 _ Type: ____

Quantity Required: ____ ____ / ____ : Unit Cost: ____ $/ ____ Cost: ____ $/ ____

2.3 _ Type: ____

Quantity Required: ____ ____ / ____ : Unit Cost: ____ $/ ____ Cost: ____ $/ ____

2.3 _ Type: ____

Quantity Required: ____ ____ / ____ : Unit Cost: ____ $/ ____ Cost: ____ $/ ____

| | |
|---|---|
| 2.3 Subtotal Expendable Tooling: | 0.97 $/ h |

2.4 Energy

2.4 1 Type: Electricity 40 kWh/machine and usage fraction is 0.925

Quantity Required: 37 kW : Unit Cost: 0.0319 $/ kWh Cost: 1.18 $/ h

2.4 _ Type: ____

Quantity Required: ____ ____ : Unit Cost: ____ $/ ____ Cost: ____ $/ ____

| | |
|---|---|
| 2.4 Subtotal Energy Costs: | 6.20 $/ h |
| 2.5 Subtotal 2.1 to 2.4: | 6.20 $/ h |
| 2.6 Handling Charge: 5.26 % of item 2.5 | 0.33 $/ h |
| 2.7 Subtotal Materials and Supplies: (2.5 + 2.6) | 6.53 $/ h |

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3.1 Direct Labor:

3.11 Category: Semiconductor Assembler (SAMICS No. B3096D) Activity: Machine operator
Amount Required: 0.4 h/ h ; Rate: $ 3.89 /h; Load 36.0 %; Cost: 2.12 $/ h

3.12 Category: Maintenance Mechanic (SAMICS No. B3736D) Activity: Service and repair
Amount Required: 0.1 h/ h ; Rate: $ 5.67 /h; Load 36.0 %; Cost: 0.77 $/ h

3.1_ Category: ______ Activity: ______
Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ __

3.1 Direct Labor Subtotal: 2.89 $/ h

3.2 Indirect Labor:

3.2_ Category: ______ Activity: ______
Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ __

3.2_ Category: ______ Activity: ______
Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ __

3.2_ Category: ______ Activity: ______
Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ __

3.2 Indirect Labor Subtotal: 0.72 $/ h

| | | |
|---|---|---|
| 3.3 Subtotal 3.1 and 3.2 | 3.61 | $/ h |
| 3.4 Overhead on Labor: 5.26 % | 0.19 | $/ h |
| 3.5 Subtotal Labor | 3.80 | $/ h |

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Process No. 3 . 1 . 0 1 - 0 1

4.1 Equipment

4.1 1 Type: Ion implanter - does both sides and has a current output of 10 mA

Cost: 700,000 $; Installation Cost: --- $; Throughput: 9.121 $m^2$ /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 85 %; Machine Oper'g Time 7040 h/y

Servicing Costs: Labor -- h/y at -- $/h;Parts or Outside Service: -- $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 150,000 $/y — 18.12 $/ h

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h;Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y — ____ $/____

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h;Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y — ____ $/____

| 4.1 Subtotal Equipment Cost: | 18.12 $/ $m^2$ |
|---|---|

Process No. 3 . 1 . 0 1 - 0 1

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4.2 Facilities:

4.2.1 Type: Machine area Floor Area: 79 $m^2$; Throughput: $6.42 \times 10^4$ $m^2$ /y

Charge Rate: 179.13* $/($m^2$·y);

| Energy Use: | | | |
|---|---|---|---|
| Heating | ____ ____/y | at ____ | $/____ |
| Air Cond'g | ____ ____/y | at ____ | $/____ |
| Lighting | ____ ____/y | at ____ | $/____ |

Maintenance Costs:

| | | |
|---|---|---|
| Labor: | ____ h/y at ____ | $/h |
| Supplies: | ____ | $/y |
| Outside Services: | ____ | $/y |

Total Cost: 14,150 $/y — 1.71 $/ h

4.2._ Type: ____ Floor Area: ____ $m^2$; Throughput: ____ ____/y

Charge Rate: ____ $/($m^2$·y);

| Energy Use: | | | |
|---|---|---|---|
| Heating | ____ ____/y | at ____ | $/____ |
| Air Cond'g | ____ ____/y | at ____ | $/____ |
| Lighting | ____ ____/y | at ____ | $/____ |

Maintenance Costs:

| | | |
|---|---|---|
| Labor: | ____ h/y at ____ | $/h |
| Supplies: | ____ | $/y |
| Outside Services: | ____ | $/y |

Total Cost: ____ $/y — ____ $/____

4.2._ Type: ____ Floor Area: ____ $m^2$; Throughput: ____ ____/y

Charge Rate: ____ $/($m^2$·y);

| Energy Use: | | | |
|---|---|---|---|
| Heating | ____ ____/y | at ____ | $/____ |
| Air Cond'g | ____ ____/y | at ____ | $/____ |
| Lighting | ____ ____/y | at ____ | $/____ |

Maintenance Costs:

| | | |
|---|---|---|
| Labor: | ____ h/y at ____ | $/h |
| Supplies: | ____ | $/y |
| Outside Services: | ____ | $/y |

Total Cost: ____ $/y — ____ $/____

*Includes energy use

| | |
|---|---|
| 4.2 Subtotal Facilities: | 1.71 $/ h |
| 4.3 Equipment and Facilities Subtotal : | 19.82 $/ h |

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Process No. 3 . 1 . 0 1 – 0 1

5. Salvaged Material (Work-in-process)

| | | | |
|---|---|---|---|
| 5.1 | Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit) | 7.675 $m^2$ / h | |
| 5.21 | Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1) | 0.078 $m^2$ / h | |
| 5.22 | Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process □ . □ . □□ – □□ | ____ ____ / ____ | |
| 5.23 | Credit for 5.22 at the Market Value of ____ $/ ____ : | ____ $/ ____ | |
| 5.24 | Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ____ $/ ____ : | ____ $/ ____ | |
| 5.25 | Net Credit for 5.22 (5.23 minus 5.24): | | ____ $/ ____ |
| 5.26 | Material of Type 1. Lost in Process (5.21 minus 5.22) | 0.78 $m^2$ / h | |
| 5.3 | Cost of Work-in-Process Not Contained in Good Output Work-in-Process (Amount 5.21 Times Unit Cost 1.1) | | 3.20 $/ h |
| 5.4 | Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.1 Times Unit Cost from 1.1) | | 316.30 $/ h |

Salvaged Materials Summary:

| | | |
|---|---|---|
| 5.8 | Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76) | ____ $/ ____ |

Process No. 3 . 1 . 0 1 — 0 1

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7. Process Cost Computation

| | | |
|---|---|---|
| 7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.) | 30.16 | $/ h |
| 7.22 Other Indirect Costs: (0.059 * (4.1) + 0.108 * (4.2)) % of 7.11 | 1.25 | $/ h |
| 7.21 Total Operating Add-on Costs of Process: | 31.41 | $/ h |
| 7.22 G & A ______ % of 7.21 | | $/ |
| 7.31 Total Gross Add-On Cost of Process | 31.41 | $/ h |
| 7.32 Credit for Salvaged Material (5.8) | | $/ |
| 7.33 Cost of Work-in-Process Lost (5.3) | 3.20 | $/ h |
| 7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32) | 34.61 | $/ h |
| 7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4) | 316.30 | $/ h |
| 7.36 Loading on Item 7.35 at Rate ______ % | | $/ |
| 7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36) | 350.91 | $/ h |

| | |
|---|---|
| 7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units) | 7.753 $m^2$ / h |
| 7.42 Practical Yield | 99 % |
| 7.43 Effective Yield (7.41 x 7.42) | 7.675 $m^2$ / h |
| 7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35 | ______ / ______ |

| | | |
|---|---|---|
| 7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44) | 45.72 | $/ $m^2$ |
| 7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44) | 4.51 | $/ $m^2$ |

Process No. 3.1.01-01

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8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 18.12 $/h from Subtotal 4.1 = 16.80 $/h

1.946* 1.71 $/h from Subtotal 4.2 = 3.33 $/h

Subtotal = 20.13 $/h

8.22 Costs of Amortization of the One-Time Cost:

0.192* 6.53 $/h from Subtotal 2.7 = 1.26 $/h

0.192* 3.80 $/h from Subtotal 3.5 = 0.73 $/h

0.2958* 18.12 $/h from Subtotal 4.1 = 5.36 $/h

2.77* 1.71 $/h from Subtotal 4.2 = 4.73 $/h

Subtotal = 12.08 $/h

8.23 Total Net Cost of Equity (8.21 + 8.22): 23.21 $/h

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 7.675 $m^2$/h from 7.44)

4.20 $/$m^2$

8.25 Price of Process (7.52 + 8.24) 8.71 $/$m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 49.92 $/$m^2$

Process No. 3 . 1 . 0 1 - 0 1

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0. Output Specification:

Name of item: Wafers with $NPP^+$ Junction

Dimensions: 7.62-cm diameter

Material: High purity silicon

Other Specifications: Output of cell is 0.717 watts ( $\eta$ = 15.7%).

Front dosage of phosphorus is $1 \times 10^{15}$ ions/cm$^2$, and was placed on selected areas using a mask. The back surface field consists of boron at a concentration of $5 \times 10^{14}$ ions/cm$^2$.

Process No. 3 . 1 . 0 1 - 0 1 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Device Fabrication

Subprocess: Formation of Potential Barrier

Option: Ion Implantation of Phosphorus (Lockheed)

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Process No. 3 . 1 . 0 1 - 0 1

**0.1 Value Added:** ________ $/________

Process Description: Ion implantation of phosphorus with a $2 \times 10^{15}$ ions/cm$^2$ dosage using $PF_5$. The output rate is 50 wafers/minute and each wafer spends an average of 20 hours at the work station. There is a 2 h load time, 16 h process time, and a 2 h unload time. Machine usage fraction is 95%; actual output is 2850 wafers/h. Filament life is assumed to be 80 mAh and the filament operates with a current of 10 mA. It takes 20 minutes to change the filament.

1. Input Specification:

Name of Item: Texture etched Si wafers

Dimensions: 7.62-cm diameter

Material: High purity silicon

Other Specifications: Ion dose is $3 \times 10^{15}$ ions/cm$^2$.

Ion implantation unit has four side load-unload chambers surrounding the central implantation chamber. Area output rate is 13 m$^2$/h.

1.1 Quantity Required: 13.0 m$^2$ /h     Unit Cost: 41.21 $/m$^2$

| | |
|---|---|
| **1.2 Input Value:** | ________ $/________ |
| **1.3 Input Cost:** | 535.73 $/h |

Note to Item 1.3: Use price, if input produced in own plant.

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Form 3

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2.1 Direct Materials:

2.1 1 Type: Phosphorous pentaflouride ($PF_5$), 99.0%;

Specification: Consumption rate of 0.0052725 mℓ/min is based on current usage. Actual usage should be (0.005275) x (2850) x 2.43 x 60. Density is 5.805 g/ℓ. Cost is approx. $400/lb (Matheson).;

Quantity Required: 2192 mℓ / min; Unit Cost: 0.0051 $/mℓ; Cost: 11.22 $/h

2.1_ Type: ______;

Specification: ______;

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: ______ $/______

2.1_ Type: ______;

Specification: ______;

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: ______ $/______

2.1 Subtotal Direct Materials: 11.22 $/h

Process No. 3 . 1 . 0 1 – 0 1

Form 4

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2 1 Type: Cooling water ;

Specification: Used to cool diffusion pumps which have a power rating of about 7 kW (SAMICS C1128D)..

Quantity Required: 7 kW / ; Unit Cost: 0.566 \$/ kWh ; Cost: 3.962 \$/ h

2.2 2 Type: Compressed air

Specification: Pressure is 50 psi. Used for operation of gate valves and air cushion bearings. Only needed when machine is running. Consumption is 0.0988 $ft^3$/min. (SAMICS C2032D).

Quantity Required: 168 ℓ / h ; Unit Cost: \$/ ; Cost: \$/

2.2 3 Type: Liquid nitrogen

Specification: Used for diffusion pump traps and is needed at all times. Cost is \$5.66/$ft^3$ (SAMICS C1080D)

Quantity Required: 3.75 ℓ / h ; Unit Cost: 0.20 \$/ ℓ ; Cost: 0.75 \$/ h

| | |
|---|---|
| 2.2 Subtotal Indirect Materials: | 4.712 \$/ h |

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2 4 Type: Argon;

Specification: Used to flush system. Consumption rate is 0.485 $ft^3$/min and usage rate is 97%. Cost is 0.14 $/$ft^3$ (SAMICS E1112D).

Quantity Required: 800 ℓ / h; Unit Cost: 0.005 $/ℓ; Cost: 4.00 $/h

2.2_ Type: ______

Specification: ______

Quantity Required: ______ / ______; Unit Cost: ______ $/ ______; Cost: ______ $/ ______

2.2_ Type: ______

Specification: ______

Quantity Required: ______ / ______; Unit Cost: ______ $/ ______; Cost: ______ $/ ______

2.2 Subtotal Indirect Materials: 4.00 $/h

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2.3 Expendable Tooling:

2.3 _ Type: ____

____ Quantity Required: ____ ____/____: Unit Cost: ____$/____ Cost: ____$/____

2.3 _ Type: ____

____ Quantity Required: ____ ____/____: Unit Cost: ____$/____ Cost: ____$/____

2.3 _ Type: ____

____ Quantity Required: ____ ____/____: Unit Cost: ____$/____ Cost: ____$/____

2.3 _ Type: ____

____ Quantity Required: ____ ____/____: Unit Cost: ____$/____ Cost: ____$/____

| | | |
|---|---|---|
| 2.3 | Subtotal Expendable Tooling: | ____$/____ |

2.4 Energy

2.4 1 Type: Electricity, used at all times; power rating is 7 kW

____ Quantity Required: 7 kW : Unit Cost: 0.0319 $/kWh Cost: 0.223 $/h

2.4 _ Type: ____

____ Quantity Required: ____ ____: Unit Cost: ____$/____ Cost: ____$/____

| | |
|---|---|
| 2.4 Subtotal Energy Costs: | 0.223 $/h |
| 2.5 Subtotal 2.1 to 2.4: | 20.12 $/h |
| 2.6 Handling Charge: 5.26 % of item 2.5 | 1.05 $/h |
| 2.7 Subtotal Materials and Supplies: (2.5 + 2.6) | 21.17 $/h |

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## 3.1 Direct Labor:

3.1 1 Category: Electronics Technician (SAMICS B3704D) Activity: Machine operation
Amount Required: 1 h/ h; Rate: $ 5.29 /h; Load 36.0 %; Cost: 7.20 $/h

3.1_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /n; Load ____ %; Cost: ____ $/ ____

3.1_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.1 Direct Labor Subtotal: 7.20 $/h

## 3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 1.80 $/h

| | | |
|---|---|---|
| 3.3 Subtotal 3.1 and 3.2 | 9.00 | $/h |
| 3.4 Overhead on Labor: 5.26% | 0.47 | $/h |
| 3.5 Subtotal Labor | 9.47 | $/h |

Process No. 3 . 1 . 01 - 01

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4.1 Equipment

4.11 Type: Ion Implantation System

Cost: 300,000 $; Installation Cost: ________ $; Throughput: 2850 wafers /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 95 %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 64,050 $/y — 7.73 $/h

4.12 Type: Central chamber and five side chambers for above

Cost: 140,000 $; Installation Cost: ________ $; Throughput: 2850 wafers /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 95 %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 29,900 $/y — 3.60 $/h

4.13 Type: Trays (2,000) @ $30. each

Cost: 60,000 $; Installation Cost: ________ $; Throughput: 2850 wafers /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 95 %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 12,800 $/y — 1.57 $/h

4.1 Subtotal Equipment Cost: 12.90 $/h

Process No. 3 . 1 . 0 1 – 0 1


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4.2 Facilities:

4.21 Type: Manufacturing space  Floor Area: 139.355 $m^2$; Throughput: 23,600,000 wafer /y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating ____ ____/y at ____ $/____
Air Cond'g ____ ____/y at ____ $/____
Lighting ____ ____/y at ____ $/____

Maintenance Costs:

Labor: ____ h/y at ____ $/h
Supplies: ____ $/y
Outside Services: ____ $/y

Total Cost: 25,000 $/y — 3.00 $/h

4.2_ Type: ____ Floor Area: ____ $m^2$; Throughput: ____ ____/y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating ____ ____/y at ____ $/____
Air Cond'g ____ ____/y at ____ $/____
Lighting ____ ____/y at ____ $/____

Maintenance Costs:

Labor: ____ h/y at ____ $/h
Supplies: ____ $/y
Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

4.2_ Type: ____ Floor Area: ____ $m^2$; Throughput: ____ ____/y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating ____ ____/y at ____ $/____
Air Cond'g ____ ____/y at ____ $/____
Lighting ____ ____/y at ____ $/____

Maintenance Costs:

Labor: ____ h/y at ____ $/h
Supplies: ____ $/y
Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

| | |
|---|---|
| 4.2 Subtotal Facilities: | 3.00 $/h |
| 4.3 Equipment and Facilities Subtotal : | 15.90 $/h |

* Includes utility use

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Process No. 3 . 1 . 01 – 01

5. Salvaged Material (Work-in-process)

| | | | |
|---|---|---|---|
| 5.1 | Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit) | 12.90 $m^2$/h | |
| 5.21 | Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1) | 0.10 $m^2$/h | |
| 5.22 | Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐ | ______ ______/______ | |
| 5.23 | Credit for 5.22 at the Market Value of ______$/______: | ______$/______ | |
| 5.24 | Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ______$/______: | ______$/______ | |
| 5.25 | Net Credit for 5.22 (5.23 minus 5.24): | | ______$/______ |
| 5.26 | Material of Type 1. Lost in Process (5.21 minus 5.22) | 0.10 $m^2$/h | |
| 5.3 | Cost of Work-in-Process Not Contained in Good Output Work-in-Process (Amount 5.21 Times Unit Cost 1.1) | | 4.12 $/h |
| 5.4 | Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.1 Times Unit Cost from 1.1) | | 531.61 $/h |

Salvaged Materials Summary:

| | | |
|---|---|---|
| 5.8 | Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76) | ______$/______ |

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Process No. 3 . 1 . 0 1 — 0 1

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7. Process Cost Computation

| | | |
|---|---|---|
| 7.11 | Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.) | 46.54 $/ h |
| 7.22 | Other Indirect Costs: (0.059 x 4.1 + 0.108 x 4.2) ______ % of 7.11 | 1.08 $/ h |
| 7.21 | Total Operating Add-on Costs of Process: | 47.62 $/ h |
| 7.22 | G & A ______ % of 7.21 | ______ $/ ______ |
| 7.31 | Total Gross Add-On Cost of Process | 47.62 $/ h |
| 7.32 | Credit for Salvaged Material (5.8) | ______ $/ ______ |
| 7.33 | Cost of Work-in-Process Lost (5.3) | 4.12 $/ h |
| 7.34 | Specific Add-On Cost of Process (7.31 + 7.33)-(7.32) | 51.74 $/ h |
| 7.35 | Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4) | 531.61 $/ h |
| 7.36 | Loading on Item 7.35 at Rate ______ % | ______ $/ ______ |
| 7.37 | Cost of Output Work-in-Process (7.34 + 7.35 + 7.36) | 583.35 $/ h |

| | | |
|---|---|---|
| 7.41 | Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units) | 13.0 $m^2$ / h |
| 7.42 | Practical Yield | 99.2 % |
| 7.43 | Effective Yield (7.41 x 7.42) | 12.9 $m^2$ / h |
| 7.44 | Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35 | ______ / ______ |

| | | |
|---|---|---|
| 7.51 | Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44) | 45.23 $/ $m^2$ |
| 7.52 | Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44) | 4.01 $/ $m^2$ |

Process No. 3.1.01-01

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8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 12.90 $/ h from Subtotal 4.1 = 11.96 $/ h

1.946* 3.00 $/ h from Subtotal 4.2 = 5.84 $/ h

Subtotal = 17.82 $/ h

8.22 Costs of Amortization of the One-Time Cost:

0.192* 21.17 $/ h from Subtotal 2.7 = 4.07 $/ h

0.192* 9.47 $/ h from Subtotal 3.5 = 1.82 $/ h

0.2958* 12.90 $/ h from Subtotal 4.1 = 3.82 $/ h

2.77* 3.00 $/ h from Subtotal 4.2 = 8.31 $/ h

Subtotal = 18.02 $/ h

8.23 Total Net Cost of Equity (8.21 + 8.22): 35.84 $/ h

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 12.9 $m^2$ / h from 7.44)

2.78 $/ $m^2$

8.25 Price of Process (7.52 + 8.24) 6.79 $/ $m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 48.00 $/ $m^2$

Process No: 3 . 1 . 0 1 - 0 1

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9. Process Economic Evaluation:

| | | |
|---|---|---|
| 9.1 | Process Cost Balance (7.52 - 0.1) | \$/ |
| 9.2 | Relative Process Performance (9.1 ÷ 0.1) | |
| 9.3 | Output Cost (7.51) | 45.23 $/m^2$ |
| 9.4 | Output Value (0.2 + 0.1) | \$/ |
| 9.5 | Relative Excess Cost [(9.3 - 9.4) ÷ 9.4] | |

Process No. 3 . 1 . 0 1 - 0 1

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0. Output Specification:

Name of item: Wafers with phosphorus PN junction

Dimensions: 7.62-cm diameter

Material: Substrate is high purity silicon

Other Specifications: Process yield is 99.2 %.

Implant dosage is $2 \times 10^{15}$ ions/$cm^2$.

Process No. 3 . 1 . 0 2 – 0 1 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Device fabrication

Subprocess: Formation of potential barrier

Option: Activation anneal after ion implantation (Motorola)

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Process No. 3 . 1 . 0 2 - 0 1

| 0.1 Value Added: | $/ |
|---|---|

Process Description: ~~Annealing of wafer, after junction has been implanted, to activate the~~ junction. Capacity of machine is 2000 wafer/h or 22.62 $m^2$/h. Machine utilization is 96%, for an effective output rate of 21.715 $m^2$/h

1. Input Specification:

Name of Item: Wafer with implanted junction(s)

Dimensions: 12-cm diameter

Material: silicon

Other Specifications:

1.1 Quantity Required: 21.715 $m^2$ / h    Unit Cost: 41.21 $/ $m^2$

| | |
|---|---|
| 1.2 Input Value: | $/ |
| 1.3 Input Cost: | 894.88 $/ $m^2$ |

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 3 . 1 . 0 2 – 0 1



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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2 1 Type: Nitrogen gas from liquid nitrogen ;

Specification: Cost of $LN_2$ is 5.66 $/ft$^3$

(SAMICS No. C1080 D)

Consumption is 3ℓ/min/tube and is used at all times

Quantity Required: 1440 ℓ / h ; Unit Cost: 0.0004 $/ ℓ ; Cost: 0.58 $/ h

2.2_ Type:

Specification:

Quantity Required: ___/___ ; Unit Cost: ___ $/___ ; Cost: ___ $/___

2.2_ Type:

Specification:

Quantity Required: ___/___ ; Unit Cost: ___ $/___ ; Cost: ___ $/___

| 2.2 Subtotal Indirect Materials: | 0.58 $/ h |
|---|---|

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2.3 Expendable Tooling:

2.3 1 Type: Quartz tubes and boats; replaced every 8 months

Quantity Required: 12 tubes / y : Unit Cost: 769 $/tube Cost: 1.16 $/ h

2.3 _ Type:

Quantity Required: / : Unit Cost: $/ Cost: $/

2.3 _ Type:

Quantity Required: / : Unit Cost: $/ Cost: $/

2.3 _ Type:

Quantity Required: / : Unit Cost: $/ Cost: $/

| | | |
|---|---|---|
| 2.3 | Subtotal Expendable Tooling: | 1.16 $/ h |

2.4 Energy

2.4 1 Type: Electricity, 140 name-plates rating, Duty cycle is 50%

Quantity Required: 70 kW : Unit Cost: 0.0319 $/kWh Cost: 2.23 $/ h

2.4 _ Type:

Quantity Required: : Unit Cost: $/ Cost: $/

| | |
|---|---|
| 2.4 Subtotal Energy Costs: | 2.23 $/ h |
| 2.5 Subtotal 2.1 to 2.4: | 3.97 $/ h |
| 2.6 Handling Charge: 5.26 % of item 2.5 | 0.21 $/ h |
| 2.7 Subtotal Materials and Supplies: (2.5 + 2.6) | 4.18 $/ h |

Process No. 3 . 1 . 0 2 - 01

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3.1 Direct Labor:

3.11 Category: Semiconductor assembler (SAMICS B3096D) Activity: machine operation

Amount Required: 1 h/ h ; Rate: $ 3.894 /h; Load 36.0 %; Cost: 5.30 $/ h

3.1_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.1_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.1 Direct Labor Subtotal: 5.30 $/ h

3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2 Indirect Labor Subtotal: 1.32 $/ h

3.3 Subtotal 3.1 and 3.2: 6.62 $/ h

3.4 Overhead on Labor: 5.26% 0.35 $/ h

3.5 Subtotal Labor: 6.97 $/ h

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Page 1 of 1
Revision 3/79 Date 10/78

Process No. 3 . 1 . 0 2 - 0 1

4.1 Equipment

4.1[1] Type: THERMCO eight tube diffusion module type 4000S72 Spec 1900

Cost: 64,270 $; Installation Cost: ---- $; Throughput: 21.715 /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 96 %; Machine Oper'g Time 7950 h/y

Servicing Costs: Labor -- h/y at -- $/h; Parts or Outside Service: --- $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 13,720 $/y — 1.73 $/h

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y — ____ $/____

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y — ____ $/____

| 4.1 Subtotal Equipment Cost: | 1.73 $/h |
|---|---|

Process No. 3 . 1 . 02 - 01

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Revision 3/79 Date 10/78

4.2 Facilities:

4.21 Type: floor space    Floor Area: 25.55 $m^2$; Throughput: 179,800 $m^2$/y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: 4600 $/y    0.58 $/h

4.2_ Type: ______ Floor Area: ______ $m^2$; Throughput: ______ ______/y

Charge Rate: ______$/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: ______$/y    ______$/______

4.2_ Type: ______ Floor Area: ______ $m^2$; Throughput: ______ ______/y

Charge Rate: ______$/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: ______$/y    ______$/______

| | |
|---|---|
| 4.2 Subtotal Facilities: | 0.58 $/h |
| 4.3 Equipment and Facilities Subtotal : | 2.31 $/h |

* includes energy use.

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Process No. 3 . 1 . 0 2 – 0 1

5. Salvaged Material (Work-in-process)

| | | | |
|---|---|---|---|
| 5.1 | Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit) | 21.584 $m^2$ / h | |
| 5.21 | Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1) | 0.130 $m^2$ / h | |
| 5.22 | Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐.☐.☐☐–☐☐ | ____ ____/____ | |
| 5.23 | Credit for 5.22 at the Market Value of ____$/____: | ____$/____ | |
| 5.24 | Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ____$/____: | ____$/____ | |
| 5.25 | Net Credit for 5.22 (5.23 minus 5.24): | | ____$/____ |
| 5.26 | Material of Type 1. Lost in Process (5.21 minus 5.22) | ____ ____/____ | |
| 5.3 | Cost of Work-in-Process Not Contained in Good Output Work-in-Process (Amount 5.21 Times Unit Cost 1.1) | | 5.37 $/h |
| 5.4 | Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.1 Times Unit Cost from 1.1) | | 889.47 $/h |

Salvaged Materials Summary:

| | | |
|---|---|---|
| 5.8 | Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76) | ____$/____ |

Form 11
Page 1 of 1

Process No. 3 . 1 . 0 2 - 0 1

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| 6.3 Liquid Byproducts/Wastes (organic) | Carry from Form 10 | ____ $/ ____ |
|---|---|---|

6.3_ Type (Composition): ____ Quantity Produced: ____ / ____

Density: ____ $g/cm^3$; Toxicity: ____ COD: ____ mg/l; BOD: ____ mg/l

Ignition Point: ____ °C; Explosive Mixture in Air: ____ % to ____ %; Other Remarks: ____

Type of Disposal: ____

Input Material for: ____ Cost(Credit) ____ $/ ____ ; Cost: ____ $/ ____

6.4 Fumes, Gaseous Byproducts/Wastes

6.41 Type (Composition): Fume gases Quantity Produced: 125 $ft^3$/ min

Energy Content (Combustion): ____ kWh/ ____ ; Explosive Mixture in Air ____ % to ____ %.

Ignition Point: ____ °C; Aerosol ☐ Precipitates in ____ minutes pH ____

Toxicity ____ Requires Scrubbing ☐ Type of Scrubber: ____

(enter scrubber under 4.1, 4.2, scrubber effluent under 6.1 to 6.3)

Other remarks: 0.46 kWh/1000 CFM → 0.0575 kWh/min

Type of Disposal: ____

Operating Costs: 16.08 $/ Y ; Cost: 0.002 $/ h

| 6. Subtotal: Byproduct/Waste Disposal Cost: | 0.002 $/ h |
|---|---|

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Process No. 3 . 1 . 02 – 01

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7. Process Cost Computation

| | |
|---|---|
| 7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.) | 13.45 $/ h |
| 7.22 Other Indirect Costs: % of 7.11 (0.059 * (4.1) + 0.108 * (4.2)) | 0.17 $/ h |
| 7.21 Total Operating Add-on Costs of Process: | 13.62 $/ h |
| 7.22 G & A ______% of 7.21 | $/ |
| 7.31 Total Gross Add-On Cost of Process | 13.62 $/ h |
| 7.32 Credit for Salvaged Material (5.8) | $/ |
| 7.33 Cost of Work-in-Process Lost (5.3) | 5.37 $/ h |
| 7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32) | 18.99 $/ h |
| 7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4) | 889.49 $/ h |
| 7.36 Loading on Item 7.35 at Rate ______% | $/ |
| 7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36) | 908.48 $/ h |

| | |
|---|---|
| 7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units) | 21.715 $m^2$ / h |
| 7.42 Practical Yield | 99.4 % |
| 7.43 Effective Yield (7.41 x 7.42) | / |
| 7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35 | 21.584 $m^2$ / h |

| | |
|---|---|
| 7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44) | 42.09 $/ $m^2$ |
| 7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44) | 0.88 $/ m2 |

Process No. 3.1.02-01

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8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

| | | | | | |
|---|---|---|---|---|---|
| 0.9274* 1.73 $/h | from Subtotal 4.1 = | 1.60 $/h | | | |
| 1.946* 0.58 $/h | from Subtotal 4.2 = | 1.13 $/h | | | |
| | Subtotal = | 2.73 $/h | | | |

8.22 Costs of Amortization of the One-Time Cost:

| | | |
|---|---|---|
| 0.192* 4.18 $/h | from Subtotal 2.7 = | 0.80 $/h |
| 0.192* 6.97 $/h | from Subtotal 3.5 = | 1.34 $/h |
| 0.2958* 1.73 $/h | from Subtotal 4.1 = | 0.51 $/h |
| 2.77* 0.58 $/h | from Subtotal 4.2 = | 1.60 $/h |
| | Subtotal = | 4.25 $/h |

8.23 Total Net Cost of Equity (8.21 + 8.22): 6.98 $/h

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 21.584 $m^2$/h from 7.44)

0.32 $/$m^2$

8.25 Price of Process (7.52 + 8.24) 1.20 $/$m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 42.41 $/$m^2$

Process No. 3 . 1 . 0 2 - 0 1

Form 15
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0. Output Specification:

Name of item: Annealed wafer

Dimensions: 12-cm diameter

Material: high purity silicon

Other Specifications:

145

Process No. 3 . 1 . 0 1 - 0 1 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Device Fabrication

Subprocess: Junction Formation

Option: Unanalyzed Ion Beam Implantation

Projection (Motorola)

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Process No. 3 . 1 . 0 1 - 0 1

**0.1 Value Added:** ________ $/ ________

Process Description: Ion implantation of PN junction (phosphorus) with a hollow cathode source. Machine current is 100 mA, uses an unanalyzed beam, and its capacity is 4800 wafers/h. Utilization rate is 80%, so effective throughput rate is 3840 12-cm diameter wafers per hour.

1. Input Specification:

Name of Item: Wafers prepared as specified

Dimensions: 12-cm diameter

Material: Silicon

Other Specifications: Throughput rate of 4800 wafers/h is equivalent to 54.29 $m^2$/h.

1.1 Quantity Required: 43.43 $m^2$ / h    Unit Cost: 41.21 $/ $m^2$

| | |
|---|---|
| 1.2 Input Value: | ________ $/ ________ |
| 1.3 Input Cost: | 1789.75 $/ h |

Note to Item 1.3: Use price, if input produced in own plant

Process No. 3 . 1 . 01 - 01

Form 3

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## 2.1 Direct Materials:

2.11 Type: Ion source (phosphorus) ;

Specification: Semiconductor grade. Assuming 10% implantation eff. and dose of $2 \times 10^{15} cm^{-2}$, consumption is 0.0001326 g/wafer. ;

Quantity Required: 0.509 g / h ; Unit Cost: 2.76 \$/ g ; Cost: 1.41 \$/ h

2.1_ Type: ______ ;

Specification: ______ ;

Quantity Required: ______ ___/___; Unit Cost: ______ \$/______; Cost: ______ \$/______

2.1_ Type: ______ ;

Specification: ______ ;

Quantity Required: ______ ___/___; Unit Cost: ______ \$/______; Cost: ______ \$/______

| | |
|---|---|
| 2.1 Subtotal Direct Materials: | 1.41 \$/ h |

Process No. 3 . 1 . 0 1 - 0 1

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2 1 Type: Liquid Nitorgen;

Specification: Liquid nitorgen consumption is 5ℓ/shift (shift = 8h).

Unit cost is $5.66/ft$^3$, (SAMICS No. C1080D).

Quantity Required: 0.625 ℓ/h; Unit Cost: 0.20 $/ℓ; Cost: 0.125 $/h

2.2 2 Type: De-ionized water

Specification: Is used continuously when operating and flow rate is 10 gallons/min.

Cost is 0.00491 $/gallons. (SAMICS C1144D)

Quantity Required: 2270 ℓ/h; Unit Cost: 0.0013 $/ℓ; Cost: 2.95 $/h

2.2_ Type: ______

Specification: ______

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: ______ $/______

2.2 Subtotal Indirect Materials: 3.07 $/h

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2.3 Expendable Tooling:

| | | | |
|---|---|---|---|
| 2.3 1 Type: Vacuum pump oil, changed bimonthly @ $17.42/bottle | | | |
| Quantity Required: 0.0029 bottles / h | Unit Cost: 17.42 $/bottle | Cost: | 0.050 $/ h |
| 2.3 _ Type: | | | |
| Quantity Required: ____ ____/____ | Unit Cost: ____ $/____ | Cost: | ____ $/____ |
| 2.3 _ Type: | | | |
| Quantity Required: ____ ____/____ | Unit Cost: ____ $/____ | Cost: | ____ $/____ |
| 2.3 _ Type: | | | |
| Quantity Required: ____ ____/____ | Unit Cost: ____ $/____ | Cost: | ____ $/____ |
| | 2.3 | Subtotal Expendable Tooling: | 0.050 $/h |



2.4 Energy

| | | | |
|---|---|---|---|
| 2.4 1 Type: Electrical energy (30 kW/machine when operating). Utilization is 90% | | | |
| Quantity Required: 27 kW | Unit Cost: 0.0319 $/kWh | Cost: | 0.86 $/ h |
| 2.4 _ Type: | | | |
| Quantity Required: ____ ____ | Unit Cost: ____ $/____ | Cost: | ____ $/____ |
| | 2.4 | Subtotal Energy Costs: | 0.77 $/h |
| | 2.5 | Subtotal 2.1 to 2.4: | 5.39 $/h |
| | 2.6 | Handling Charge: 5.26 % of item 2.5 | 0.28 $/h |
| | 2.7 | Subtotal Materials and Supplies: (2.5 + 2.6) | 5.67 $/h |

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3.1 Direct Labor:

3.11 Category: Semiconductor assembler (SAMICS B3096D) Activity: machine monitoring

Amount Required: 1 h/ h ; Rate: $ 3.89 /h; Load 36.0 %; Cost: 5.29 $/ h

3.12 Category: Maintenance mechanic (SAMICS B3736D) Activity: service and repair

Amount Required: 0.1 h/ h ; Rate: $ 5.67 /h; Load 36.0 %; Cost: 0.77 $/ h

3.1_ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.1 Direct Labor Subtotal: 6.06 $/ h

3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 1.52 $/ h

| | | |
|---|---|---|
| 3.3 Subtotal 3.1 and 3.2 | 7.58 | $/ h |
| 3.4 Overhead on Labor: 5.26 % | 0.40 | $/ h |
| 3.5 Subtotal Labor | 7.98 | $/ h |

Process No. 3 . 1 . 01 - 01

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4.1 Equipment

4.1.1 Type: Advanced ion implanter n-type (phosphrous)

Cost: 85,000 $; Installation Cost: ________ $; Throughput: 360,000 $m^2$ /y;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 80 %; Machine Oper'g Time 6620 h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 18,000 $/y | 2.19 $/h

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ________ % of Cost/y; Capital Cost: ________ $/y | ________ $/____

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ________ % of Cost/y; Capital Cost: ________ $/y | ________ $/____

4.1 Subtotal Equipment Cost: 2.19 $/h

Process No. 3 . 1 . 0 1 - 0 1

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## 4.2 Facilities:

4.2.1 Type: Machine area   Floor Area: 37.2 $m^2$; Throughput: 360,000 $m^2$/y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

| | | | |
|---|---|---|---|
| Heating | ____ /y at | $/____ | |
| Air Cond'g | ____ /y at | $/____ | |
| Lighting | ____ /y at | $/____ | |

Maintenance Costs:

| | | |
|---|---|---|
| Labor: | ____ h/y at | ____ $/h |
| Supplies: | | ____ $/y |
| Outside Services: | | ____ $/y |

Total Cost: 6,600 $/y — 0.80 $/h

4.2._ Type: ____ Floor Area: ____ $m^2$; Throughput: ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

| | | | |
|---|---|---|---|
| Heating | ____ /y at | $/____ | |
| Air Cond'g | ____ /y at | $/____ | |
| Lighting | ____ /y at | $/____ | |

Maintenance Costs:

| | | |
|---|---|---|
| Labor: | ____ h/y at | ____ $/h |
| Supplies: | | ____ $/y |
| Outside Services: | | ____ $/y |

Total Cost: ____ $/y — ____ $/____

4.2._ Type: ____ Floor Area: ____ $m^2$; Throughput: ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

| | | | |
|---|---|---|---|
| Heating | ____ /y at | $/____ | |
| Air Cond'g | ____ /y at | $/____ | |
| Lighting | ____ /y at | $/____ | |

Maintenance Costs:

| | | |
|---|---|---|
| Labor: | ____ h/y at | ____ $/h |
| Supplies: | | ____ $/y |
| Outside Services: | | ____ $/y |

Total Cost: ____ $/y — ____ $/____

*Includes energy use

| | |
|---|---|
| 4.2 Subtotal Facilities: | 0.80 $/h |
| 4.3 Equipment and Facilities Subtotal : | 3.00 $/h |

Revision ______ Date 4/79

Process No. 3 . 1 . 0 1 – 0 1

5. Salvaged Material (Work-in-process)

| | | | |
|---|---|---|---|
| 5.1 | Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit) | 7.675 $m^2$ / h | |
| 5.21 | Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1) | 0.078 $m^2$ / h | |
| 5.22 | Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐ | ____ / ____ | |
| 5.23 | Credit for 5.22 at the Market Value of ____ $/ ____ : | ____ $/ ____ | |
| 5.24 | Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ____ $/ ____ : | ____ $/ ____ | |
| 5.25 | Net Credit for 5.22 (5.23 minus 5.24): | | ____ $/ ____ |
| 5.26 | Material of Type 1. Lost in Process (5.21 minus 5.22) | 0.078 $m^2$ / h | |
| 5.3 | Cost of Work-in-Process Not Contained in Good Output Work-in-Process (Amount 5.21 Times Unit Cost 1.1) | | 3.20 $/ h |
| 5.4 | Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.1 Times Unit Cost from 1.1) | | 316.30 $/ h |

Salvaged Materials Summary:

| | | |
|---|---|---|
| 5.8 | Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76) | ____ $/ ____ |

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Process No. 3 . 1 . 0 1 – 0 1

| | |
|---|---|
| Carry from Form 10 | ______ $/ ______ |

6.3 Liquid Byproducts/Wastes (organic)

6.3_ Type (Composition): ______ Quantity Produced: ______ / ______

Density: ______ g/cm$^3$; Toxicity: ______ COD: ______ mg/l; BOD: ______ mg/l

Ignition Point: ______ $^{o}$C; Explosive Mixture in Air: ___% to ___%; Other Remarks: ______

______

Type of Disposal: ______

Input Material for: ______ Cost(Credit) ____ $/ ______; Cost: ______ $/ ______

6.4 Fumes, Gaseous Byproducts/Wastes

6.4 1 Type (Composition): Exhaust gases Quantity Produced: 40ft3 / min

Energy Content (Combustion): ______ kWh/ ______; Explosive Mixture in Air ___% to ___%.

Ignition Point: ______ $^{o}$C; Aerosol ☐ Precipitates in ______ minutes pH ______

Toxicity ______ Requires Scrubbing ☐ Type of Scrubber: ______

(enter scrubber under 4.1, 4.2, scrubber effluent under 6.1 to 6.3)

Other remarks: 40 ft3/min

______

Type of Disposal: Removal by fan (0.46kW/1000 CFM)

Operating Costs: 5 $/ Y ; Cost: 0 $/ h

| | |
|---|---|
| 6. Subtotal: Byproduct/Waste Disposal Cost: | |

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Page 1 of 1

Process No. 3 . 1 . 0 1 – 0 1

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7. Process Cost Computation

| | |
| --- | --- |
| 7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.) | 16.64 $/ h |
| 7.22 Other Indirect Costs: ______ % of 7.11 (0.059*(4.1)+0.108*(4.2)) | 0.22 $/ h |
| 7.21 Total Operating Add-on Costs of Process: | 16.86 $/ h |
| 7.22 G & A ______ % of 7.21 | $/ |
| 7.31 Total Gross Add-On Cost of Process | 16.86 $/ h |
| 7.32 Credit for Salvaged Material (5.8) | $/ |
| 7.33 Cost of Work-in-Process Lost (5.3) | 3.58 $/ h |
| 7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32) | 20.44 $/ h |
| 7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4) | 1786.17 $/ h |
| 7.36 Loading on Item 7.35 at Rate ______ % | $/ |
| 7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36) | 1806.61 $/ h |

| | |
| --- | --- |
| 7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units) | 43.43 $m^2$ / h |
| 7.42 Practical Yield | 99.8 % |
| 7.43 Effective Yield (7.41 x 7.42) | 43.34 $m^2$ / h |
| 7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35 | / |

| | |
| --- | --- |
| 7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44) | 41.68 $/ $m^2$ |
| 7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44) | 0.47 $/ $m^2$ |

Process No. 3.1.01-01

Form 13-2
Page 1 of 1
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8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 2.19 $/ h from Subtotal 4.1 = 2.03 $/ h

1.946* 0.80 $/ h from Subtotal 4.2 = 1.56 $/ h

Subtotal = 3.59 $/ h

8.22 Costs of Amortization of the One-Time Cost:

0.192* 5.67 $/ h from Subtotal 2.7 = 1.09 $/ h

0.192* 7.98 $/ h from Subtotal 3.5 = 1.53 $/ h

0.2958* 2.19 $/ h from Subtotal 4.1 = 0.65 $/ h

2.77* 0.80 $/ h from Subtotal 4.2 = 2.23 $/ h

Subtotal = 5.50 $/ h

8.23 Total Net Cost of Equity (8.21 + 8.22): 9.09 $/ h

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 43.34 $m^2$ / h from 7.44)

0.21 $/ $m^2$

8.25 Price of Process (7.52 + 8.24) 0.58 $/ $m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 41.89 $/ $m^2$

Process No. 3 . 1 . 0 1 - 0 1

Form 15
Page 1 of 1

Revision ______ Date 9/78

0. Output Specification:

Name of item: Phosphorus implanted wafers

Dimensions: 12-cm diameter

Material: silicon

Other Specifications: Ion dose is $2 \times 10^{15}\ cm^{-2}$

Process No. 3 . 1 . 0 1 – 0 1 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Device Fabrication

Subprocess: Junction Formation

Option: Projected ion implantation of phosphorus (n-layer) (Spire, NIMP III) using a high current machine

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Form 2

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Process No. 3 . 1 . 0 1 - 0 1

| 0.1 Value Added: | $/ |
|---|---|

Process Description: High throughput rate phosphorous ion implantation using 5% $PH_3$ in $H_2$ for $n^+$ layer formation. Two machines needed for each factory since 1.27 machines utilized 100% are required to achieve the IPEG factory output goals for 1986. Cassettes (200x200 mm) can hold four 10-cm diameter wafers with a packing factor of 78.5%. Output rate per machine is 18,000 10-cm diameter wafers/h.

1. Input Specification:

Name of Item: Texture or polish-etched circular wafers

Dimensions: 10-cm diameter

Material: Single crystal silicon

Other Specifications: The output rate per machine is (180 $m^2$/h) x 0.785 or 141.3 $m^2$/h.

The factory output is 1.27*141.37 or 179.54 $m^2$/h.

Belt moves at a speed of 30 cm/sec.

1.1 Quantity Required: 179.54 $m^2$ / h    Unit Cost: 41.21 $/$m^2$

| 1.2 Input Value: | $/ |
|---|---|
| 1.3 Input Cost: | 7398.93 $/h |

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 3 . 1 . 01 - 01

Form 3

Page 1 of 1

2.1 Direct Materials:

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2.1.1 Type: 5% phosphine in $H_2$;

Specification: Only used when machine is operating and consumption is 0.21 $ft^3$/min/machine. Cost is 0.82 \$/$ft^3$. (SAMICS No. E14720);

Quantity Required: 453 ℓ/ h; Unit Cost: 0.029 \$/ ℓ; Cost: 13.21 \$/ h

2.1_ Type: ;

Specification: ;

Quantity Required: /; Unit Cost: \$/; Cost: \$/

2.1_ Type: ;

Specification: ;

Quantity Required: /; Unit Cost: \$/; Cost: \$/

| 2.1 Subtotal Direct Materials: | 13.21 \$/ h |
|---|---|

Process No. 3 . 1 . 01 - 01

Form 4

Page 1 of 1

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2 1 Type: Cooling Water;

Specification: Cooling water is needed to cool diffusion pump of both machines continuously. Consumption is $2.05 \times 10^{-2}$ kWh/min/machine. Cost is \$5.66/kWh (SAMICS No. C11281D).

Quantity Required: 2.46 kW /___; Unit Cost: 0.566 \$/kWh; Cost: 1.39 \$/h

2.2 2 Type: $N_2$ gas at high pressure

Specification: Used for both machines continuously. Consumption is 0.15 $ft^3$/min/machine. Price is 0.10 \$/$ft^3$. (SAMICS No. E1780D).

Quantity Required: 510 ℓ /h; Unit Cost: 0.00353 \$/$m^3$; Cost: 1.80 \$/h

2.2_ Type:

Specification:

Quantity Required: ___ /___; Unit Cost: ___ \$/___; Cost: ___ \$/___

2.2 Subtotal Indirect Materials: 3.19 \$/h

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## 2.3 Expendable Tooling:

2.3 1 Type: Spare parts, includes filaments, vacuum components, pump oils, etc. Quantity Required: 1.27 machine/___: Unit Cost: 8.40 $/h Cost: 10.67 $/ h

2.3 _ Type: ___ Quantity Required: ___ ___/___: Unit Cost: ___$/___ Cost: ___$/___

2.3 _ Type: ___ Quantity Required: ___ ___/___: Unit Cost: ___$/___ Cost: ___$/___

2.3 _ Type: ___ Quantity Required: ___ ___/___: Unit Cost: ___$/___ Cost: ___$/___

| | |
|---|---|
| 2.3 Subtotal Expendable Tooling: | 10.67 $/ h |

## 2.4 Energy

2.4 1 Type: Electricity, power rating is 200 kWh. Assumes a 95% duty cycle Quantity Required: 380 kW: Unit Cost: 0.0319$/ kWh Cost: 12.12 $/h

2.4 _ Type: ___ Quantity Required: ___ ___: Unit Cost: ___$/___ Cost: ___$/___

| | |
|---|---|
| 2.4 Subtotal Energy Costs: | 12.12 $/h |
| 2.5 Subtotal 2.1 to 2.4: | 39.19 $/h |
| 2.6 Handling Charge: 5.26 % of item 2.5 | 2.06 $/h |
| 2.7 Subtotal Materials and Supplies: (2.5 + 2.6) | 41.25 $/h |

Process No. 3 . 1 . 0 1 - 0 1

Form 6
Page 1 of 1
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3.1 Direct Labor:

3.1_1 Category: Semiconductor Assembler (SAMICS No. B3096D) Activity: Machine supervision
Amount Required: 2 h/ h ; Rate: $ 3.89 /h; Load 36.0 %; Cost: 10.58 $/h

3.1_2 Category: Maintenance mechanic (SAMICS No. B3736D) Activity: Machine maintenance
Amount Required: 0.2 h/ h ; Rate: $ 5.67 /h; Load 36.0 %; Cost: 1.54 $/h

3.1_3 Category: Electronic Technician (SAMICS No. B3704D) Activity: Electronics maintenance and repair
Amount Required: 0.2 h/ h ; Rate: $ 5.29 /h; Load 36.0 %; Cost: 1.44 $/h

3.1 Direct Labor Subtotal: 13.56 $/h

3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category: ______ Activity: ______
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ______ Activity: ______
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ______ Activity: ______
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 3.39 $/h

| | | |
|---|---|---|
| 3.3 Subtotal 3.1 and 3.2 | 16.95 | $/h |
| 3.4 Overhead on Labor: 5.26 % | 0.89 | $/h |
| 3.5 Subtotal Labor | 17.84 | $/h |

Process No. 3 . 1 . 0 1 - 0 1

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4.1 Equipment

4.1_1 Type: Two ion implanters

Cost: 2,500,000 $; Installation Cost: 30,000 $; Throughput: 179.45 $m^2$ /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ______ $/h; Parts or Outside Service: ________ $/y

Useful Life: 7 y; Charge Rate: 21.35% of Cost/y; Capital Cost: 540,000 $/y | 65.24 $/h

4.1_ Type: ____________________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ______ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ______ % of Cost/y; Capital Cost: ________ $/y | ______ $/____

4.1_ Type: ____________________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ______ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ______ % of Cost/y; Capital Cost: ________ $/y | ______ $/____

| 4.1 Subtotal Equipment Cost: | 65.24 $/h |
|---|---|

Process No. 3 . 1 . 0 1 - 0 1

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4.2 Facilities:

4.2_1 Type: Machine area Floor Area: 93 $m^2$; Throughput: $1.703 \times 10^6$ $m^2$/y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: 16,660 $/y 2.01 $/h

4.2_ Type: ______ Floor Area: ______ $m^2$; Throughput: ______ ______/y

Charge Rate: ______ $/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: ______$/y ______$/______

4.2_ Type: ______ Floor Area: ______ $m^2$; Throughput: ______ ______/y

Charge Rate: ______ $/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: ______$/y ______$/______

4.2 Subtotal Facilities: 2.01 $/______

4.3 Equipment and Facilities Subtotal : 67.25 $/ h

*Includes energy use

Form
Page 1 of 1

Process No. 3 . 1 . 0 1 – 0 1

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6.3 Liquid Byproducts/Wastes (organic)

| Carry from Form 10 | $/ |
|---|---|

6.3_ Type (Composition): ______ Quantity Produced: ____/____

Density: ______ g/cm$^3$; Toxicity: ______ COD: ______ mg/l; BOD: ______ mg/l

Ignition Point: ____ °C; Explosive Mixture in Air: ___% to ___%; Other Remarks: ______

Type of Disposal: ______

Input Material for: ______ Cost(Credit) ____ $/ ____; Cost: ____ $/ ____

6.4 Fumes, Gaseous Byproducts/Wastes

6.4 1 Type (Composition): gas fumes Quantity Produced: 5334 ft$^3$/ min

Energy Content (Combustion): ____ kWh/ ____; Explosive Mixture in Air ___% to ___%.

Ignition Point: ____ °C; Aerosol [ ] Precipitates in ____ minutes pH ____

Toxicity ______ Requires Scrubbing [x] Type of Scrubber: $NH_3$

(enter scrubber under 4.1, 4.2, scrubber effluent under 6.1 to 6.3)

Other remarks: Contains phosphine, phosphorous, nitrogen and phosphorous pentoxide

Type of Disposal: Scrubbed and vented in air

Operating Costs: 700 $/ y; Cost: 0.085 $/ h

| 6. Subtotal: Byproduct/Waste Disposal Cost: | 0.0007 |
|---|---|

Form 9-1

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Process No. [3] . [1] . [0 1] – [0 1]

5. Salvaged Material (Work-in-process)

| | | | |
|---|---|---|---|
| 5.1 | Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit) | 179.36 $m^2$ / h | |
| 5.21 | Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1) | 0.18 $m^2$ / h | |
| 5.22 | Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process [ ] . [ ] . [   ] – [   ] | ______ ______/______ | |
| 5.23 | Credit for 5.22 at the Market Value of ______$/______: | ______$/______ | |
| 5.24 | Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ______$/______: | ______$/______ | |
| 5.25 | Net Credit for 5.22 (5.23 minus 5.24): | | ______$/______ |
| 5.26 | Material of Type 1. Lost in Process (5.21 minus 5.22) | 0.18 ______ / h | |
| 5.3 | Cost of Work-in-Process Not Contained in Good Output Work-in-Process (Amount 5.21 Times Unit Cost 1.1) | | 7.40 $/ h |
| 5.4 | Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.1 Times Unit Cost from 1.1) | | 7391.42 $/ h |

Salvaged Materials Summary:

| | | |
|---|---|---|
| 5.8 | Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76) | ______$/______ |

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7. Process Cost Computation

| | | |
|---|---|---|
| 7.11 | Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.) | 126.43 \$/ h |
| 7.22 | Other Indirect Costs: ~~(0.059 * (4.1) + 0.108 * (4.2))~~ % of 7.11 | 4.07 \$/ h |
| 7.21 | Total Operating Add-on Costs of Process: | 130.50 \$/ h |
| 7.22 | G & A ______% of 7.21 | ______\$/______ |
| 7.31 | Total Gross Add-On Cost of Process | 130.50 \$/ h |
| 7.32 | Credit for Salvaged Material (5.8) | ______\$/______ |
| 7.33 | Cost of Work-in-Process Lost (5.3) | 7.40 \$/ h |
| 7.34 | Specific Add-On Cost of Process (7.31 + 7.33)-(7.32) | 137.90 \$/ h |
| 7.35 | Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4) | 7391.42 \$/ h |
| 7.36 | Loading on Item 7.35 at Rate ______% | ______\$/______ |
| 7.37 | Cost of Output Work-in-Process (7.34 + 7.35 + 7.36) | 7529.32 \$/ h |

| | | |
|---|---|---|
| 7.41 | Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units) | 179.54 $m^2$ / h |
| 7.42 | Practical Yield | 99.9% |
| 7.43 | Effective Yield (7.41 x 7.42) | 179.36 $m^2$/h |
| 7.44 | Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35 | ______/______ |
| 7.51 | Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44) | 41.98 \$/ $m^2$ |
| 7.52 | Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44) | 0.77 \$/ $m^2$ |

Process No. 3.1.01-01

Form 13-2
Page 1 of 1
Revision 11/78 Date 8/78

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

| | | | |
|---|---|---|---|
| 0.9274* 65.24 $/h | from Subtotal 4.1 = | 60.50 $/h | |
| 1.946* 2.01 $/h | from Subtotal 4.2 = | 3.91 $/h | |
| | Subtotal = | 67.41 $/h | |

8.22 Costs of Amortization of the One-Time Cost:

| | | | |
|---|---|---|---|
| 0.192* 41.25 $/h | from Subtotal 2.7 = | 7.92 $/h | |
| 0.192* 17.84 $/h | from Subtotal 3.5 = | 3.43 $/h | |
| 0.2958* 65.24 $/h | from Subtotal 4.1 = | 19.30 $/h | |
| 2.77* 2.01 $/h | from Subtotal 4.2 = | 5.57 $/h | |
| | Subtotal = | 36.22 $/h | |

8.23 Total Net Cost of Equity (8.21 + 8.22): 103.63 $/h

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 179.36 $m^2$/h from 7.44)

0.58 $/$m^2$

8.25 Price of Process (7.52 + 8.24) 1.35 $/$m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 42.56 $/$m^2$

'rocess No. 3.1.01-01

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). Output Specification:

Name of item: Phosphorus implanted wafers

Dimensions: 10-cm diameter

Material: high purity silicon

Other Specifications: Dopant concentration is $1 \times 10^{15}$ $cm^{-2}$. Implant layer is approximately 0.1 μm deep.