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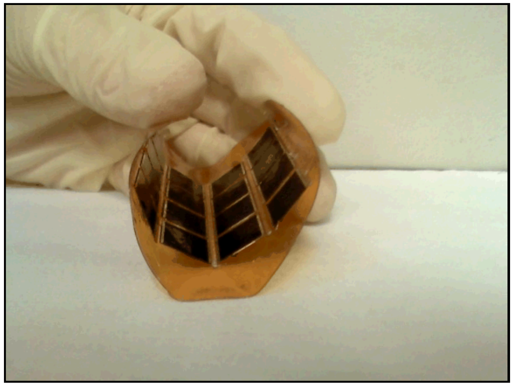
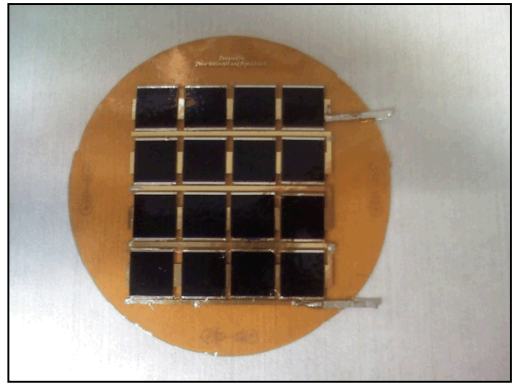
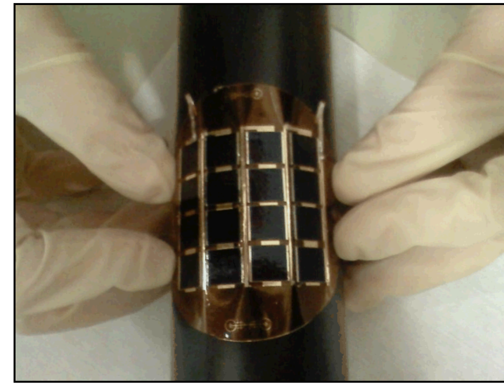
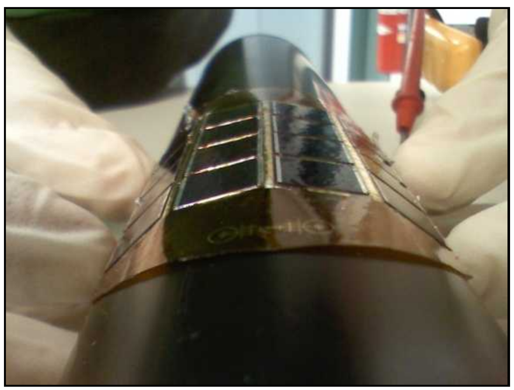
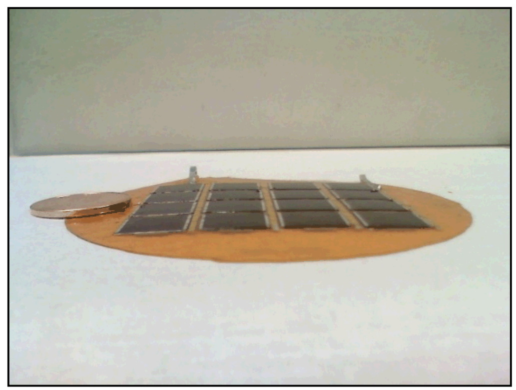
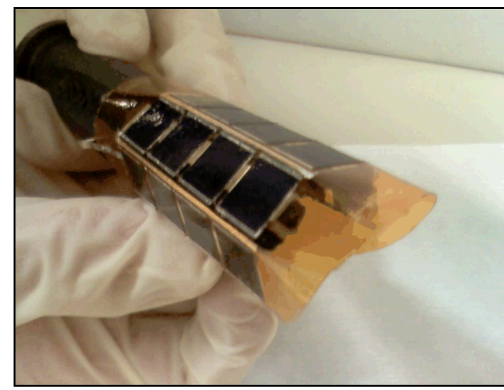
SAND2010-6580C

Flexible Implementation of Rigid Solar Cell Technologies

Andrew E. Hollowell
aehollo@sandia.gov
(505) 844 8301

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Project Background

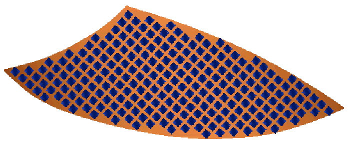
- There is a need for lightweight and flexible photovoltaic (PV) devices
- Current technologies: a-Si and organic materials
  - Lack the efficiency and lifetime needed in many applications

ARL Micro Autonomous Systems and Technology (MAST) Project

Flexible PV systems with high W/g ratio for non-fixed winged robots

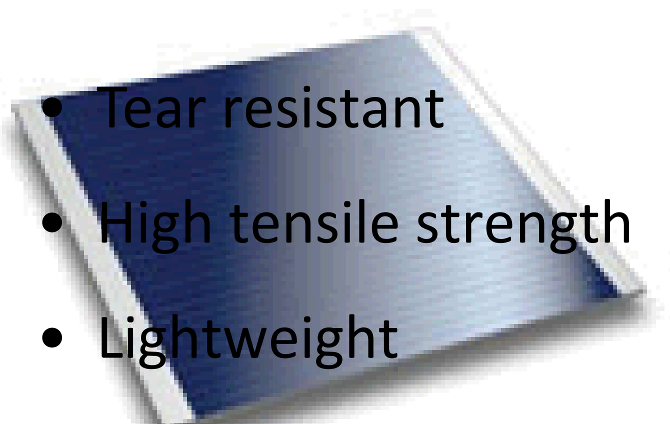
Most important quality is flexibility and a high power to weight ratio > 0.133W/g.

Up to 3 foot wingspan



Our Solution

Integrate rigid, highly efficient solar cells onto a flexible material



- Tear resistant
- High tensile strength
- Lightweight
- Extremely flexible

Emcore™ triple-junction Solar Cell

- High efficiency
- Lightweight
- Can be thinned
- Commercially produced

Dupont™ Kapton® polyimide film

Dupont™ and Kapton® are trademarks of E.I. du Pont De Nemours and Company

Our Solution

Integrate rigid, highly efficient solar cells onto a flexible material

I will explain how we implemented our solution using:

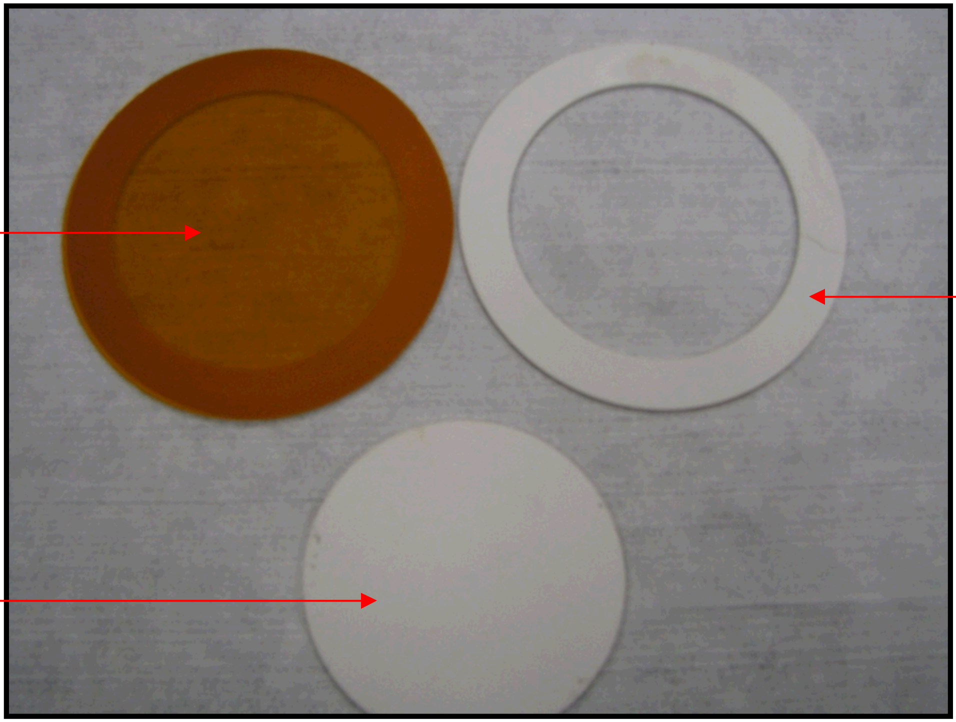
- Processing Techniques
- Cell Mounting
- Electrical Connection
- Packaging

and other techniques to create a device that beats its competitors

Preparing the Kapton® for Processing

The Kapton® must remain flat and rigid for photolithographic processing and metal deposition

Mounted Kapton®



Alumina ring

Center Disc

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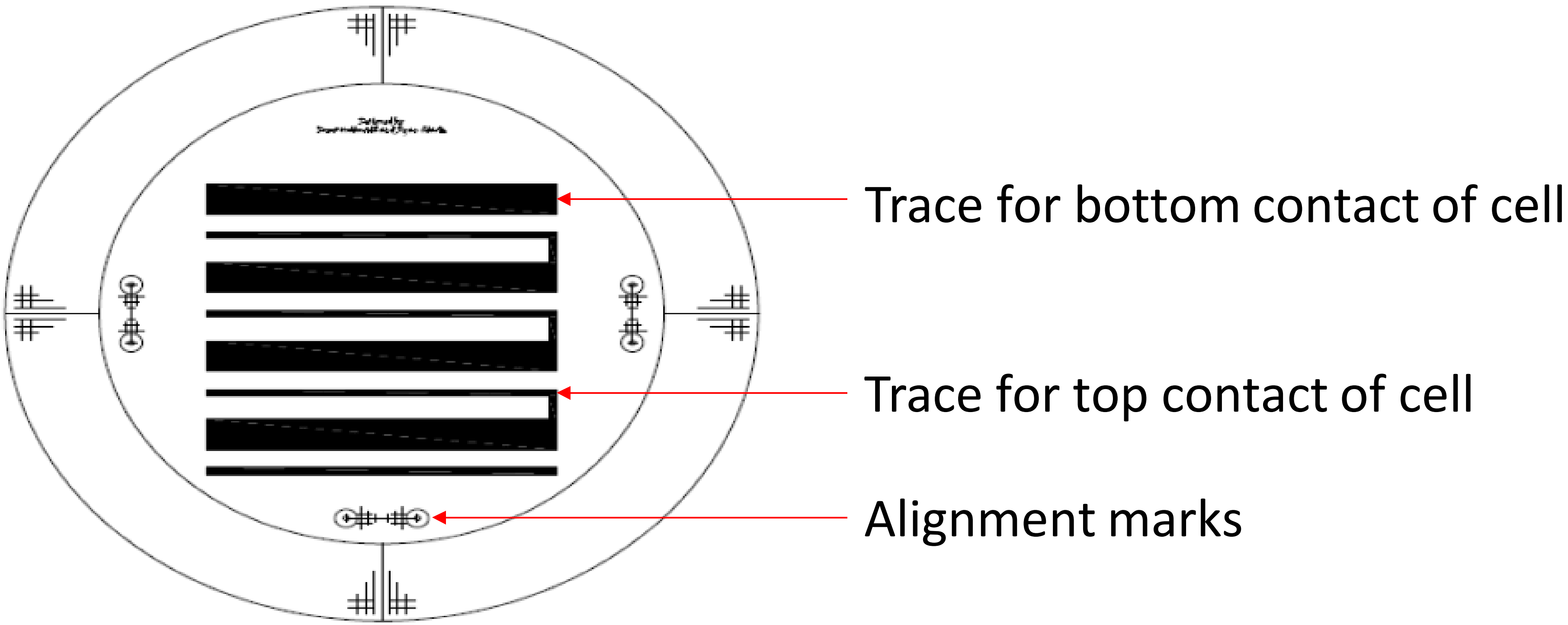
Electrical Contacts: Interconnect Layout



Series/parallel arrangement allowing different voltages and currents to be generated

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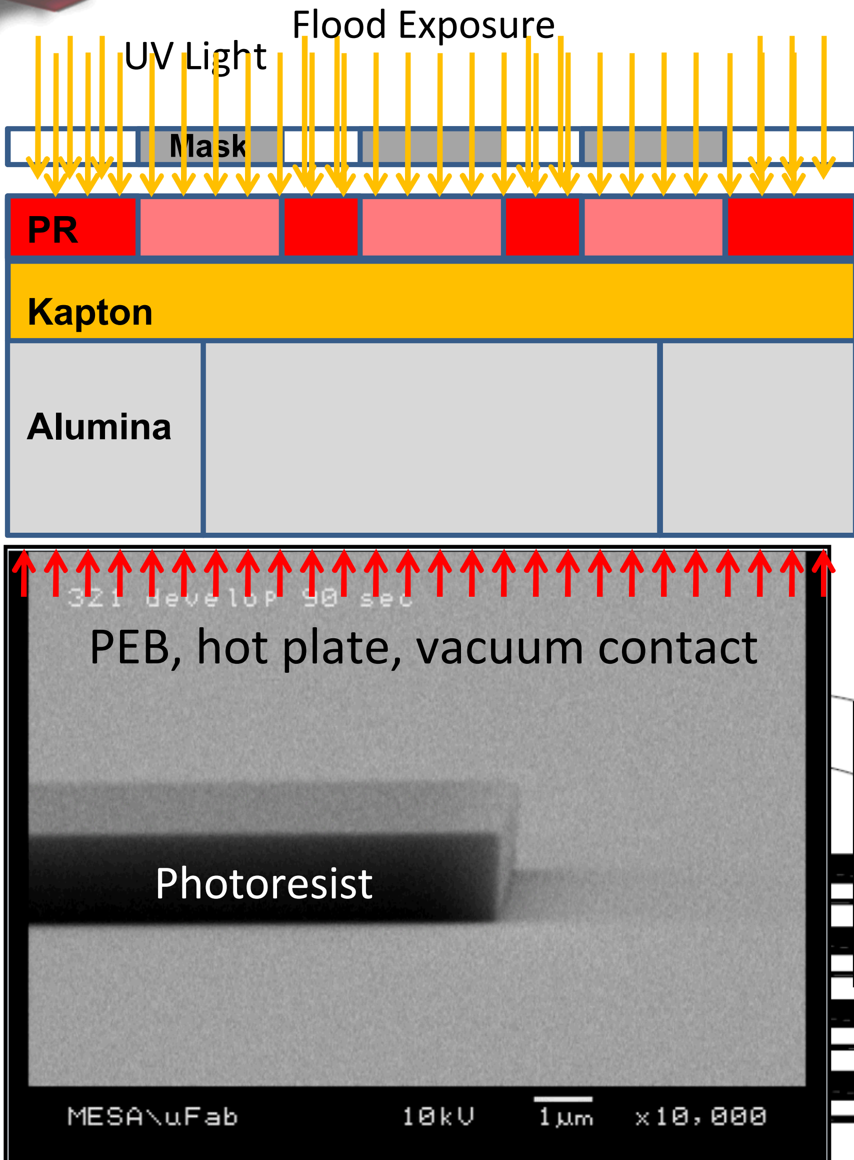
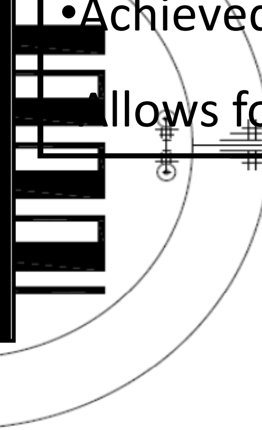
Patterning the Contacts: 1st Layer Photolithography



- Spin 1.1µm of positive PR
- UV Exposure
- Post exposure bake (PEB) crosslinks PR forming polymers
- Flood Exposure to complete image reversal process
- Develop PR

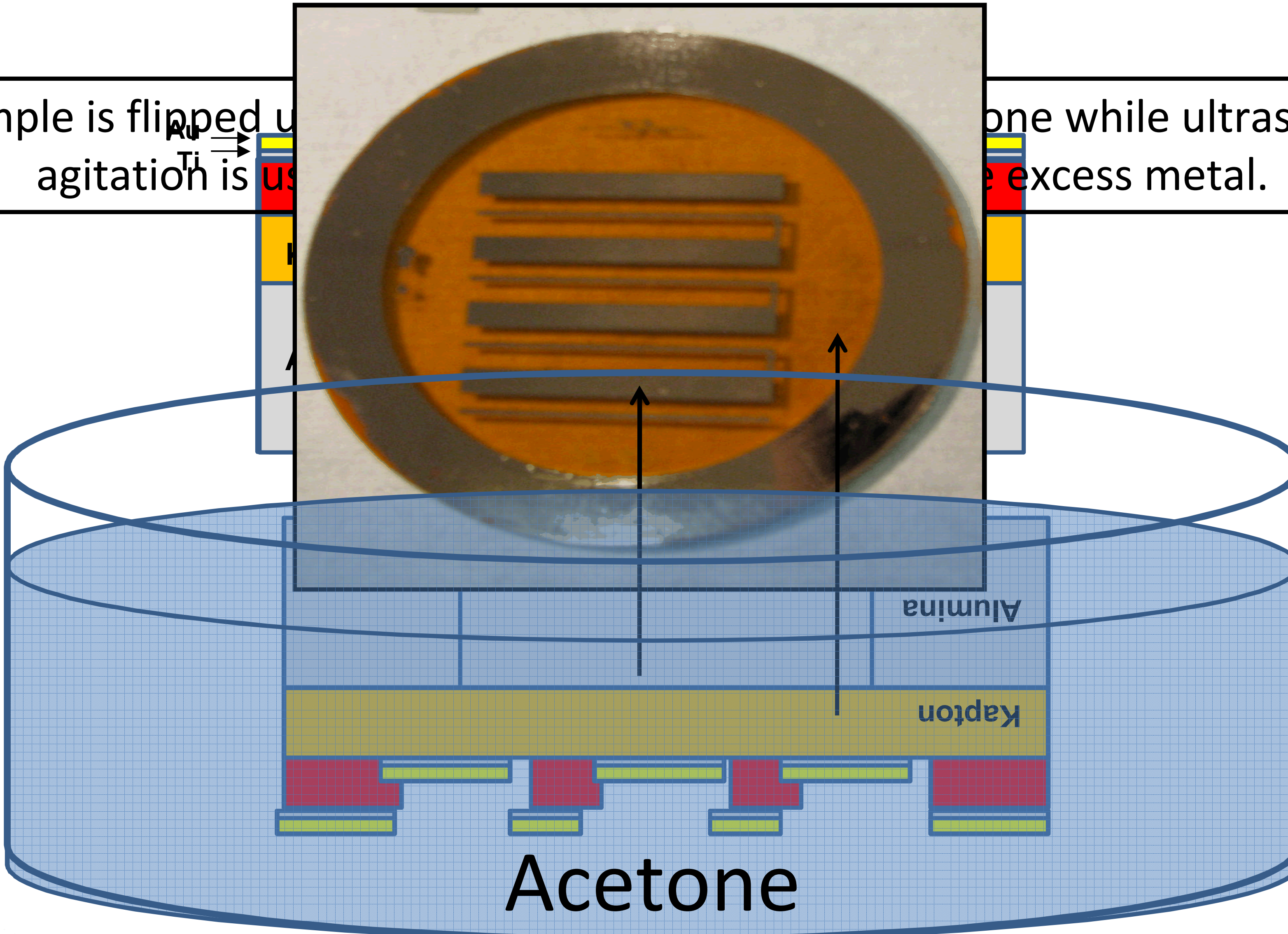


Reentrant PR Sidewall Profile

- Achieved through PR image reversal
- Allows for clean metal lift off process

Depositing the Contacts: Metal Evaporation

Sample is flipped u… …one while ultrasonic agitation is us… …e excess metal.



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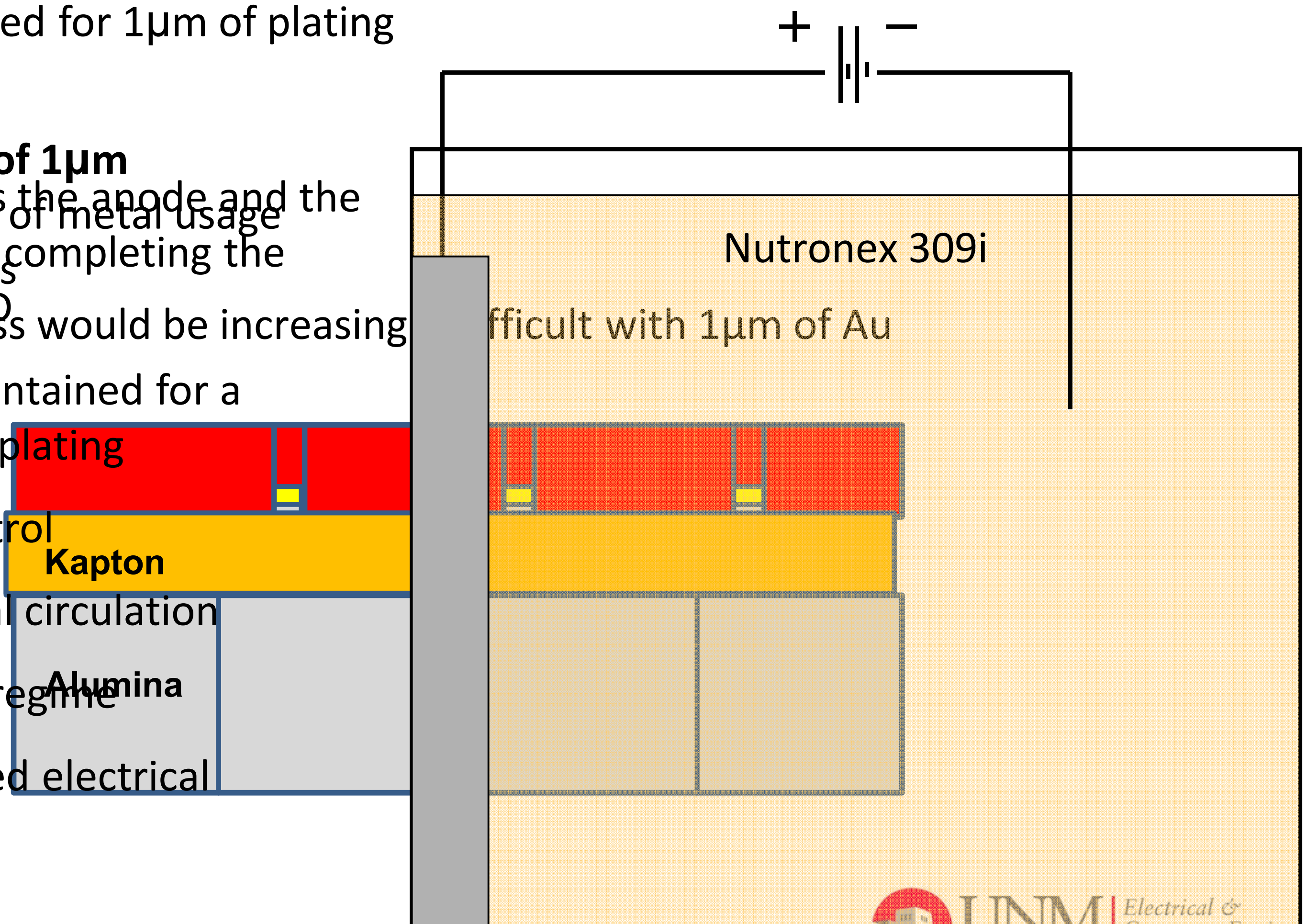
Depositing the Contacts: Electrochemical Deposition (ECD)

- 1000Å of Au is not sufficient for wire bonding
- PR is used to pattern areas Au will be electroplated for minimal additive weight
- 3µm of PR is patterned for 1µm of plating

ECD vs. evaporation of 1µm

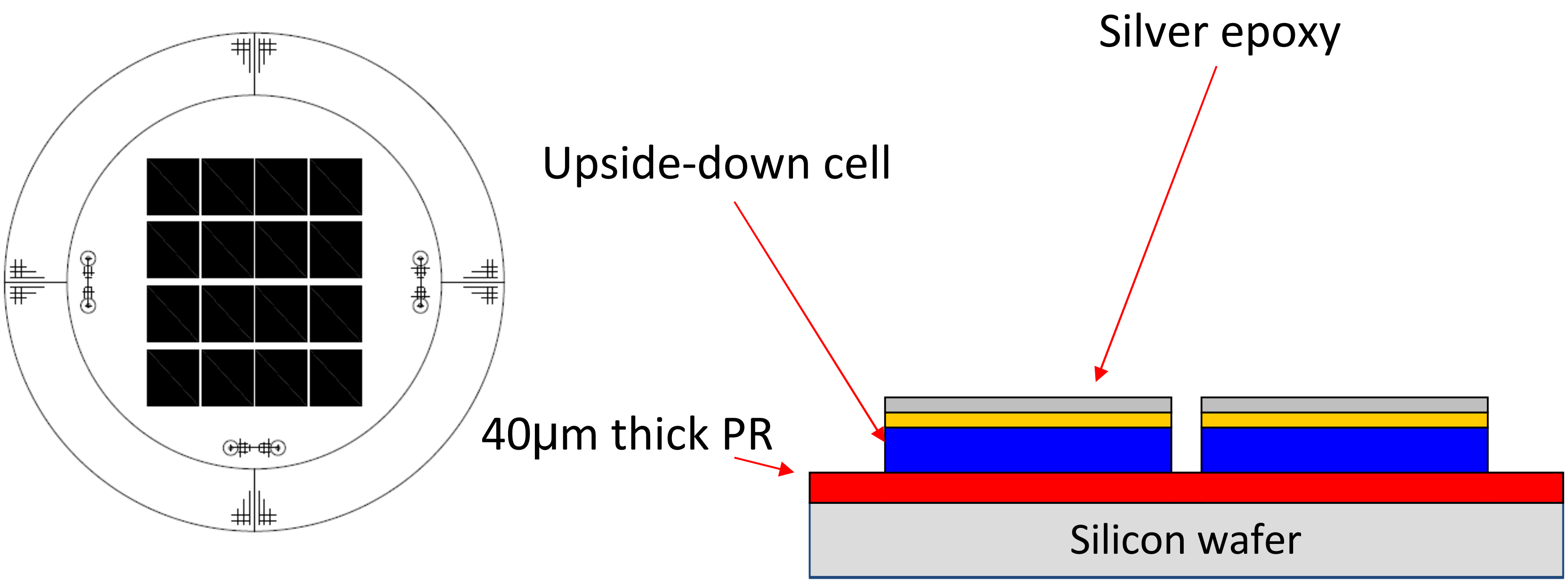
- Conservation of metal usage
- Faster Process
- Lift off process would be increasing fficult with 1µm of Au

- A bias is applied across the anode and the cathode (the substrate) completing the circuit and initiating ECD
- Bath dynamics are maintained for a uniform and controlled plating
  - Temperature control
  - Constant chemical circulation
  - Controlled pulse regime
  - Chemically isolated electrical connection



Cell Placement

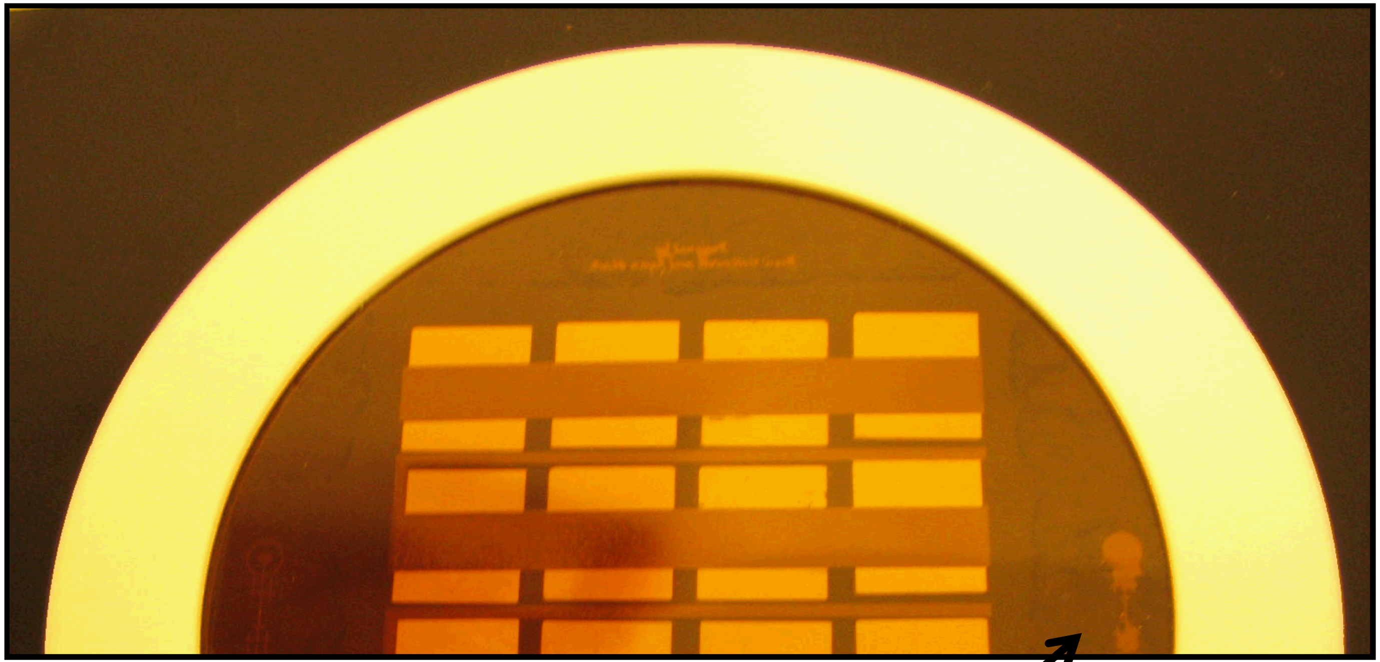
Another photolithography process is performed on a silicon wafer, creating a mold to align the solar cells



Spacing allows room for flexing while avoiding cell-to-cell interference

Cell Placement

The processed Kapton® is then aligned manually upside down on the cells



Alignment marks allow for an automated mounting process.

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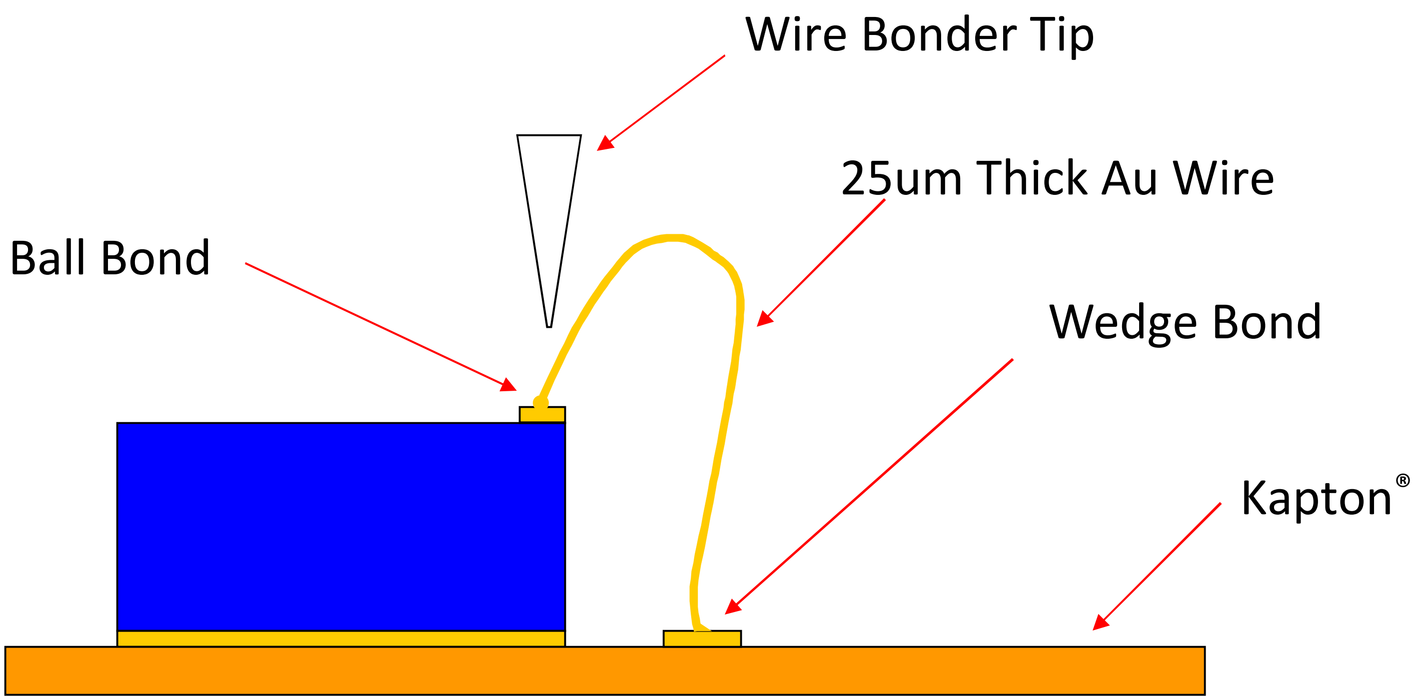
Wire Bonding

An ultrasonic wire bonder is used to connect the cells to the interconnects



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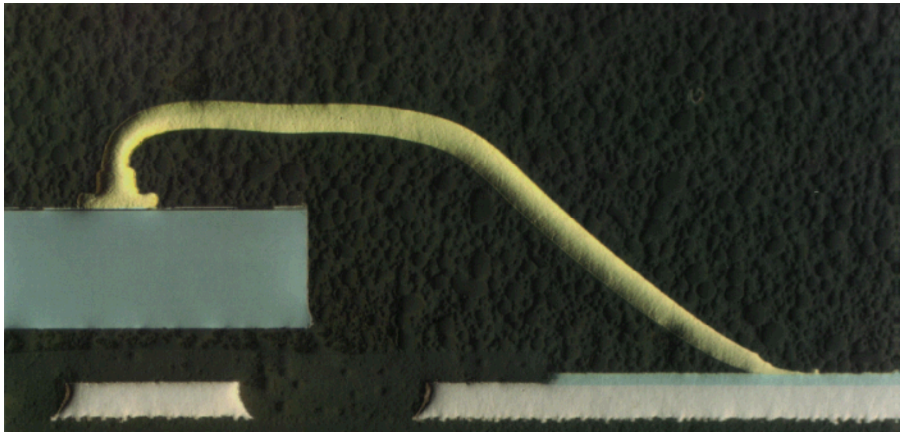
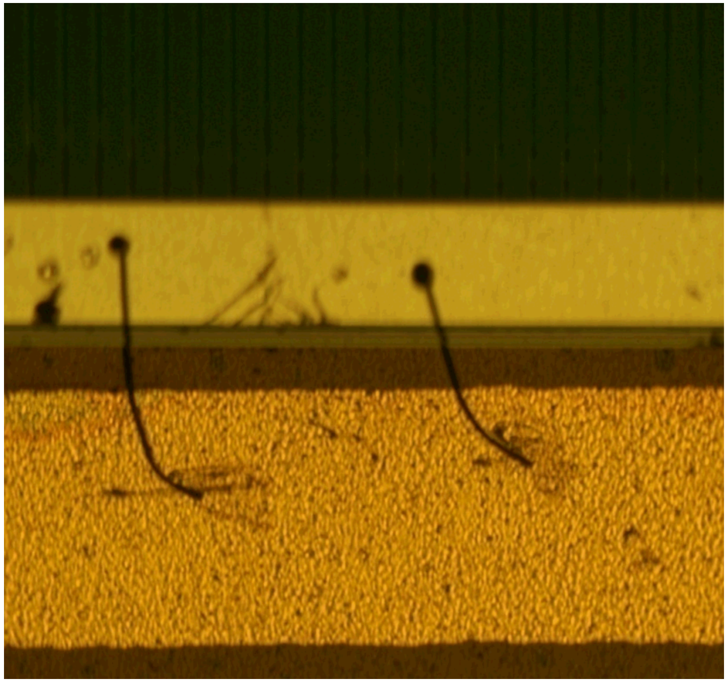
Wire Bonding Examples



Example of a ball/wedge wire bond from a device to a bus.



Microscope image of a cell connected to the bus on our device

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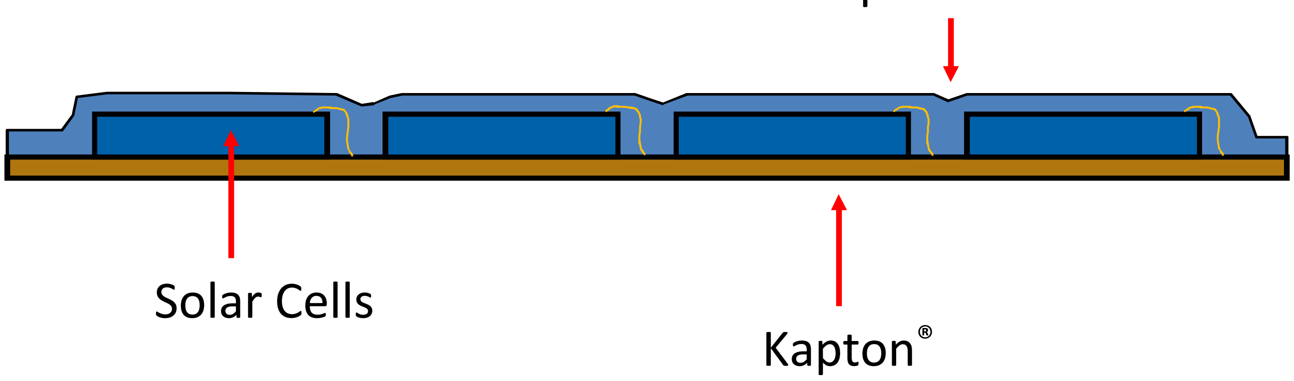
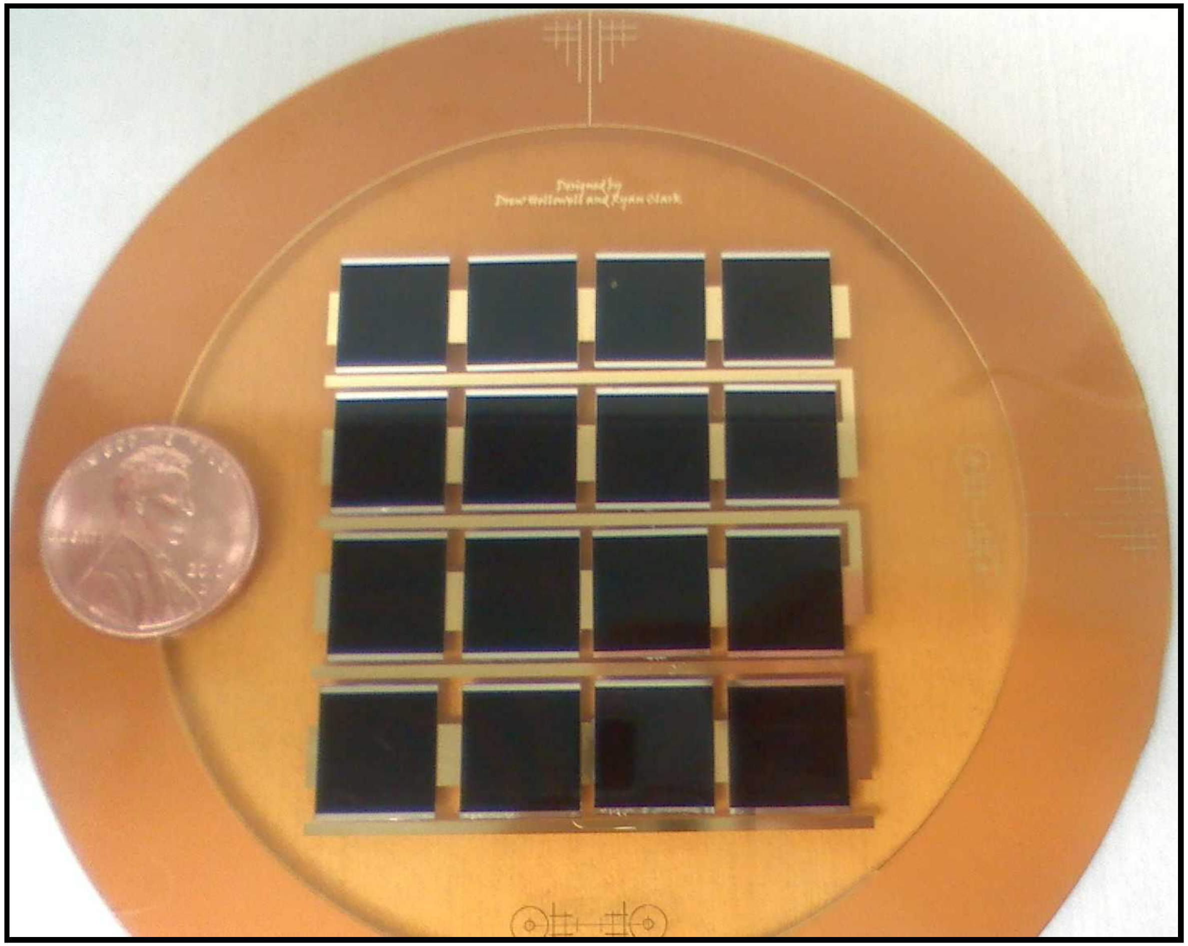
Top Laminate

A low Volatility Organic Compound coats the device

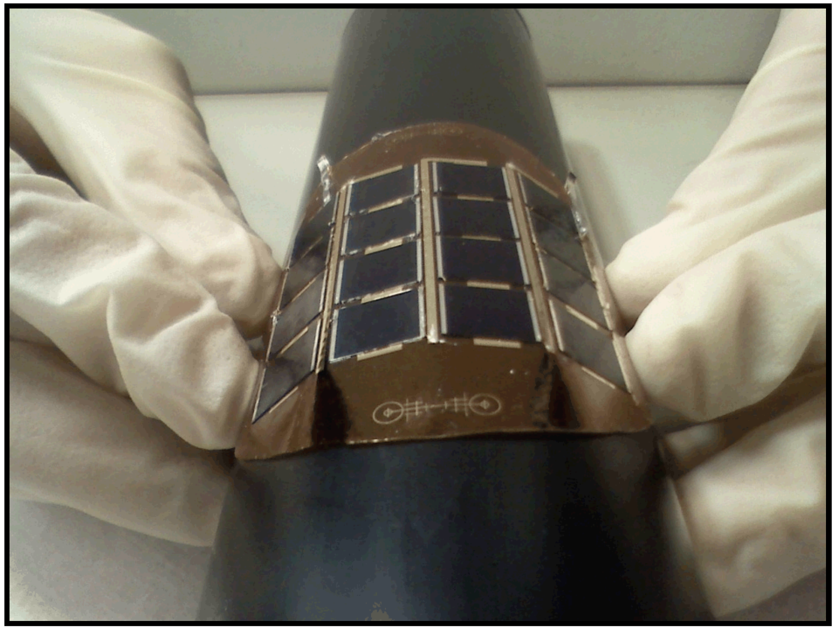
- Protects the cells and wire bonds
- Applied using an air powered spray gun to ensure uniformity
- Anti Reflective Coating to increase cell efficiency



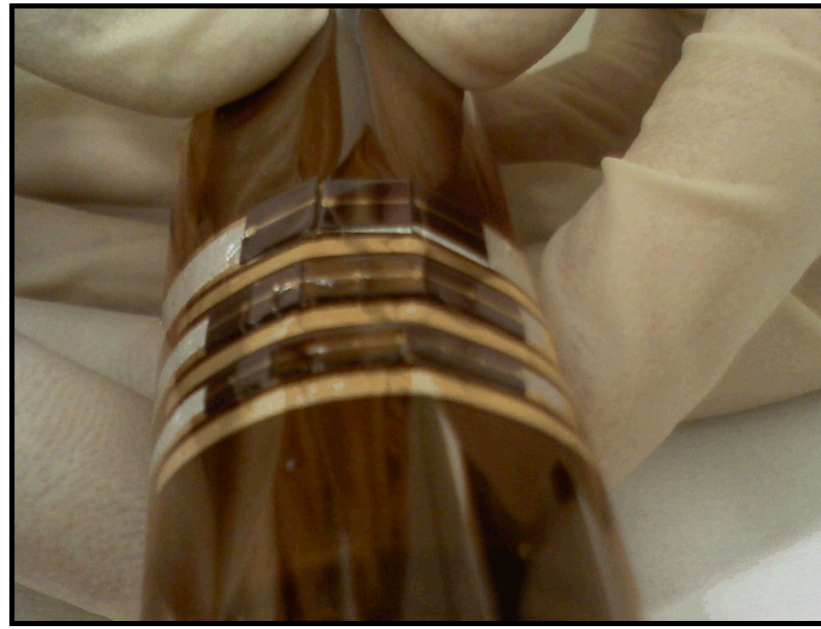
Completed Device



Flexing Demonstration



1.1cm x 1cm cells, flexing around a 6 cm tube



5, 3, and 2mm cells, flexing around a 2 cm tube

Power/Weight Analysis

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Item

Kapton®

Titanium

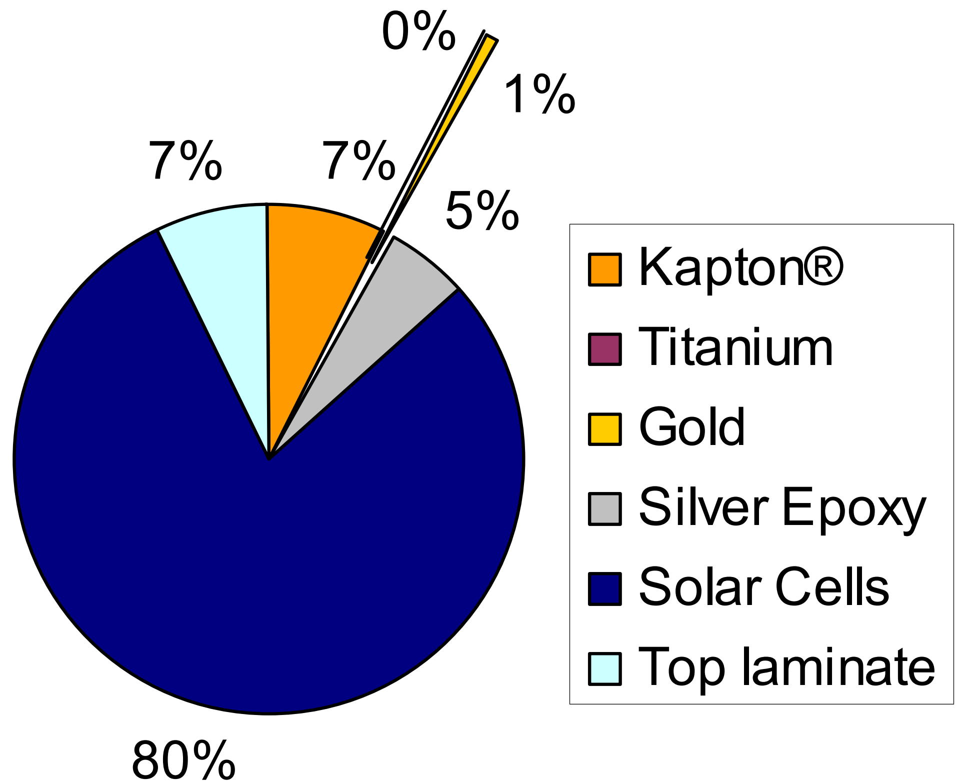
Gold

Silver Epoxy

Solar Cells

Top laminate

Total



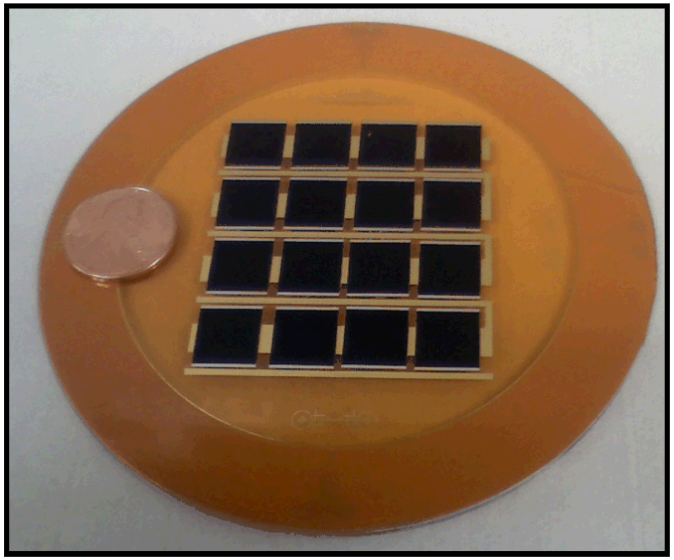
28g

ams

$$\frac{16 cells \times 31 \frac{mW}{cell}}{2.23 grams} = \frac{.496W}{2.23g} = .222 \, Watts/gram$$

Device Performance

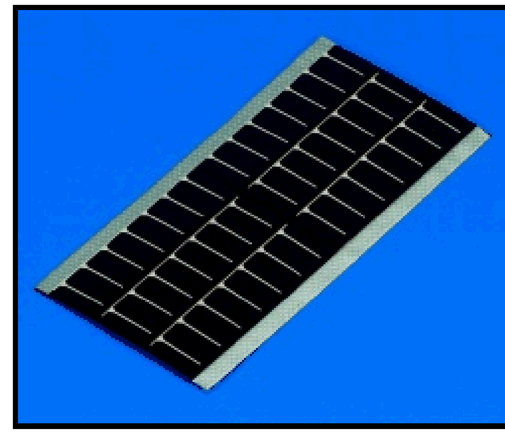
Our Design using rigid cells on Kapton®



- Power/weight = 0.22 W/gram
- Used commercially available components
- Can be scaled to any size
- Different cell configurations possible for any I/V desired
- Good flexibility and can perform 90° bends

2 times!

PowerFilm® using thin film amorphous silicon



- Power/weight = 0.116 W/gram
- Printed in a factory
- Can be scaled to any size
- Only limited voltage configurations are available
- Good flexibility but can not perform 90° bends

http://www.powerfilmsolar.com/oem-components/module-series.php

- Not only have we produced a flexible array of solar cells with a high W/g, our engineering methods can be integrated anywhere rigid components can benefit from flexibility.
  - Flexible displays (e.g. lighting, computers, readers)
  - Portable power (e.g. clothing and accessories)

Future Goals

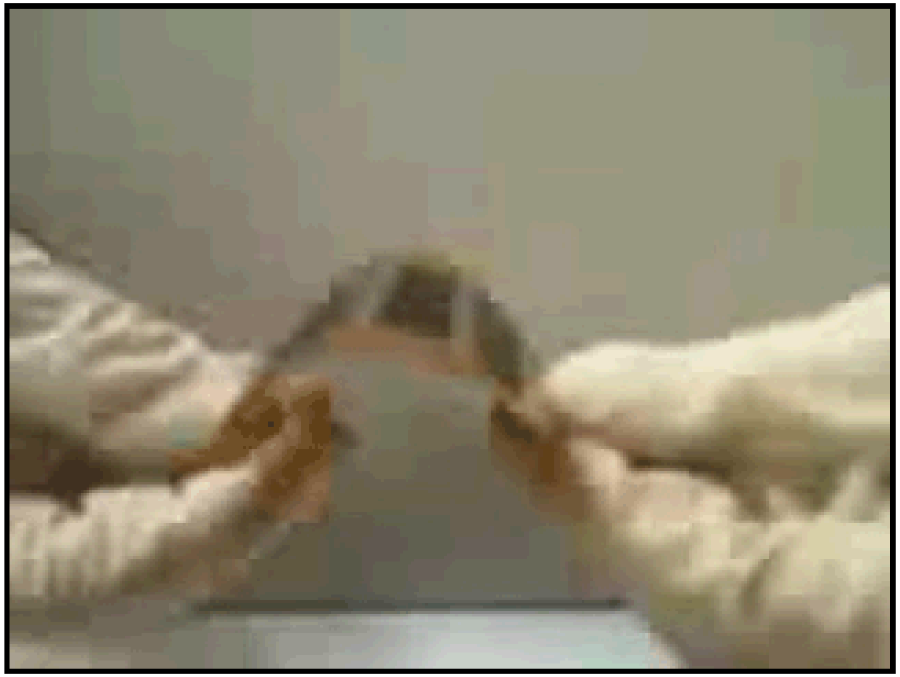
- Characterize wire bonding to electroplated Au with various hardnesses.
- Build a device with 7mm X 7mm triple junction solar cells and silicon cells to show the versatility of our process.
- Incorporate 0.4mm X 0.4mm X 25µm DWELL cells into our design.
- Thin Emcore triple junction solar cells to achieve an increase power to weight ratio.
- Incorporate an anti reflective coating into the top laminate of our device.
- Incorporate a concentration lens into the top laminate of our device.

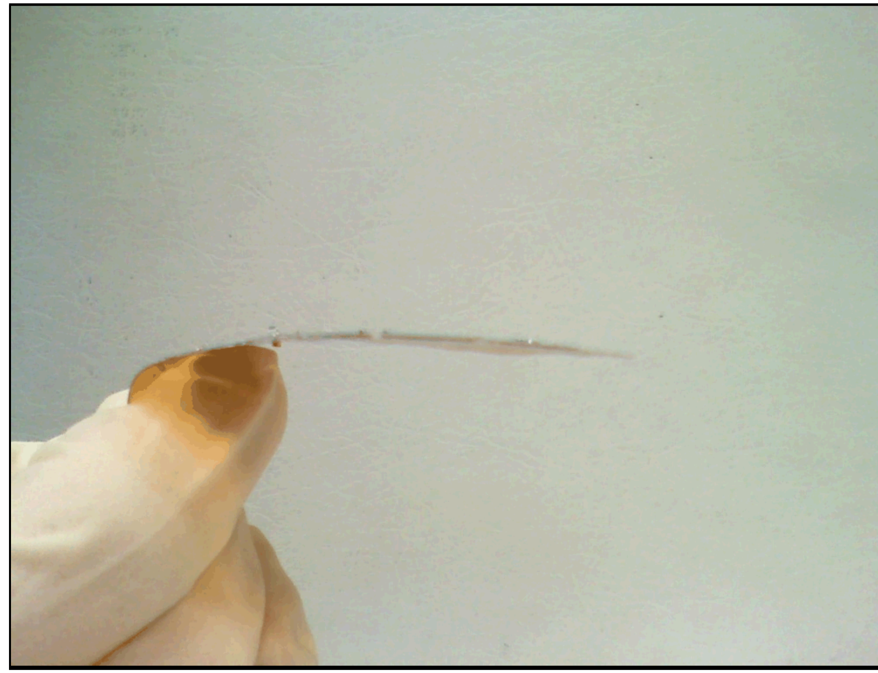
Acknowledgements

- Ryan Andrew Clark
- Sandia National Laboratories
- SNL Metal Micromachining Team
  - Adam M. Rowen, James R. Gillen , Christian L. Arrington, Jonathan J. Coleman
- Dr. Olga Lavrova
- Dr. Luke Lester and his team at CHTM
  - Kai Yang, Mohammed El-Emawy, Therese Saiz

Thank You for Your Attention

Provisional Patent Application # 61/400,445





Andrew E. Hollowell
aehollo@sandia.gov
(505) 844 8301

Adam Rowen
amrowen@sandia.gov
(505) 844 3767

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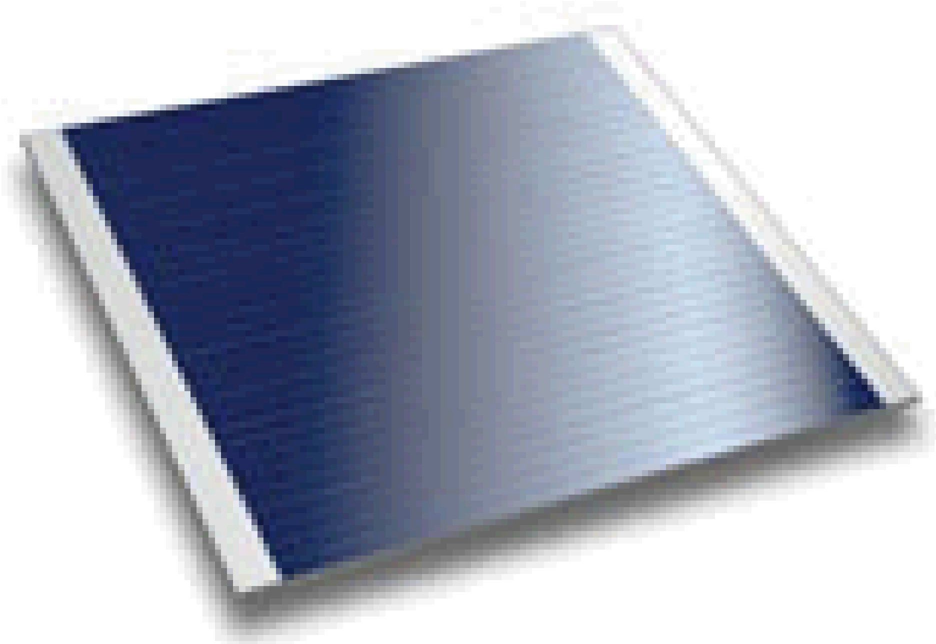
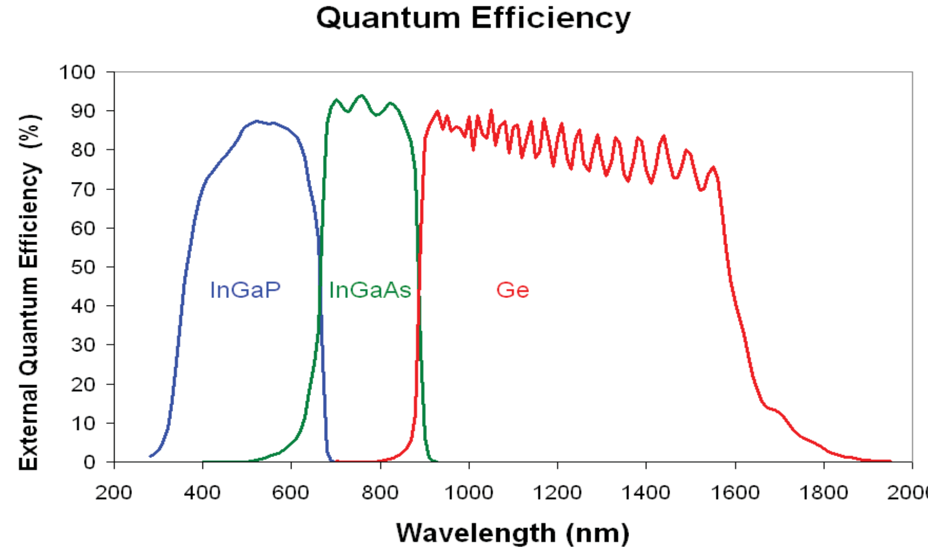
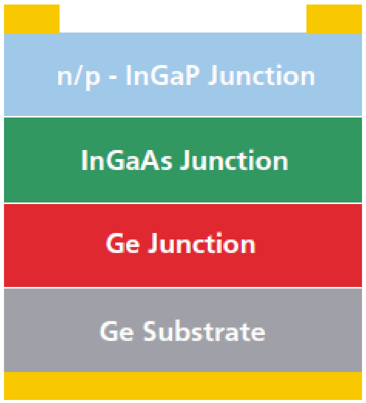
Emcore™ triple-junction Solar Cell





Standard CTJ Cell Dimensions

External Dimensions	10.68 x 10.075 mm
Designed Aperture Area	10 x 10 mm
Total Nominal Active Area	100 mm^2
Bondable Perimeter Busbar	0.235 mm
Total Cell Thickness	~0.2 mm



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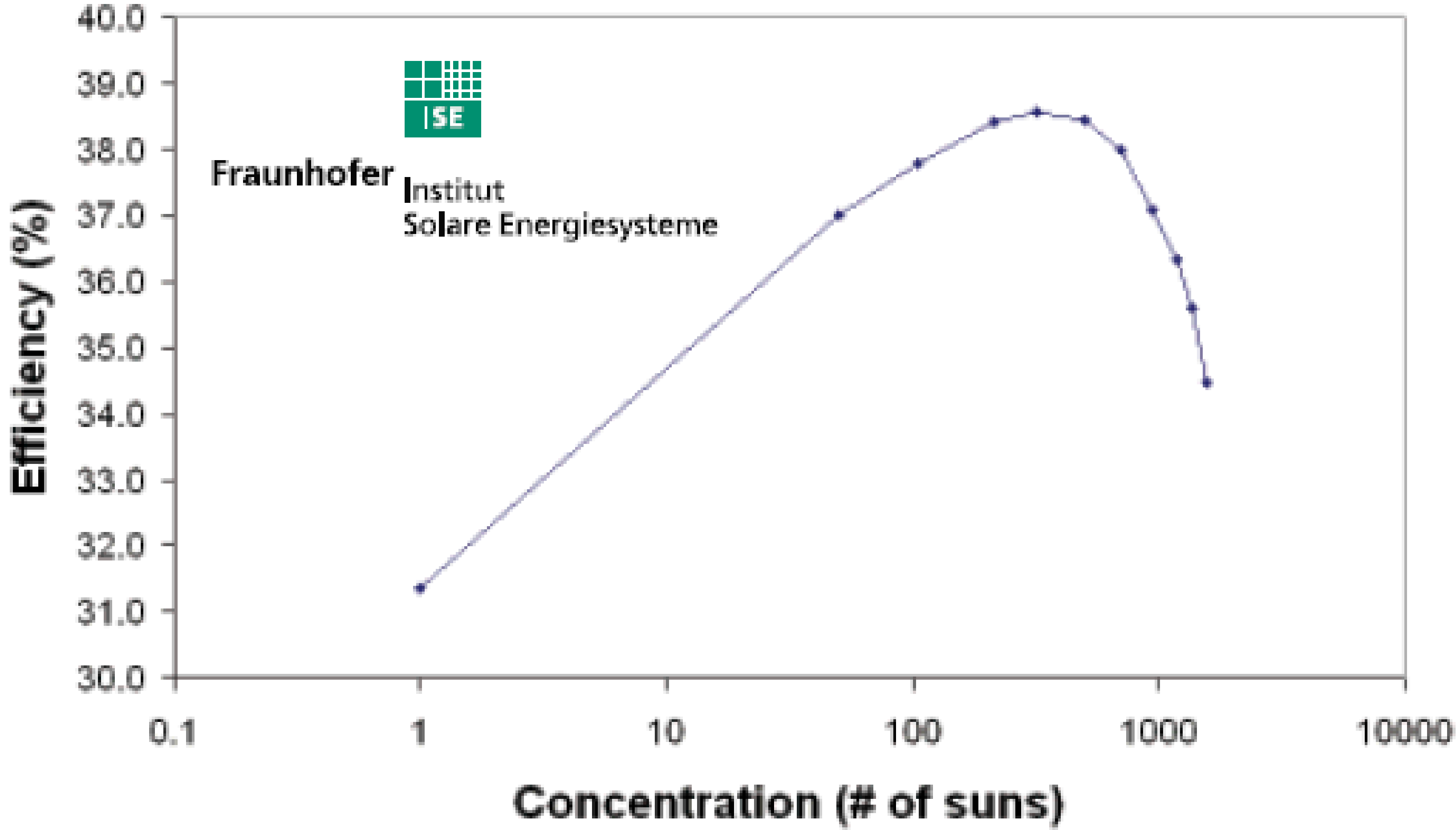
Efficiency vs. Concentration



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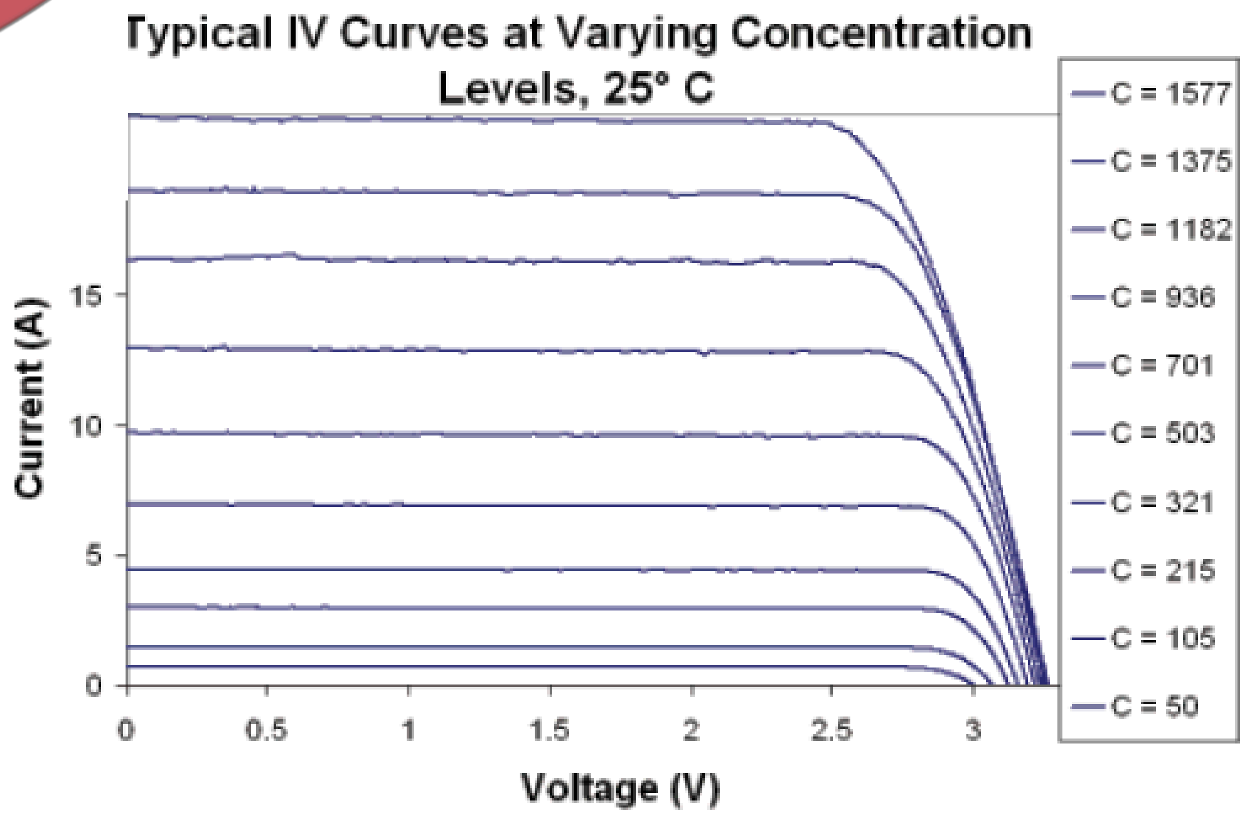

	1X Concentration	503X Concentration	1182X Concentration
Efficiency	31.4%	39.0%	36.3%
V_{oc}	2.605 V	3.193 V	3.251 V
J_{sc}	13.85 mA / cm²	6.96 A/cm²	16.37 A/cm²
V_{mp}	2.33 V	2.84 V	2.68 V
J_{mp}	13.4 mA / cm²	6.8 A/cm²	16.04 A/cm²
P_{mp}	31.4 mW / cm²	19.3 W/cm²	42.9 W/cm²

Dupont™ Kapton® Polyimide Film

Property	23°C	200°C
Ultimate Tensile Strength, Mpa	231	139
Ultimate Elongation, %	72	83
Density, g/cc	1.42	1.42
Tensile Modulus, GPa	2.5	2.0