SAND2015-0239PE

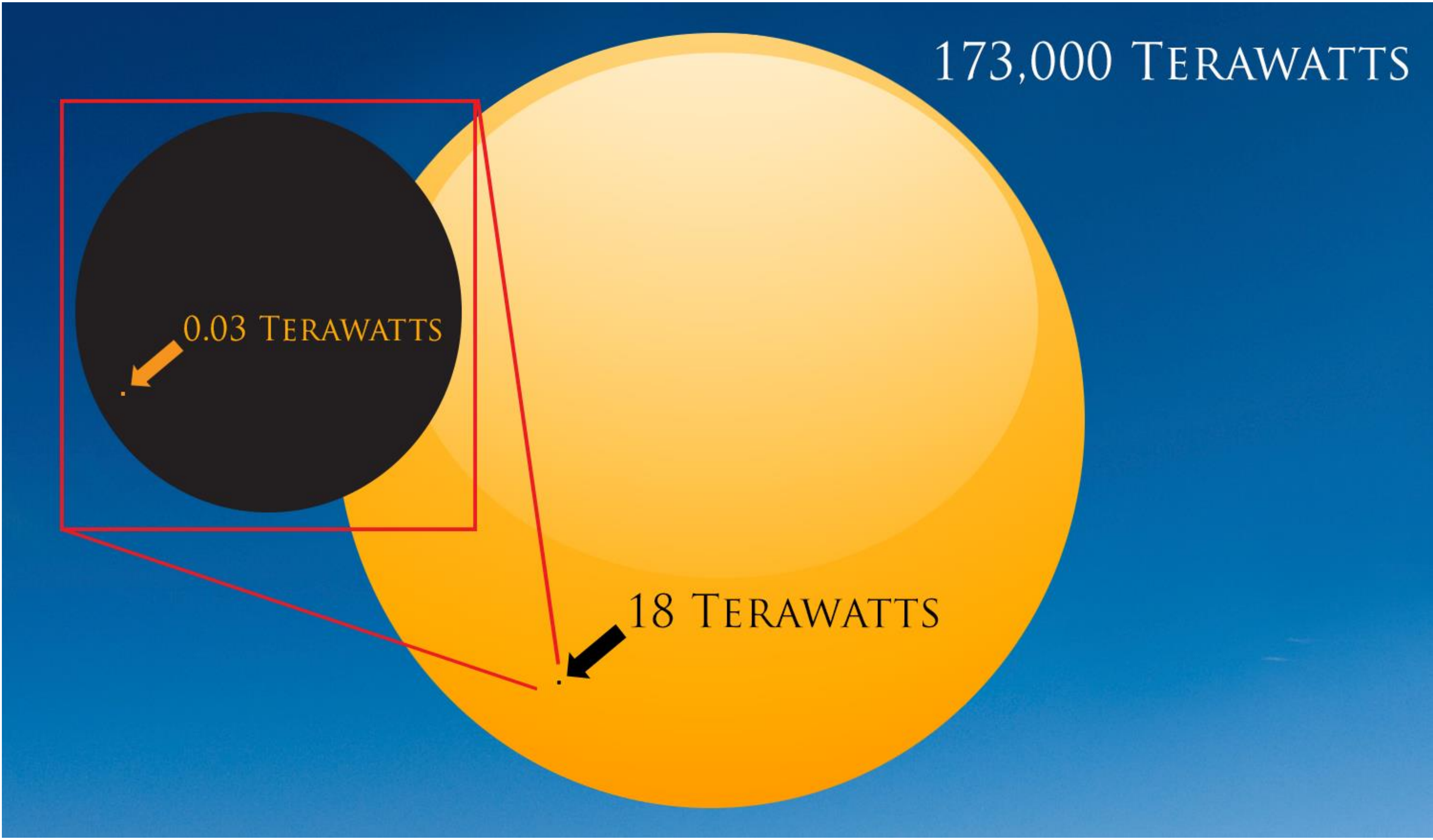
Miniaturization effects of solar cells: Microsystems Enabled Photovoltaics

Jose Luis Cruz-Campa, Ph.D.

January 21, 2015

Outline

1. Better materials in Thin film cells
2. Flexible crystalline silicon cells
3. Compact concentrators


173,000 Terawatts
0.03 Terawatts
18 Terawatts

Reconstructed from http://www.treehugger.com/solar-technology/surface-area-required-to-power-the-whole-world-with-solar-and-wind-power.html

Four Solar technologies

Illumination
Passive heating

Active heating

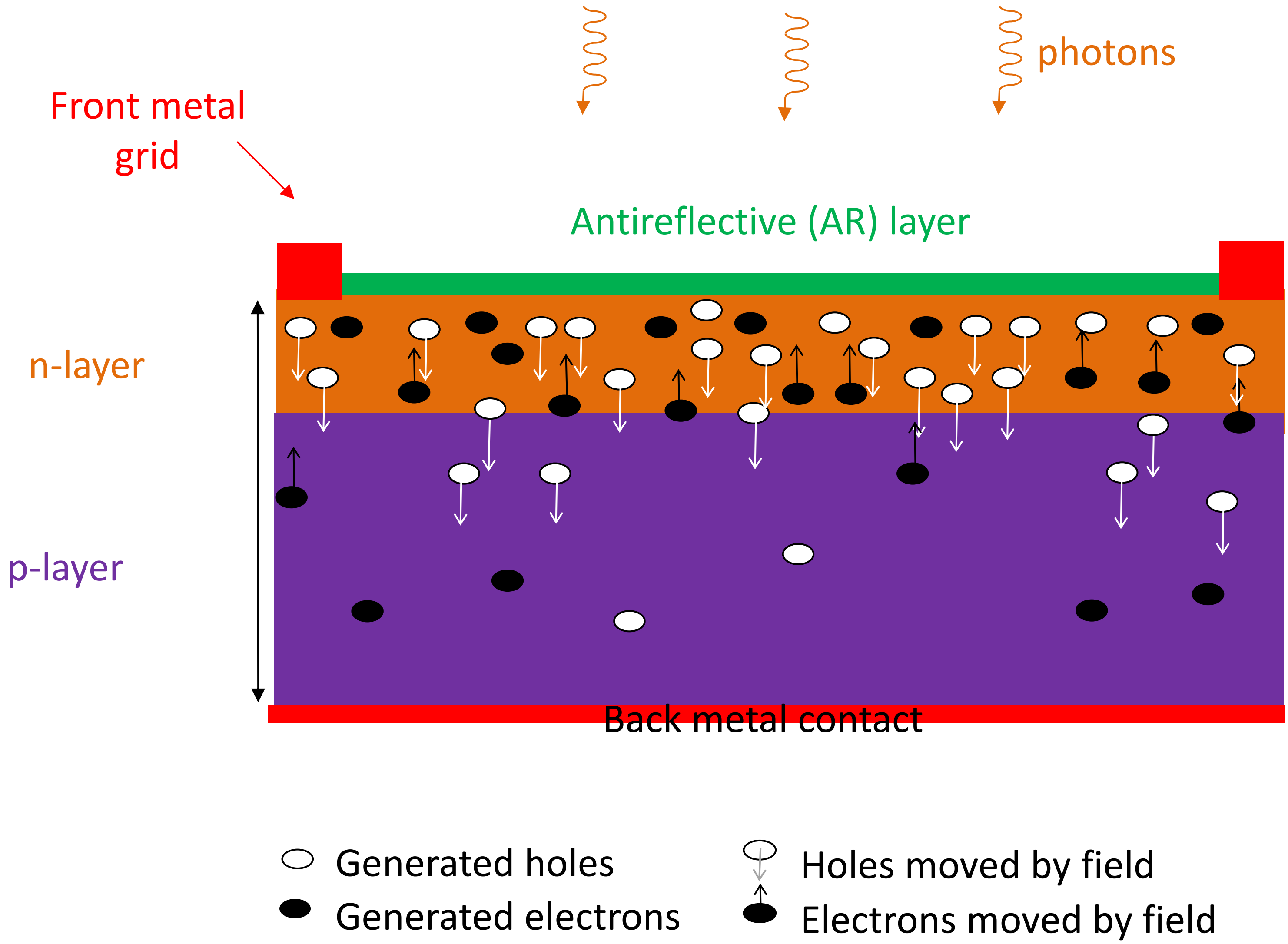
Solar-thermal

Photovoltaics (PV)

Advantages

Applications

How does a PV cell work?

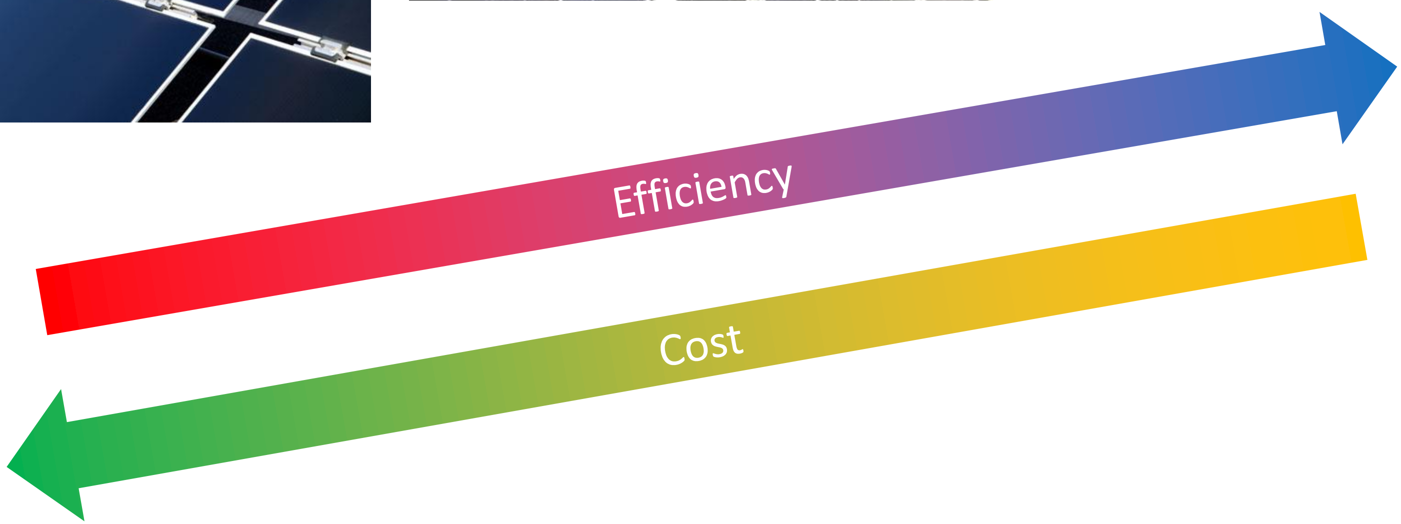


Three types of PV

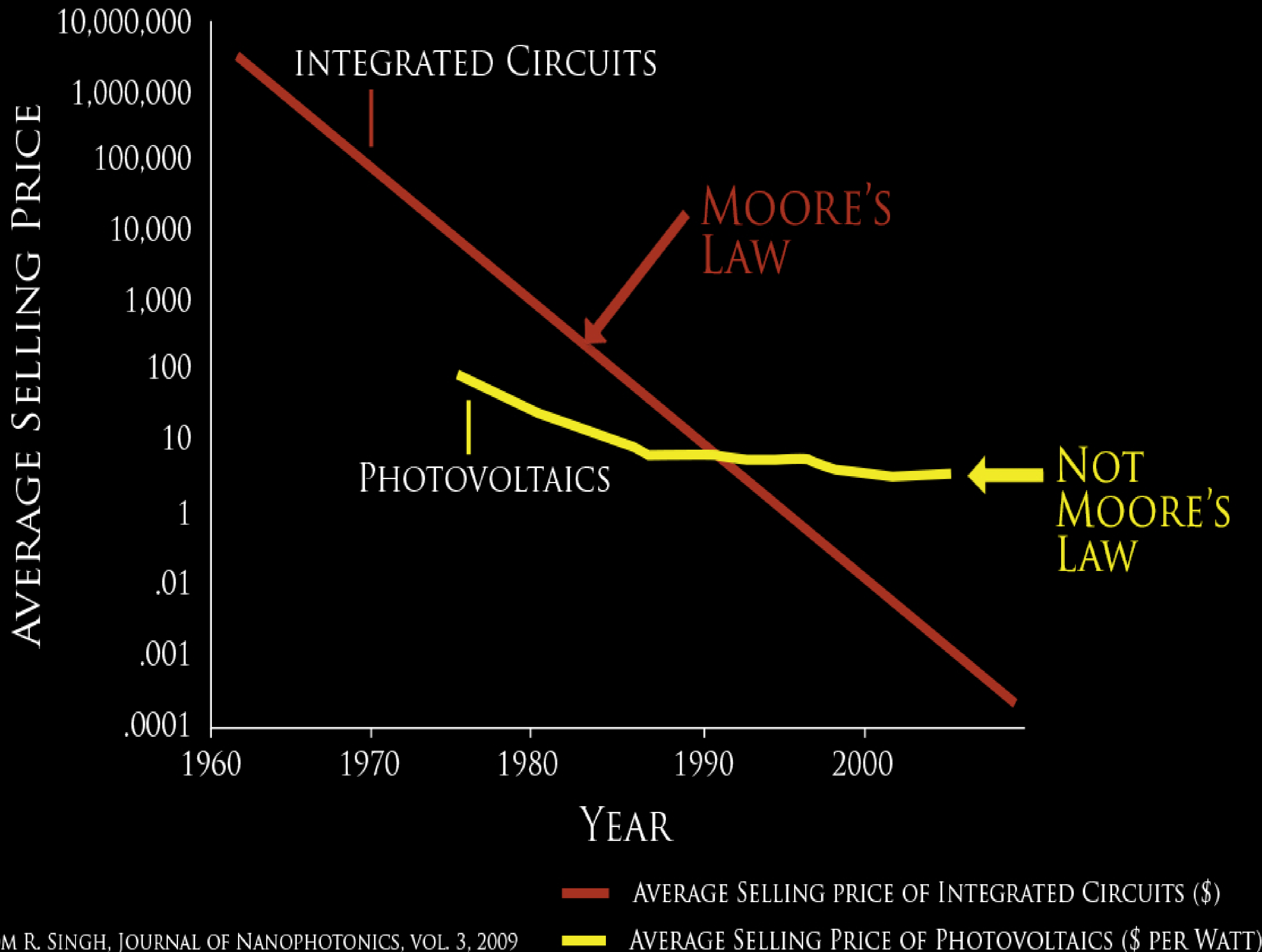
Concentrated PV

Crystalline silicon PV

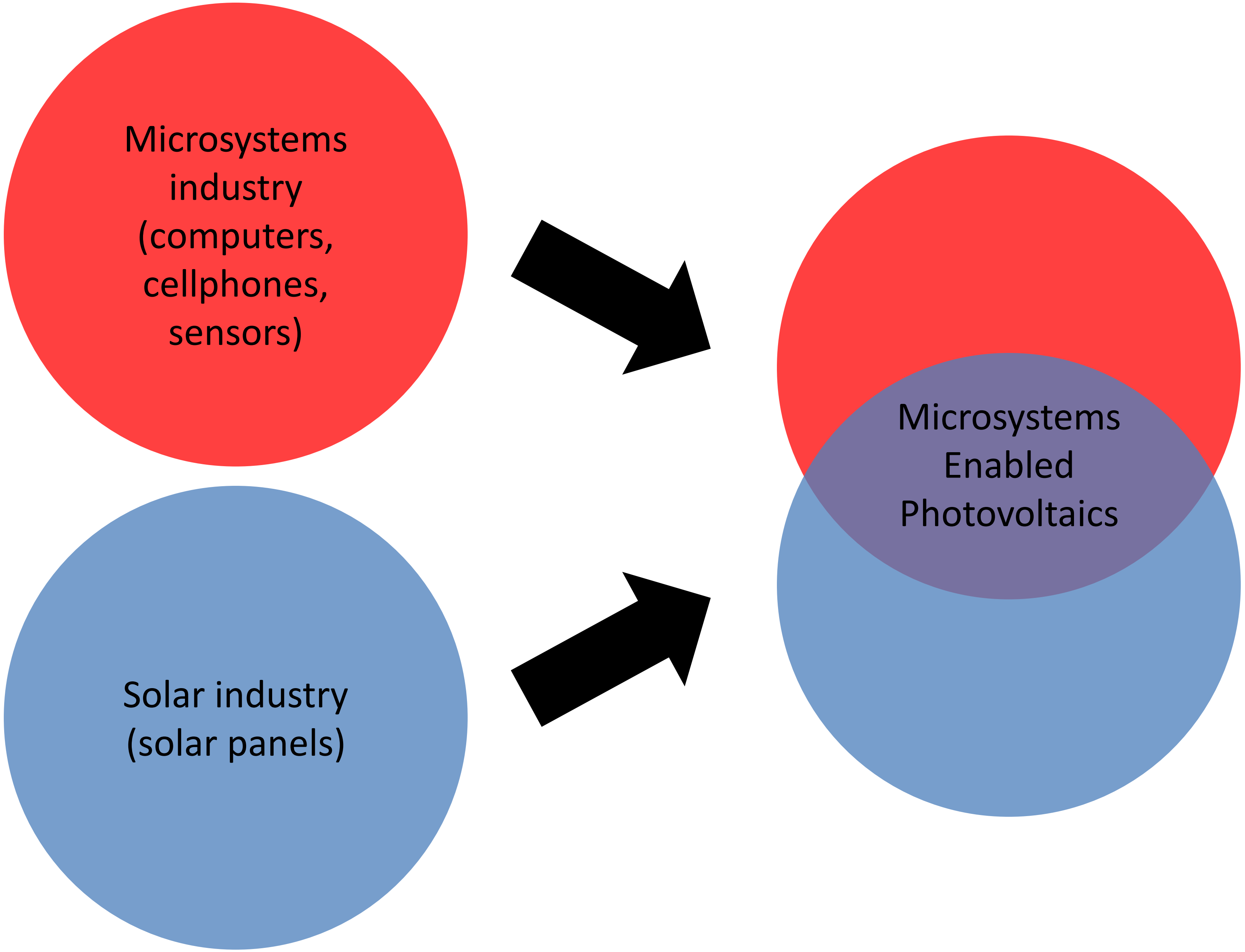
Thin Film PV



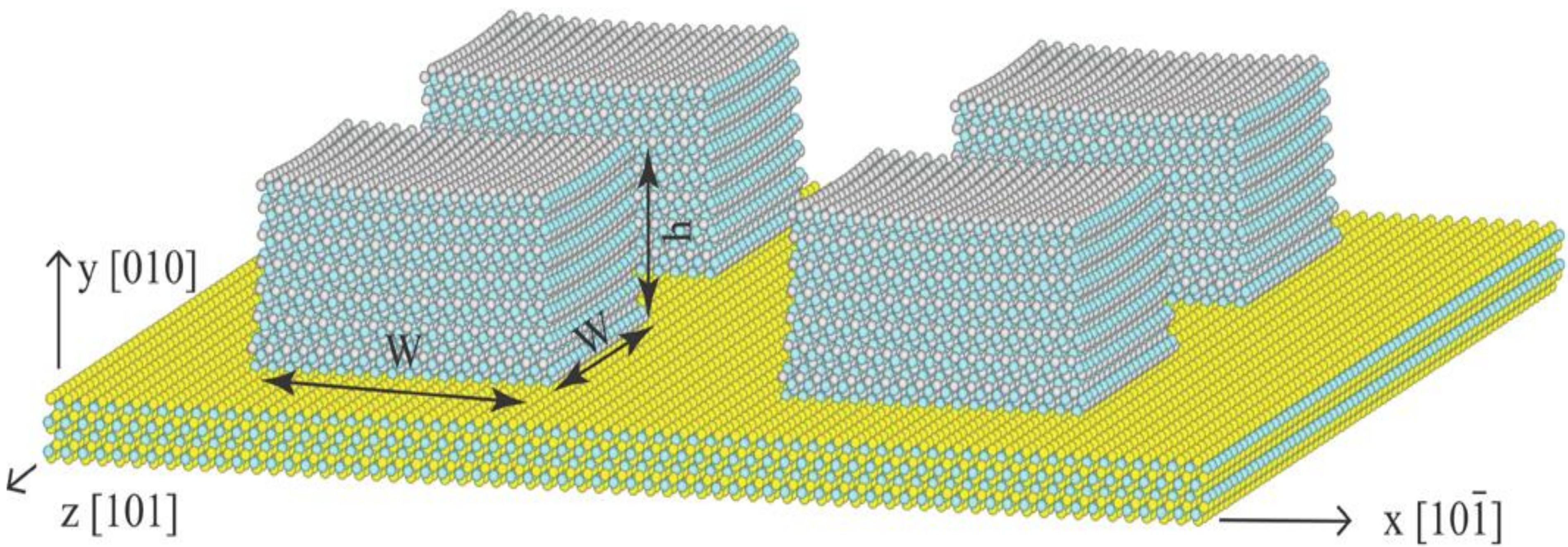
Reduced Cost



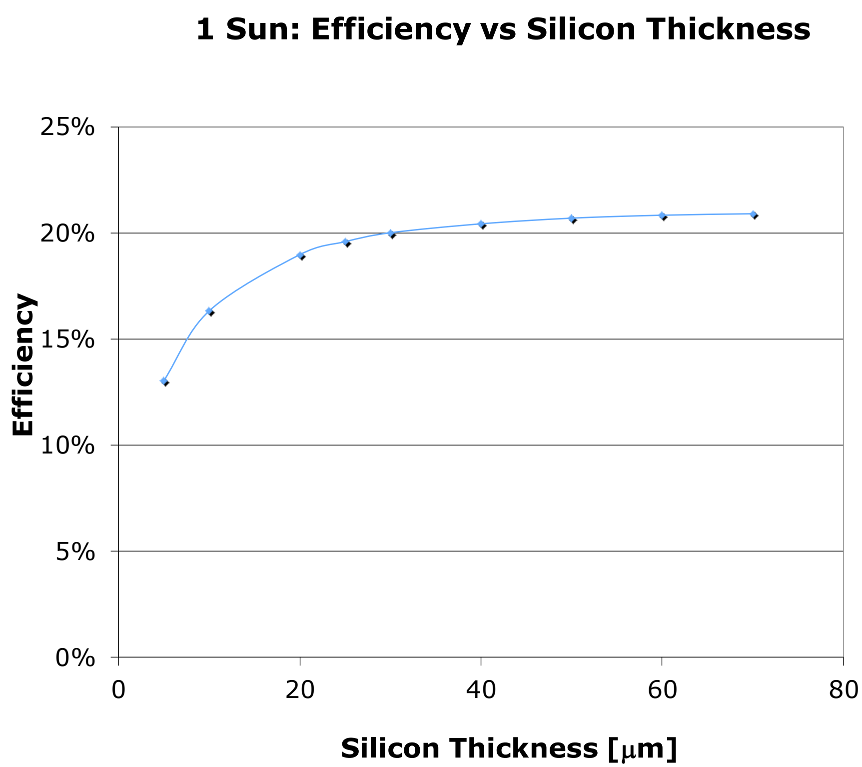
Derived from R. Singh, Journal of Nanophotonics, vol. 3, 2009

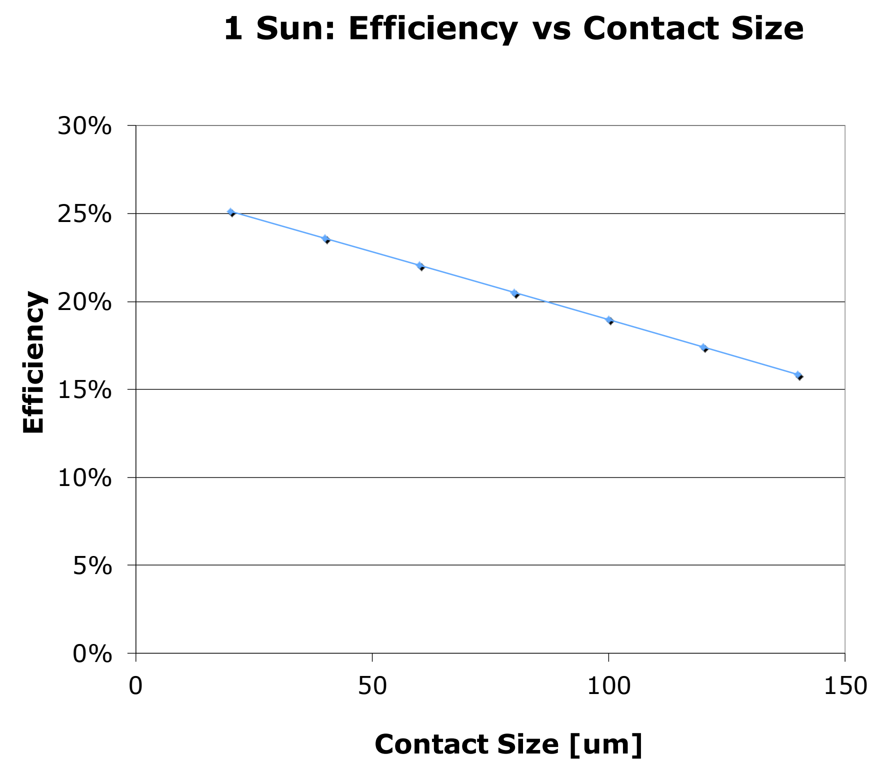

Microsystems industry (computers, cellphones, sensors)
Solar industry (solar panels)
Microsystems Enabled Photovoltaics

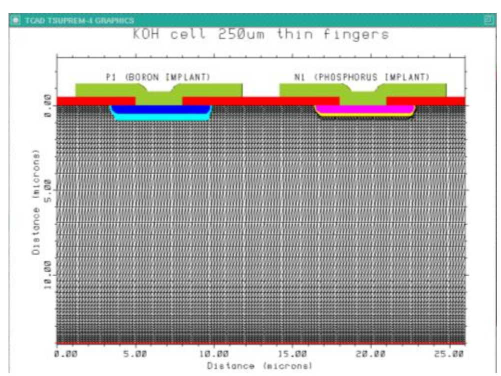
3 examples motivating the research



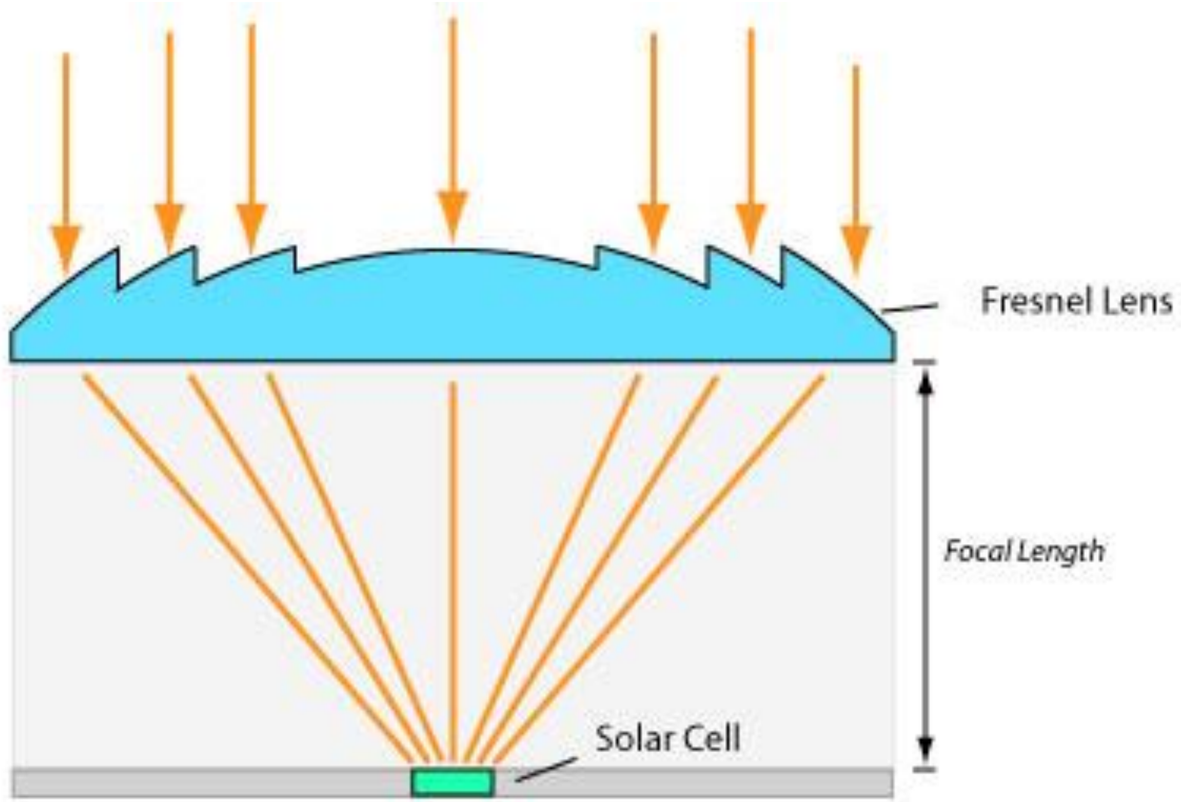
Cruz-Campa, J.L et al., "Nanopatterning and bandgap grading to reduce defects in CdTe solar cells," *Photovoltaic Specialists Conference (PVSC), 2012 38th IEEE* , vol., no., pp.000838,000842, 3-8 June 2012







Jose L. Cruz-Campa, Gregory N. Nielson, Paul J. Resnick, Murat Okandan1, Ralph Young, David Zubia, Vipin Gupta, Ultrathin and Micro Sized Solar Cell Performance Optimization Via Simulations, Progress in Photovoltaics, Volume 21, Issue 5, 2012



Gregory N. Nielson ; Murat Okandan ; Jose Luis Cruz-Campa et al. Leveraging scale effects to create next-generation photovoltaic systems through micro- and nanotechnologies. Proc. SPIE 8373, Micro- and Nanotechnology Sensors, Systems, and Applications IV, 837317, 2012

With the advantages of using microsystems and small cells, a new area of research was born

http://www.youtube.com/watch?v=noh8MXTj8qo

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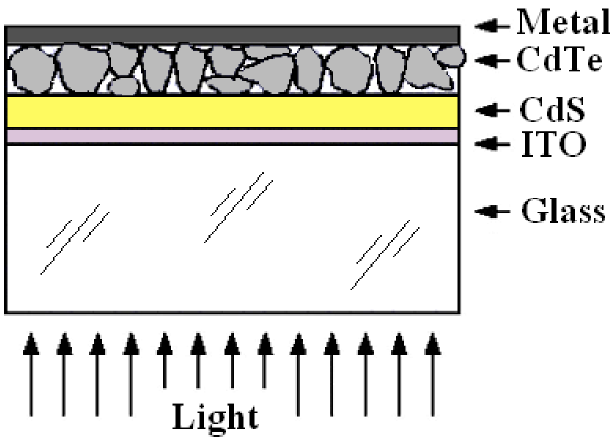
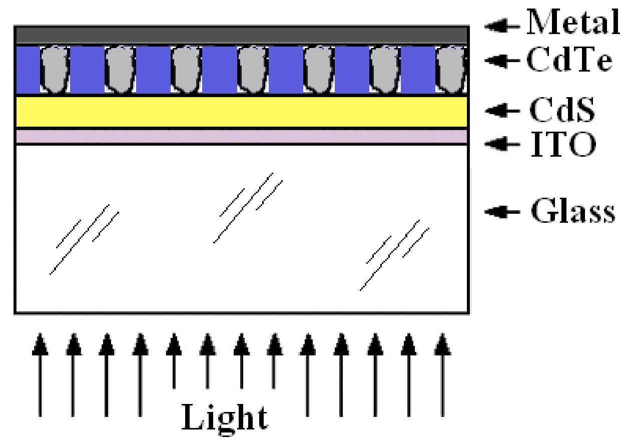
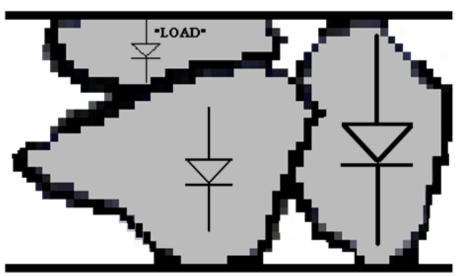
Thin Film PV

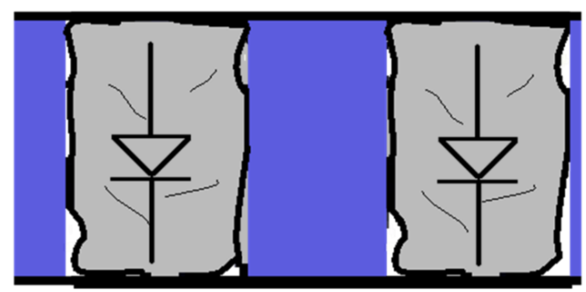
Normal cell

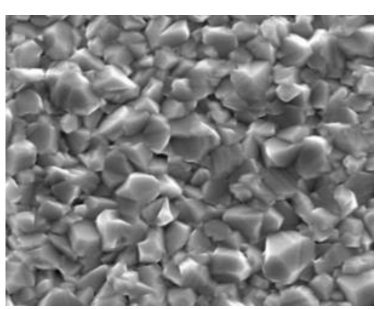
Microsystems enabled cell

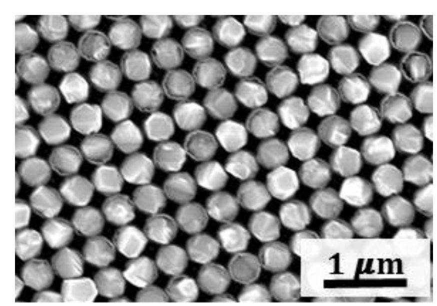


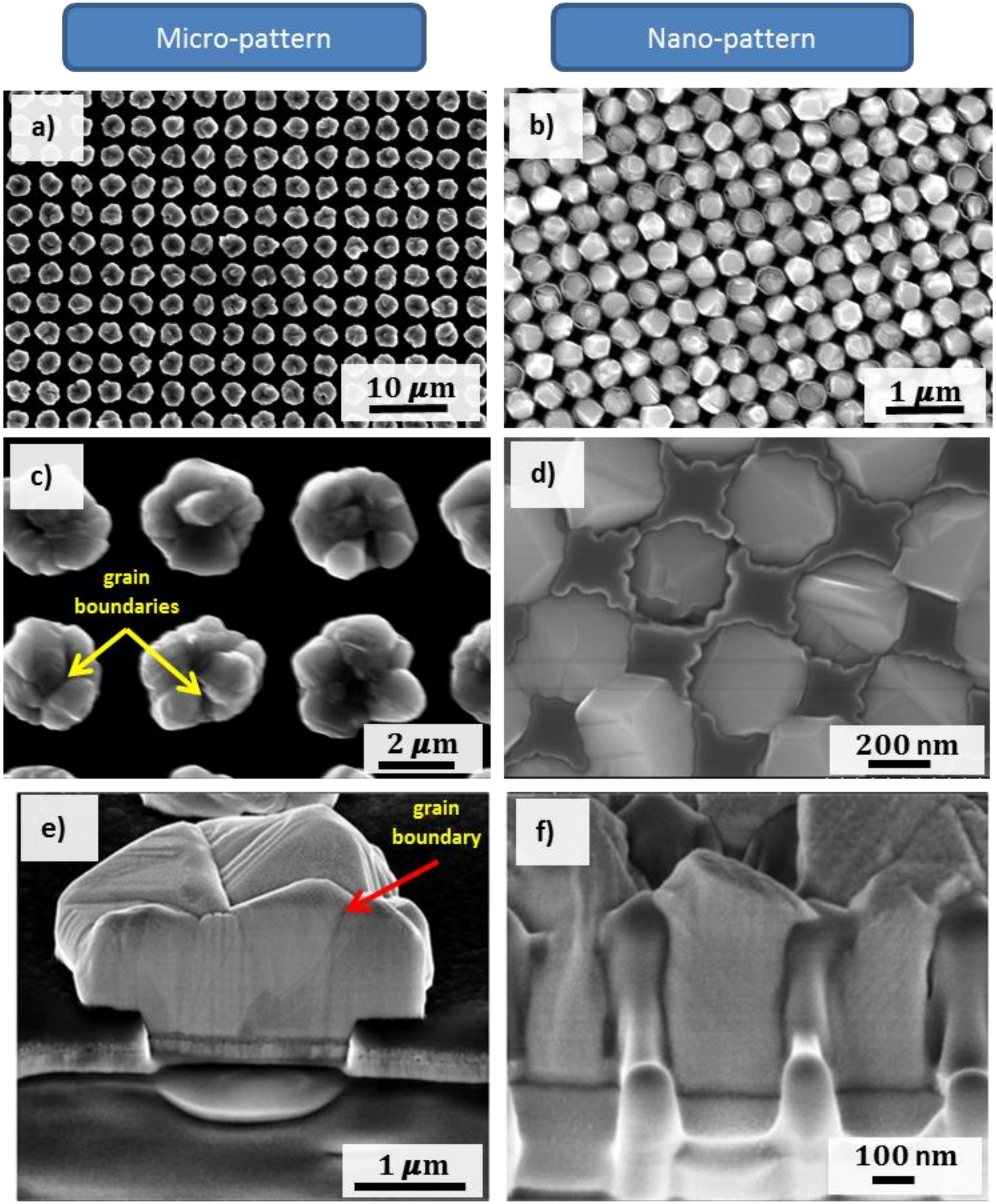




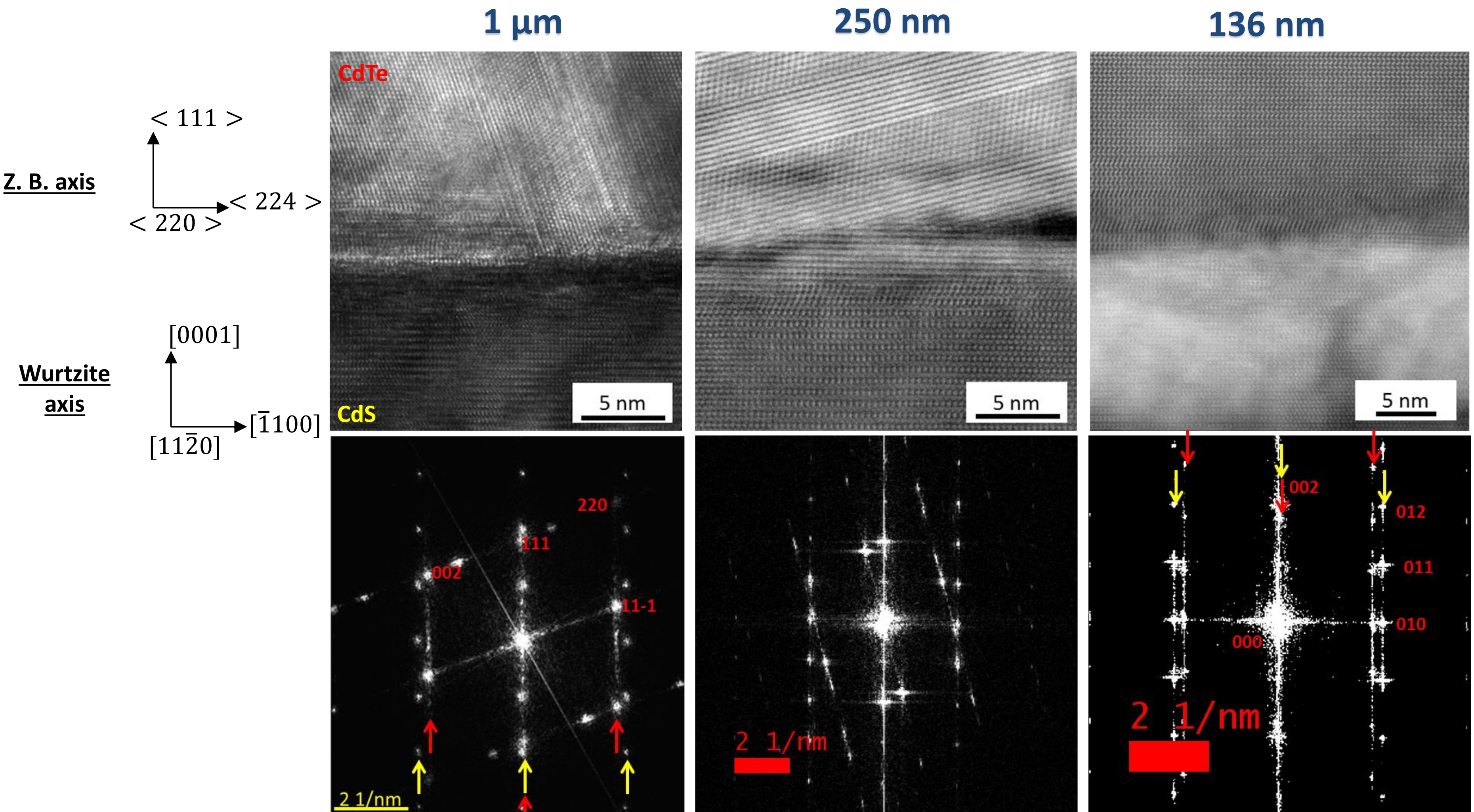








Brandon A. Aguirre, Jose L. Cruz-Campa et. al "Selective Growth of CdTe on Nano-patterned CdS via Close-Space Sublimation", Journal of Electronic Materials, 43, 2014 pp 2651-2657



CdTe has Z. B. atomic configuration

CdTe has Z. B. atomic configuration
S.F. and twins are observed

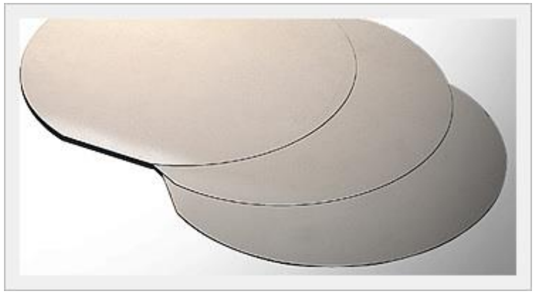
CdTe has wurtzite atomic configuration
S.F. observed close to the interface

Reduction of island size

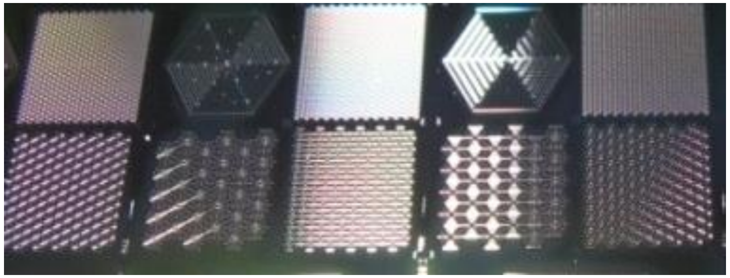
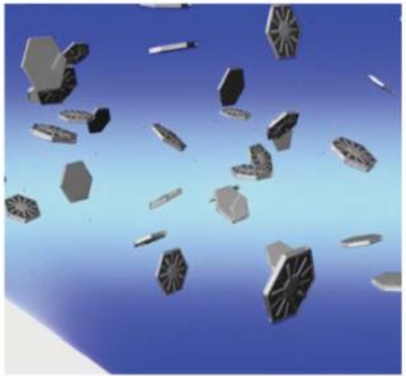
Material quality improves

Crystalline silicon PV

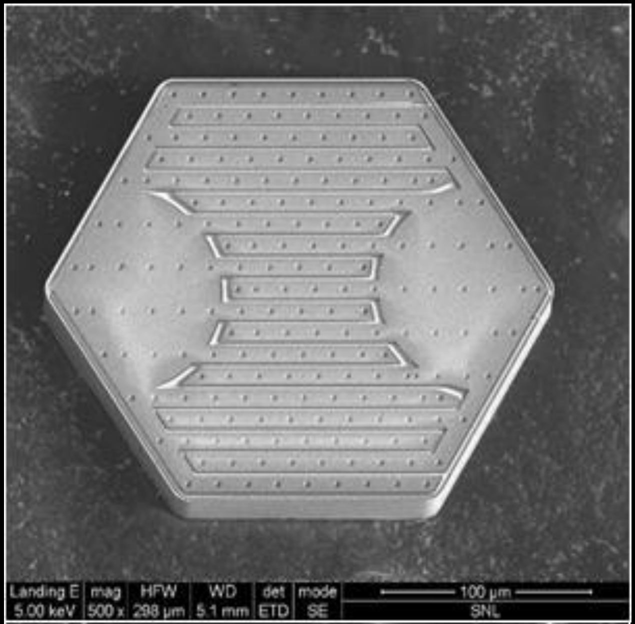
Conventional process



Sandia Process

V. Gupta, J. L. Cruz-Campa, M. Okandan, G. N. Nielson, *Microsystems-Enabled Photovoltaics: A Path to the Widespread Harnessing of Solar Energy*, Future Photovoltaics **1**, (2010) 28-36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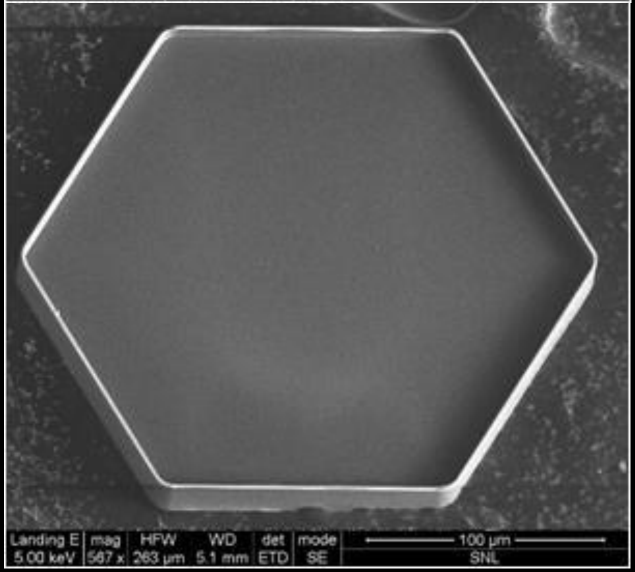
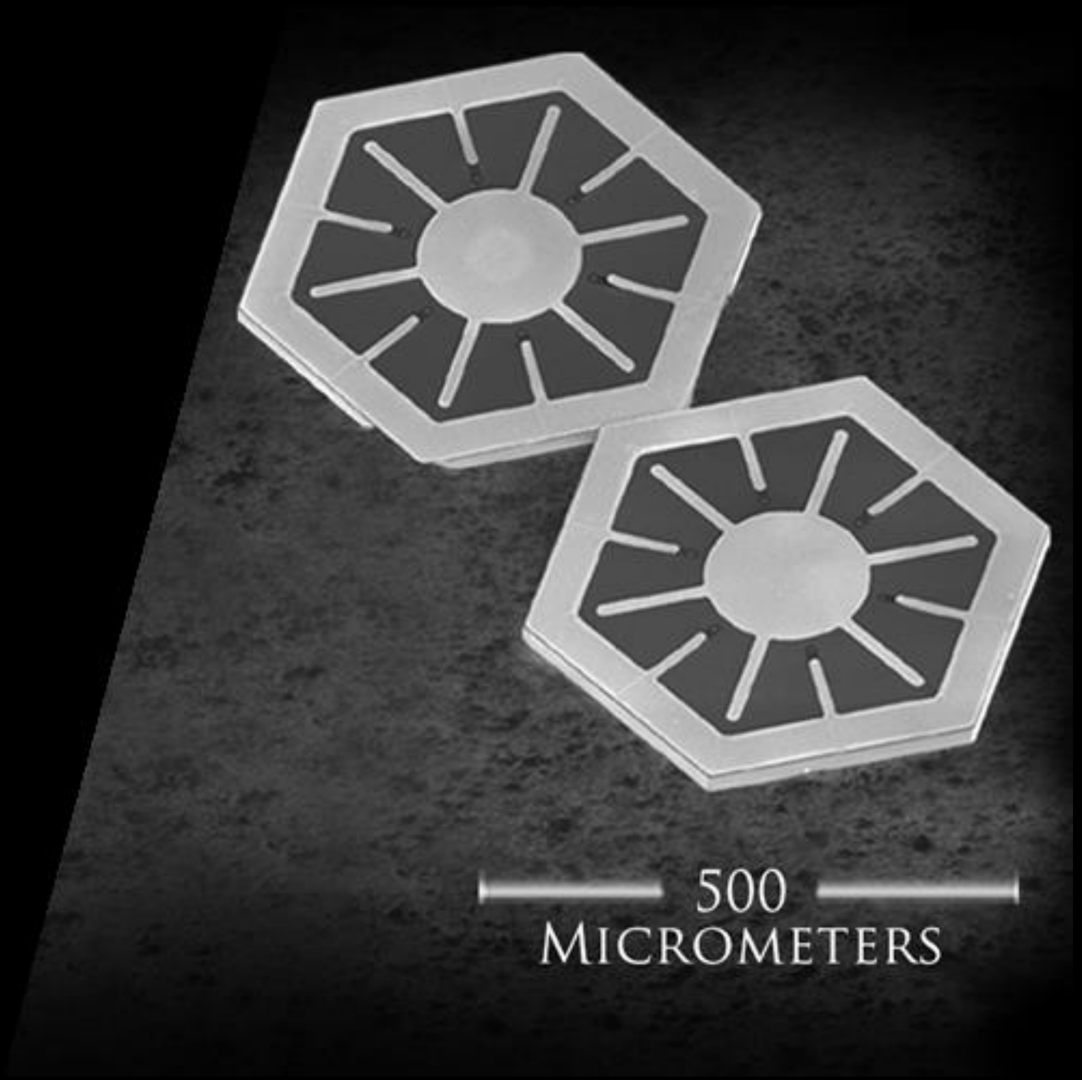
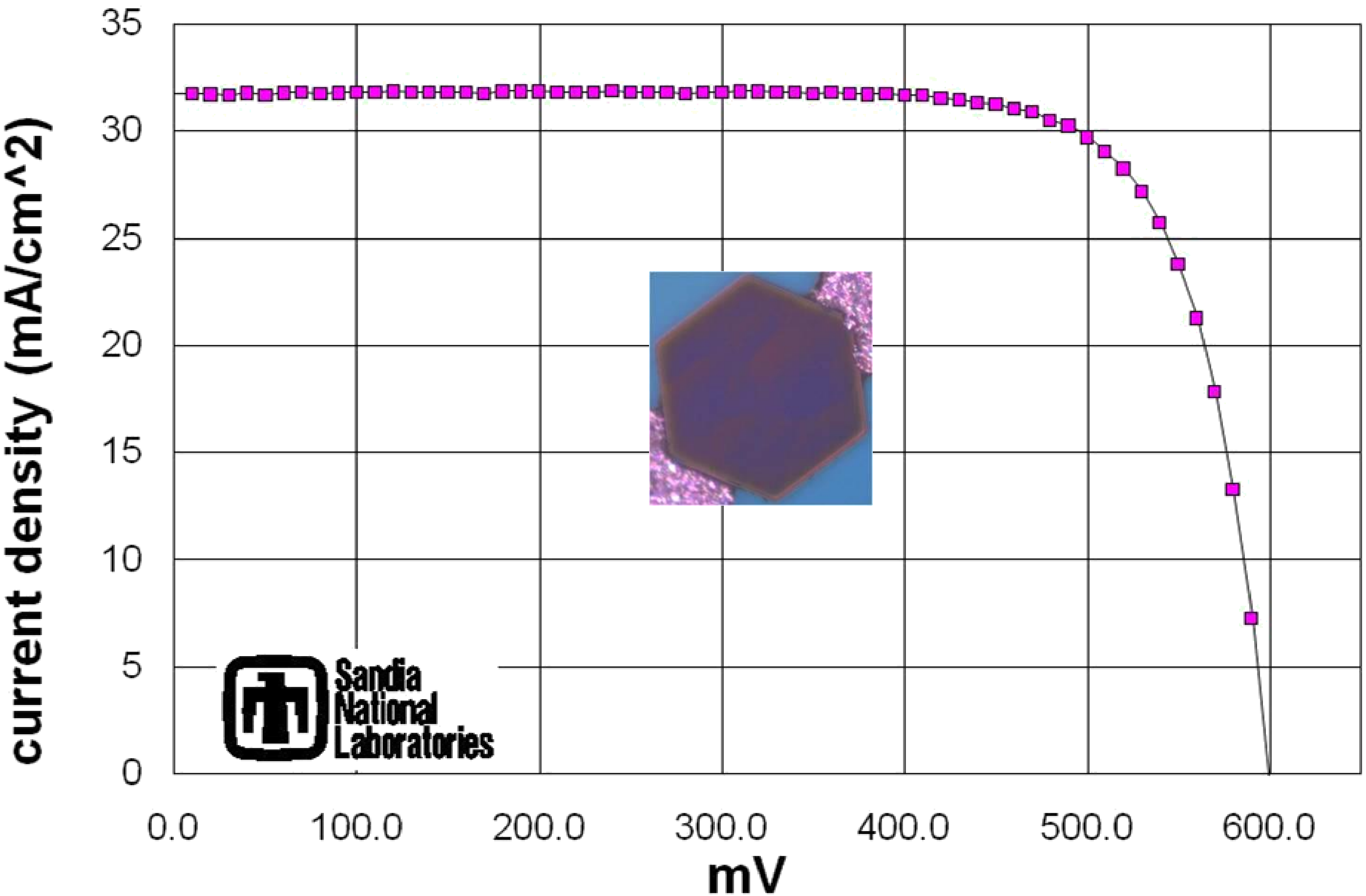
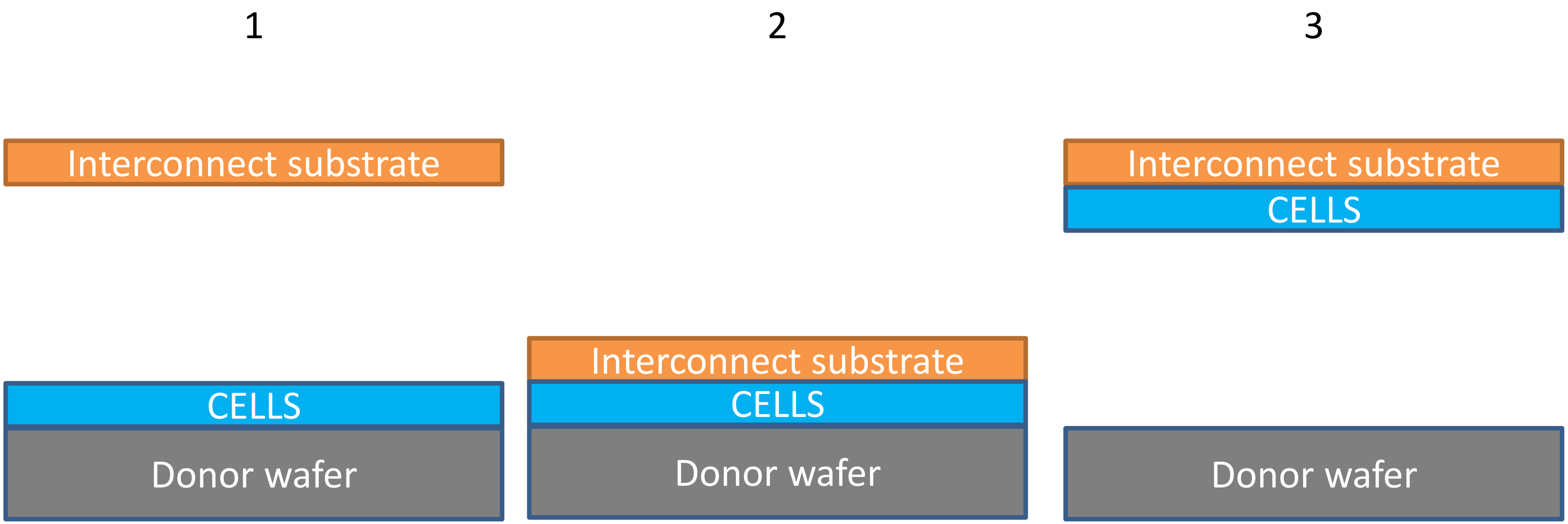
5.00 keV | 500 x | 298 µm | 5.1 mm | ETD | SE
100 µm
SNL

Landing E | mag | HFW | WD | det | mode
5.00 keV | 567 x | 263 µm | 5.1 mm | ETD | SE
100 µm
SNL

500
MICROMETERS

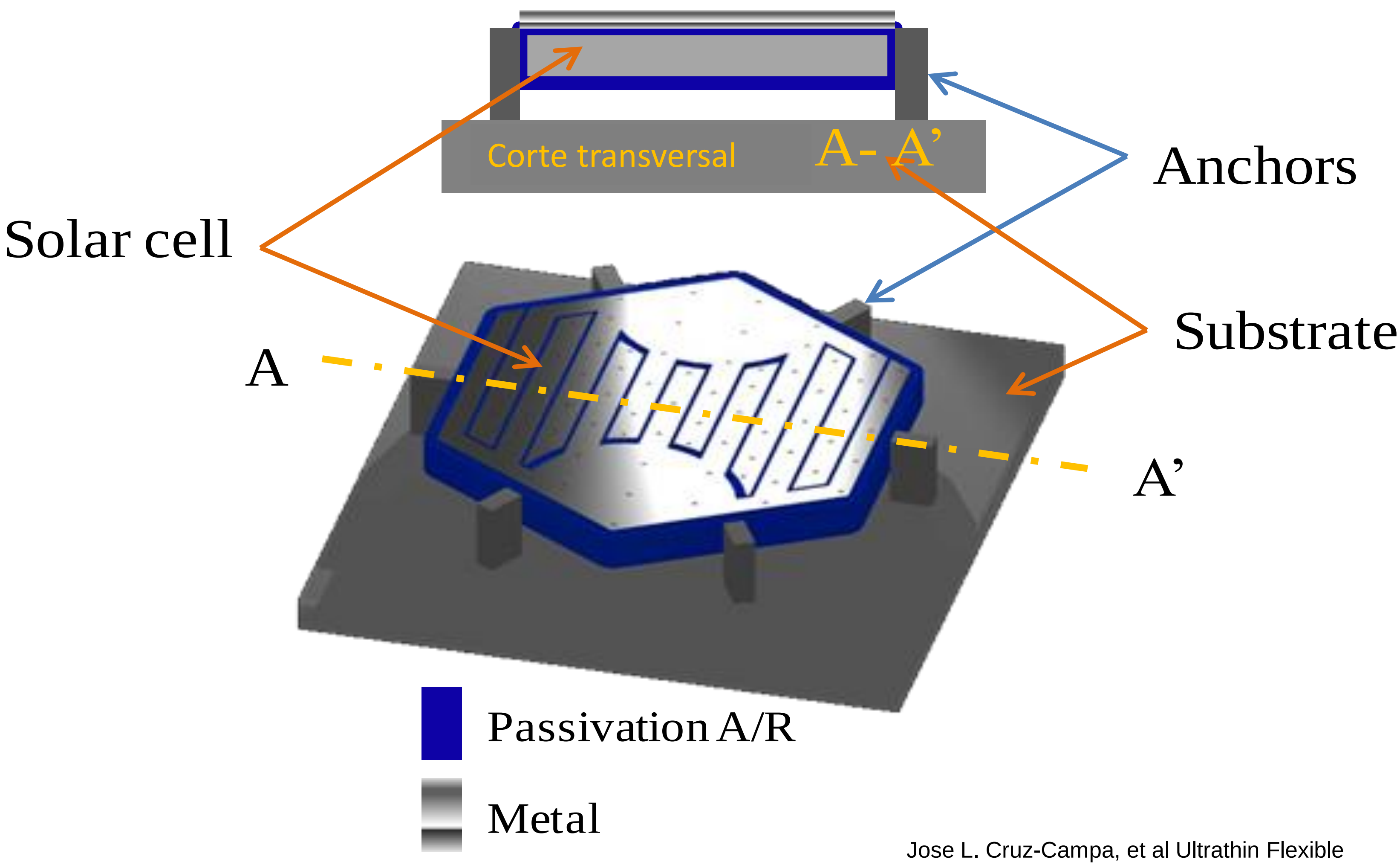


08/20/09 2:18 PM	25.0 °C	0.0003763 cm^2	31.75 J_{sc}(mA/cm^2)	0.784 FF	AM1.5G
	1.0000 M*	597.3 V_{oc}(mV)	11.946 I_{sc}(uA)	14.86 % Eff	1.00 Suns
	1.0000 S*	501. V_{mp}(mV)	11.161 I_{mp}(uA)		

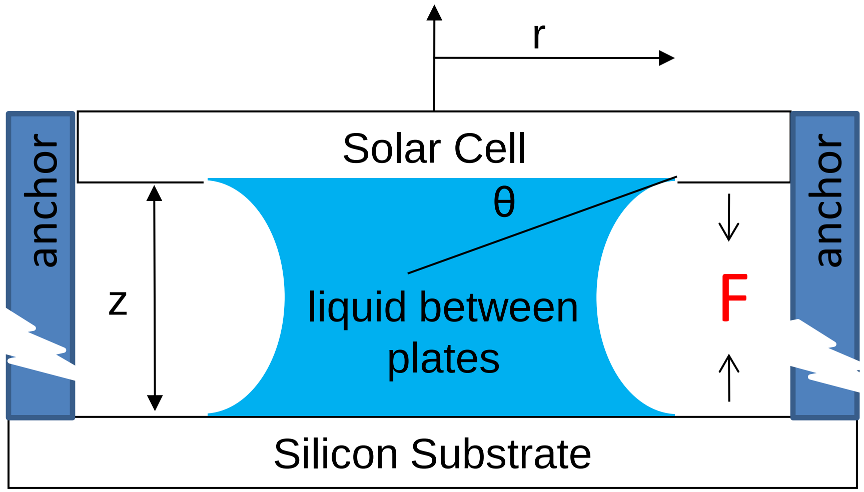


Advantages:

- Less handling
- Less placements per module
- Higher uniformity



Jose L. Cruz-Campa, et al Ultrathin Flexible Crystalline Silicon: Microsystems Enabled Photovoltaics, Journal of Photovoltaics 1, pp 3-8, 2011



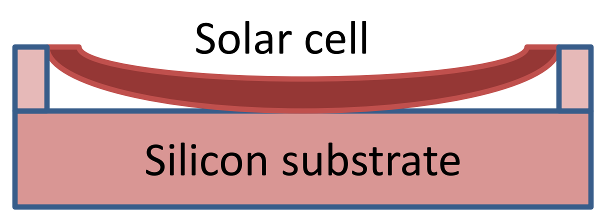
capillary forces

$$\sigma = \frac{F}{wt^{*}\#anchors}$$

$$F = \frac{2\pi\gamma}{z} r^{2} \cos\theta$$

Deflection

$$\delta = \frac{Fr^{3}}{(48)EI}$$



Spinning

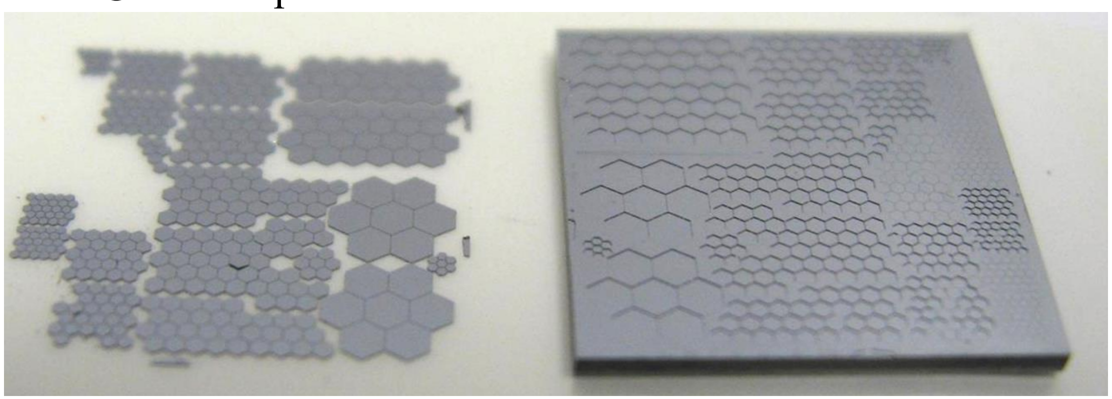
Lateral size (µm)	3 anchors	6 anchors middle	6 anchors corners	6 spring anchors	12 anchors	18 anchors
250	☺	😐	😐	☺	😐	😐
375	☺	☺	😐	☺	😐	😐
500	☺	☺	☺		☺	☺
750		☺			☺	☺
1000					☹	☺

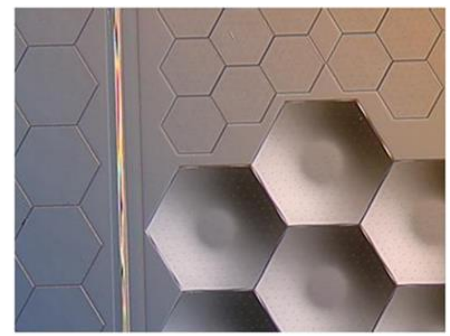
design fabricated | design not fabricated

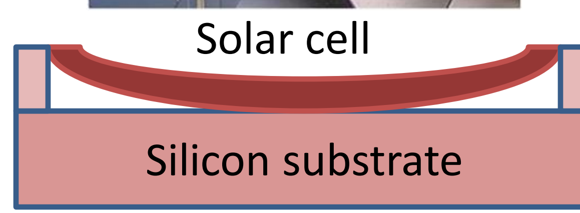
☺ Successful (suspended/transferred)

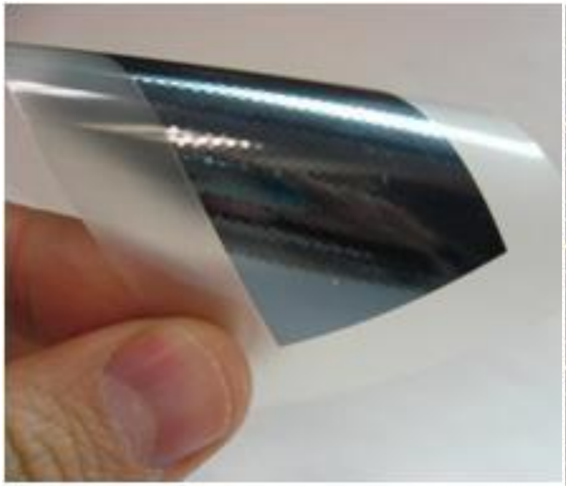
😐 suspended/ not transferred

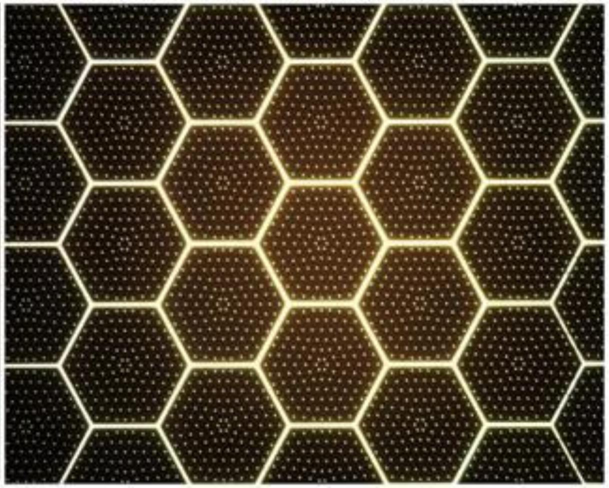
☹ Not suspended

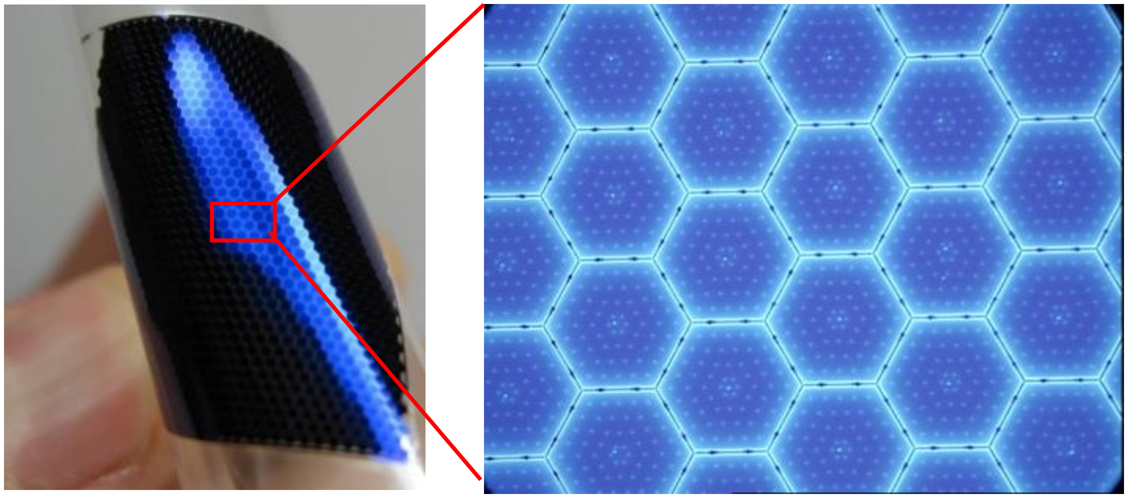




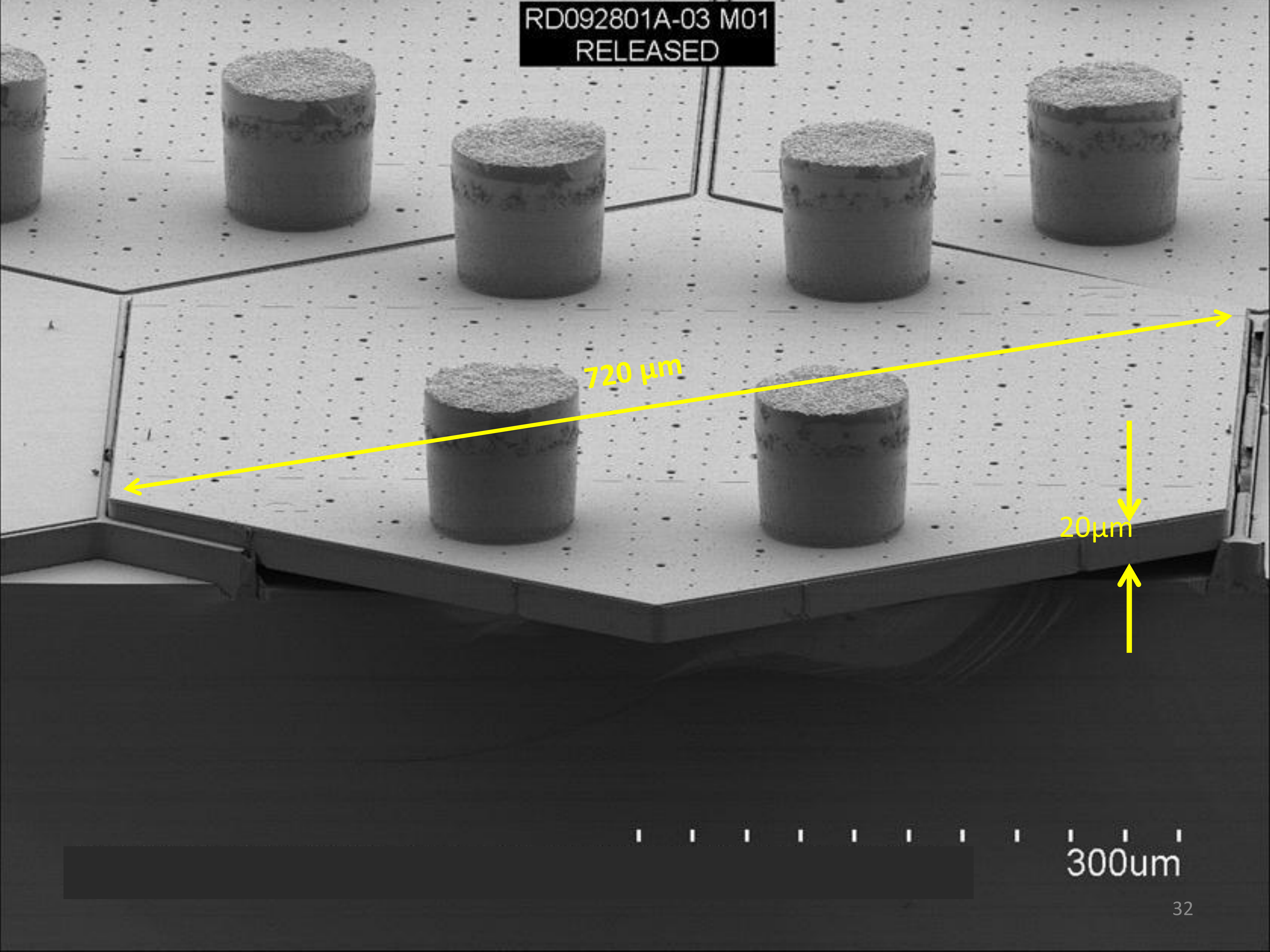


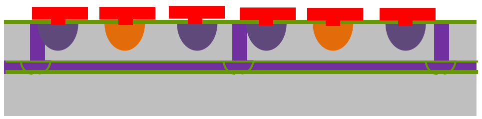




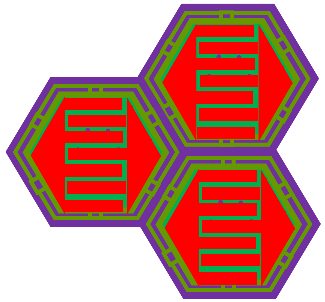


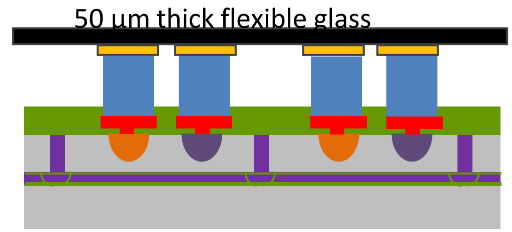
Jose L. Cruz-Campa, Gregory N. Nielson, Paul J. Resnick, Carlos A. Sanchez, Peggy J. Clews, Murat Okandan, Vipin Gupta, Ultrathin Flexible Crystalline Silicon: Microsystems Enabled Photovoltaics, Journal of Photovoltaics 1, 2011. Pages 3-8


RD092801A-03 M01
RELEASED
720 µm
20µm
300um

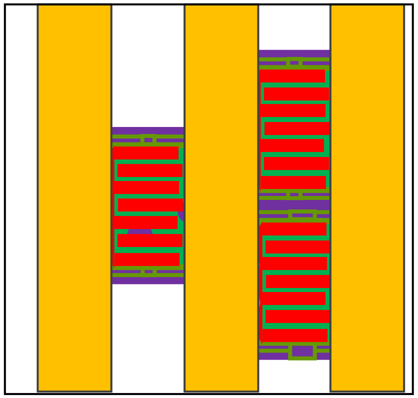


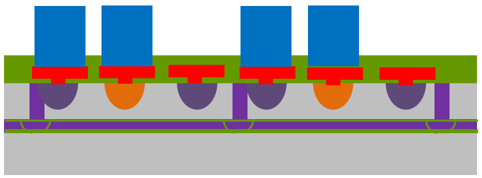
Finished cell with metallization



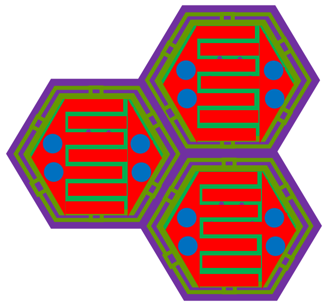


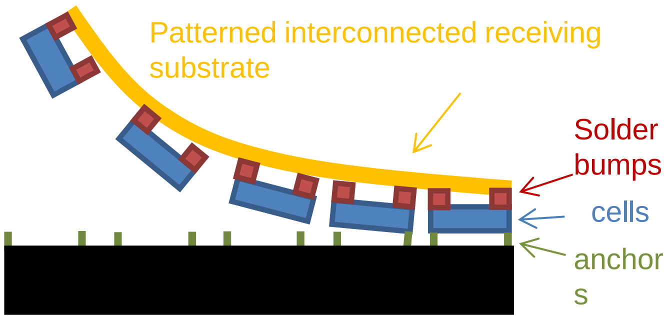
XeF2 etch and bump metal melt to mechanically and electrically connect to receiving substrate





Nitride deposition and pattern and solder bump creation

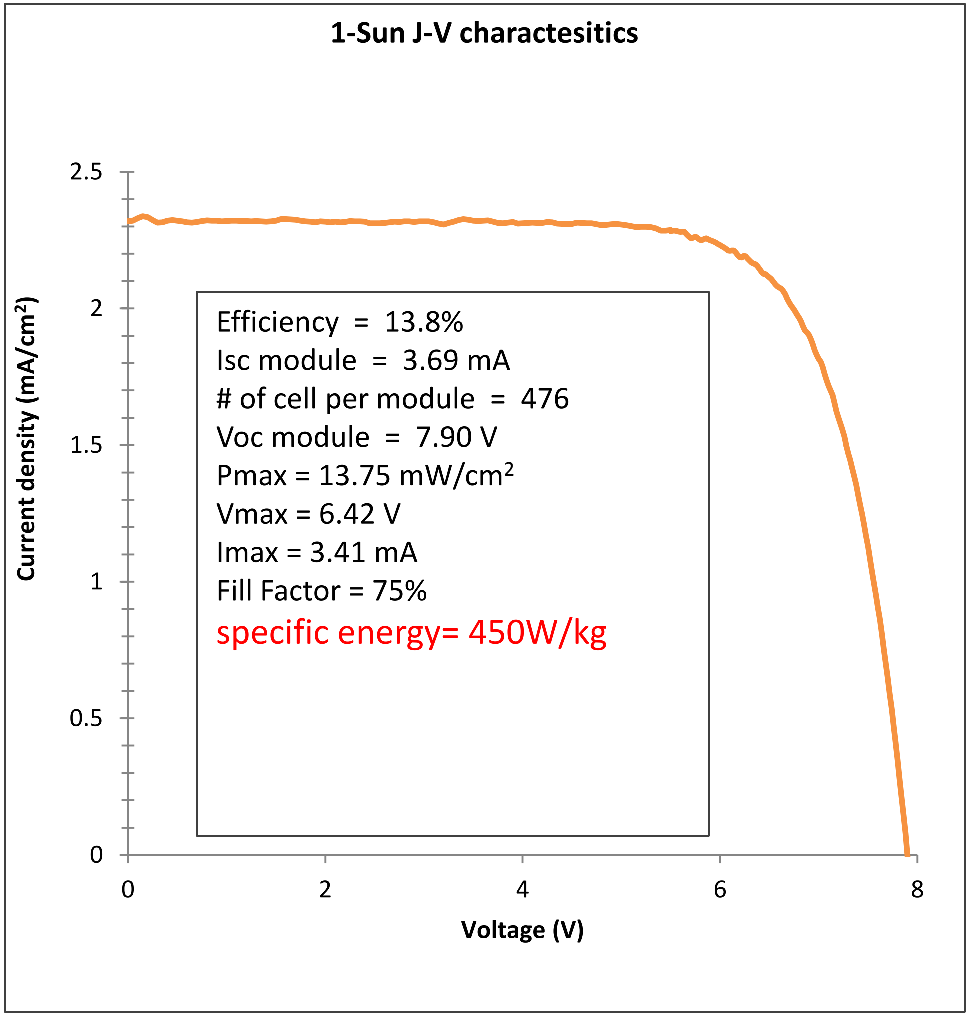


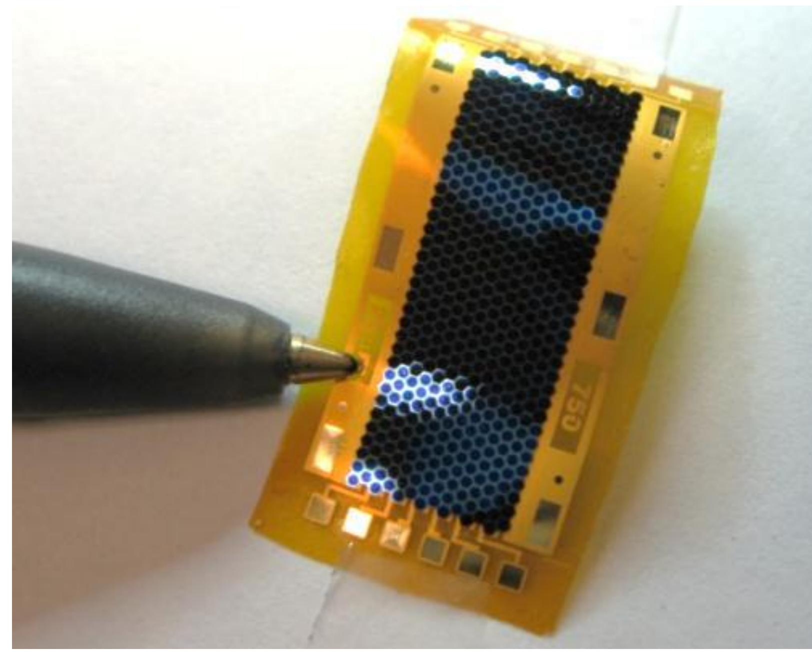


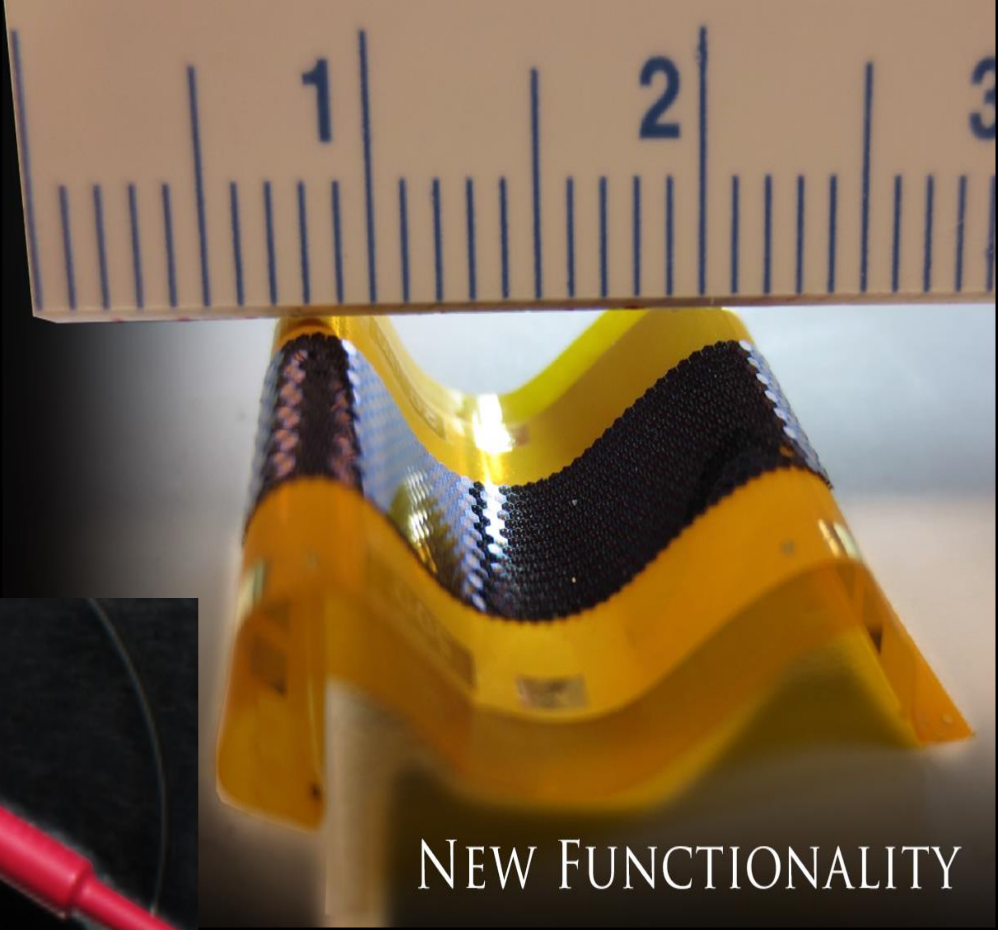
Detachment of cells

Jose L. Cruz-Campa, Gregory N. Nielson, Murat Okandan, Paul J. Resnick, Carlos A. Sanchez, Vipin P. Gupta, and Jeffrey S. Nelson, Ultrathin and flexible single crystal silicon mini-modules, Proceedings of EU PVSEC 2012, in press

Sandia is the first one to prove such a high energy density with such a small bending radius

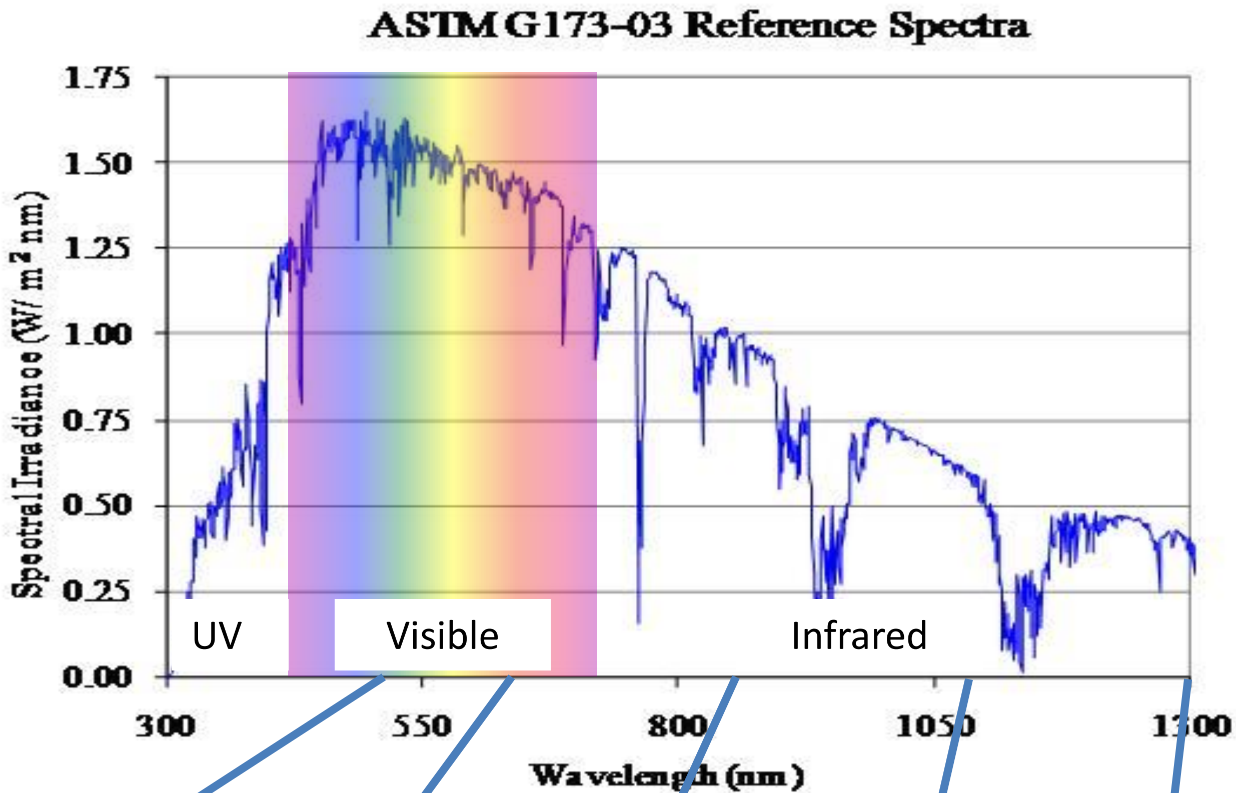





1
2
3
New Functionality

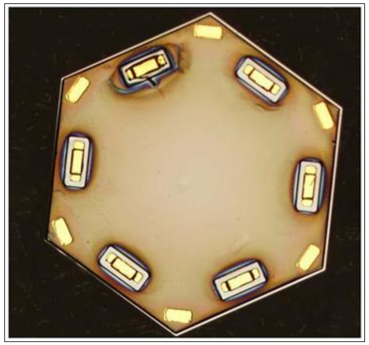

Improved Performance
7.54

Concentrated PV

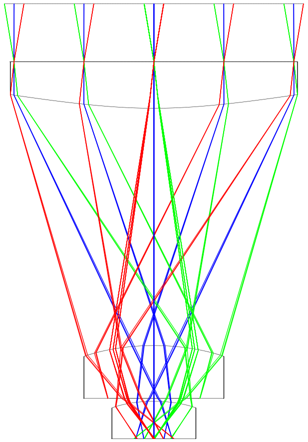


Material	InGaN 2.2 eV	InGaP 1.85eV	GaAs 1.4eV	Si 1.1EV	InGaAsP 0.9eV	InGaAs 0.6eV
Wavelengths best absorbed	Less than 560nm	Less than 670nm	Less than 886nm	Less than 1127nm	Less than 1378nm	Less than 2070nm

Our approach has a defined path to make solar the least expensive energy source



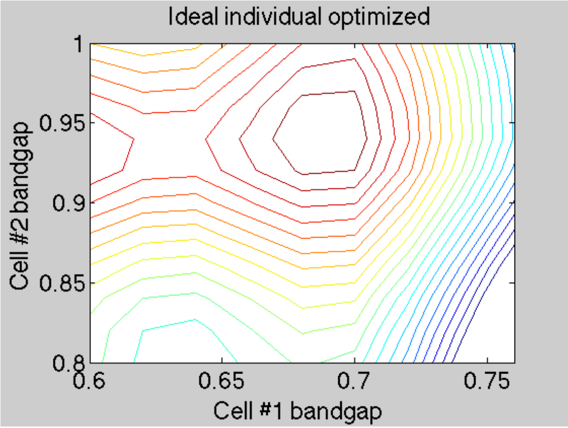
Small cells



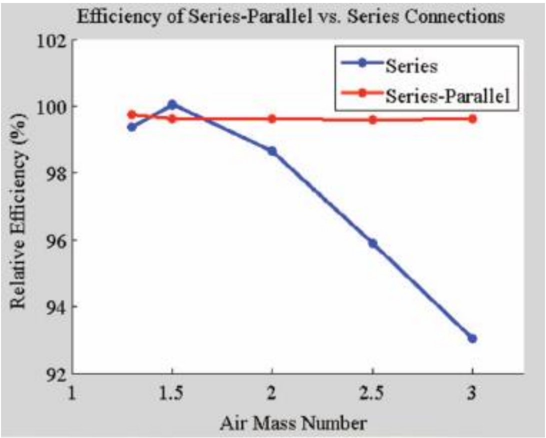
New optical refractive designs for tracking

Low-cost, coarse 2-axis tracking with high acceptance angle and flat external surface

Use of mature microsystems technologies

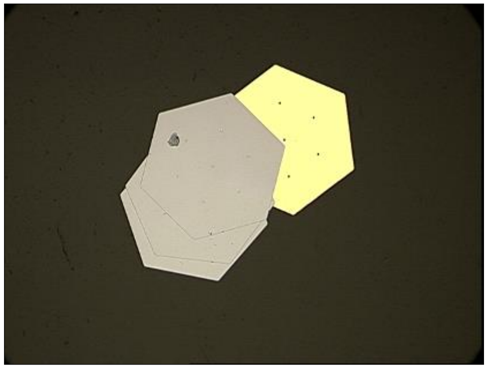


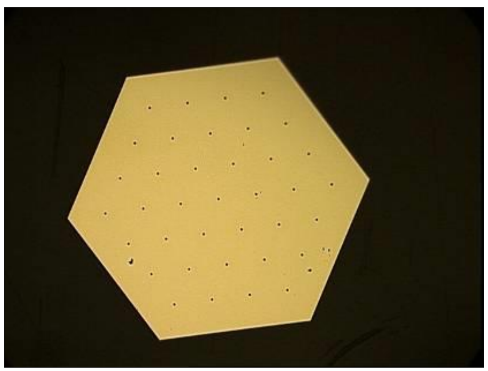
Feasibility to break the efficiency records



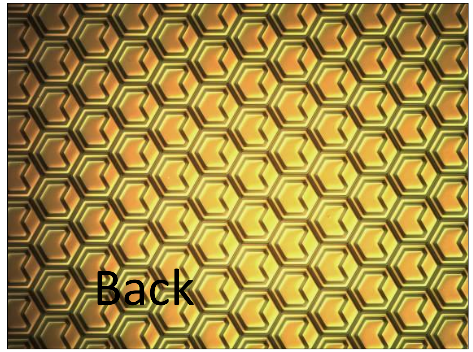
Optimized interconnections for higher efficiency

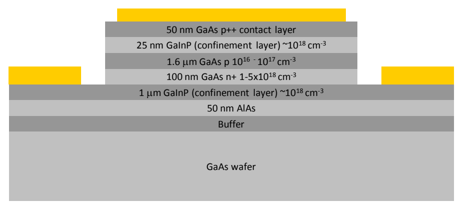
Our designs have evolved into a more complex, more functional cells



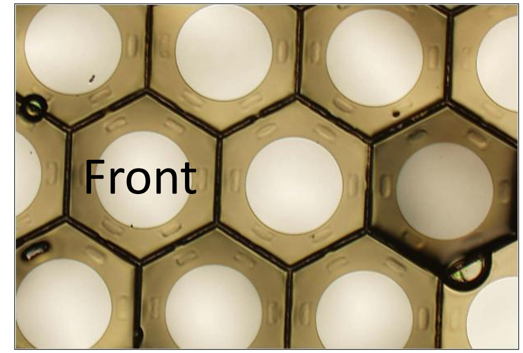


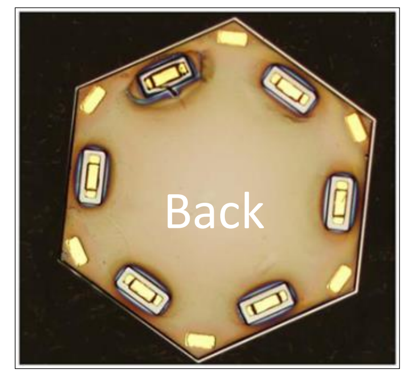
Single junction with front-back contacts



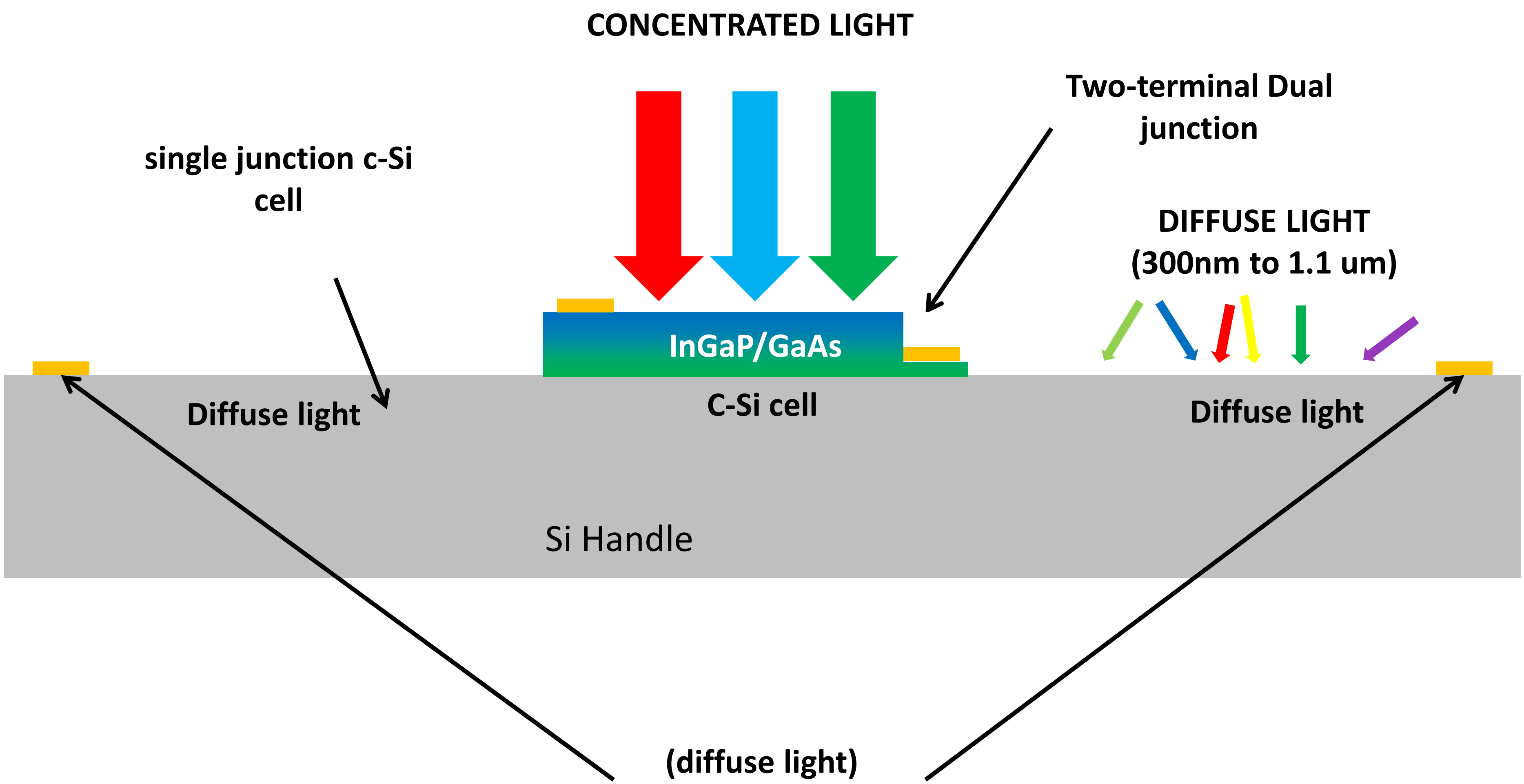


Single junction with all back contacts at different levels

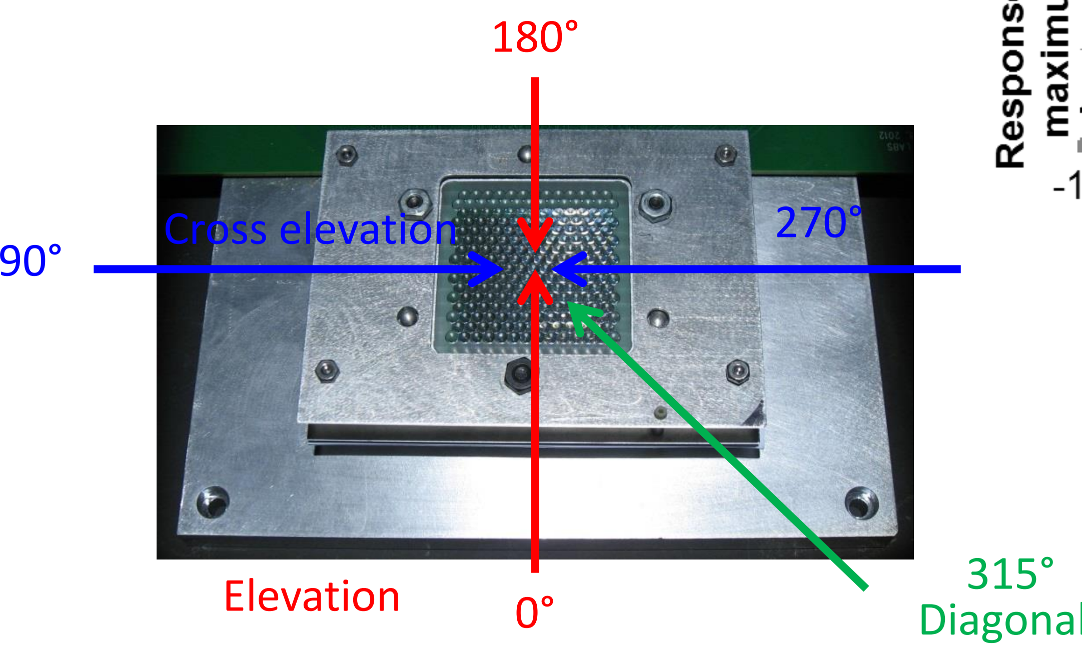


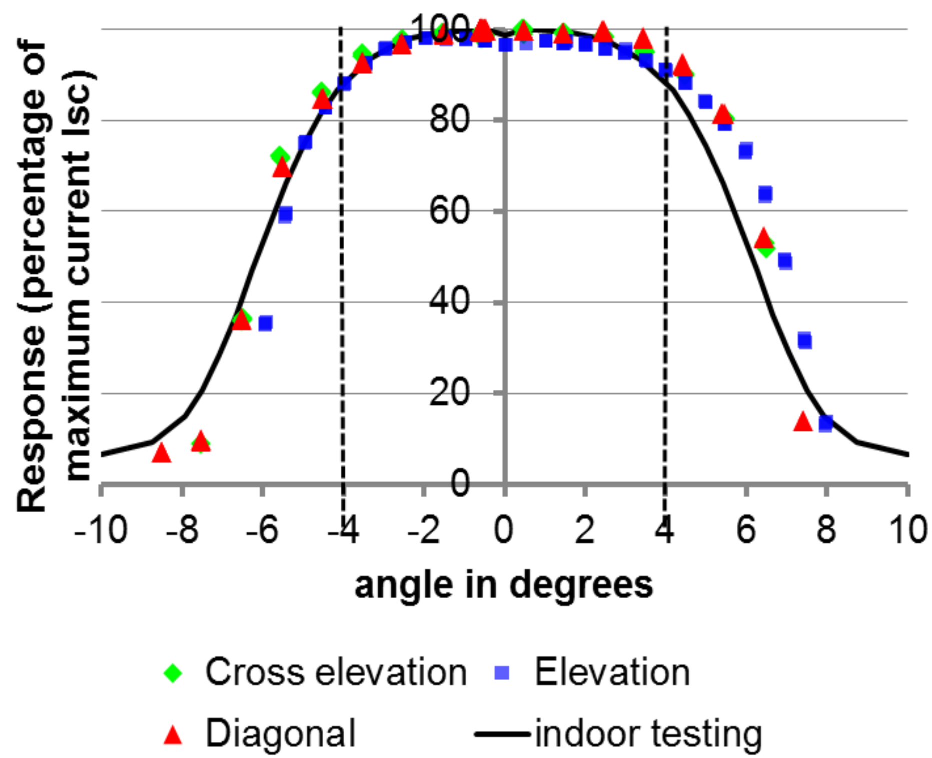


Double junction with all back contacts at the same level

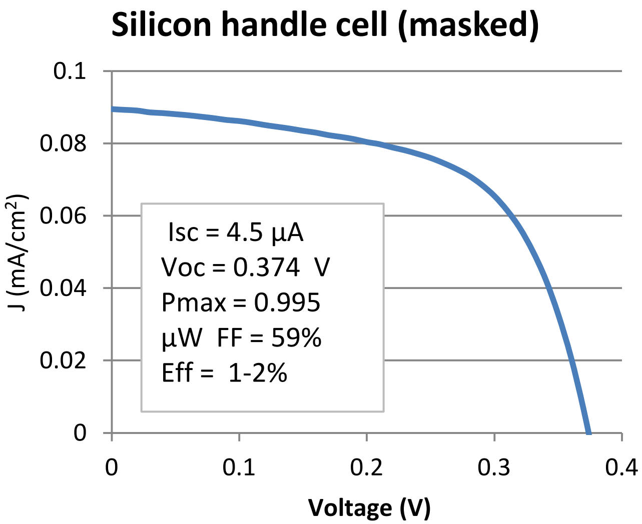


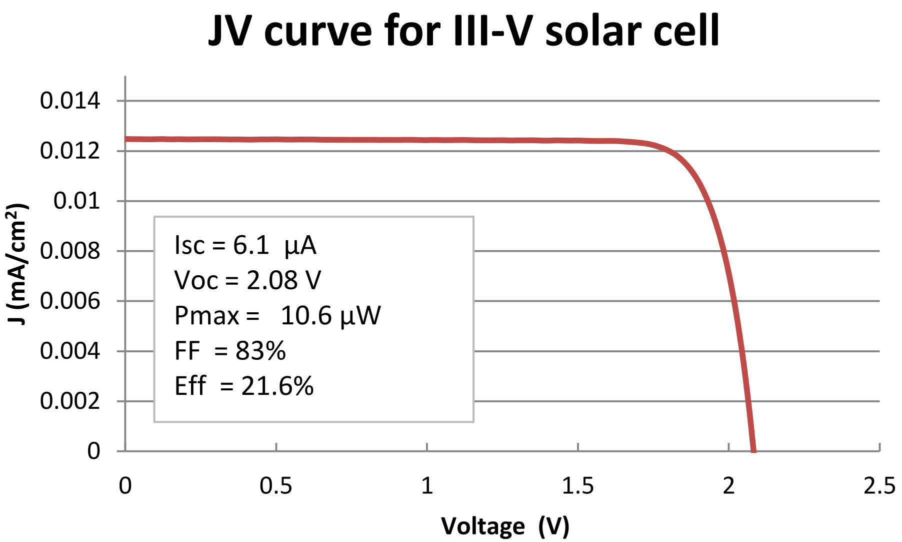
M. Haney, T. Gu, G. Agrawal, "Hybrid Micro-scale CPV/PV Architecture", Proceedings PVSC, 2014

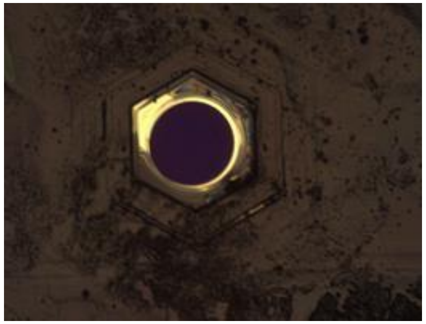




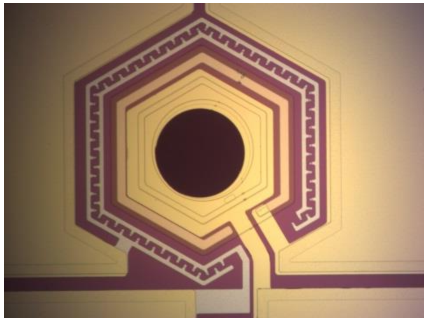
J. L. Cruz-Campa, et. al. “Flat Plate Concentrators with Large Acceptance Angle Enabled by Microcells and Mini Lenses: Performance Evaluation”, 28th European Photovoltaic Solar Energy Conference and Exhibition, Pp 612 – 616, 2013







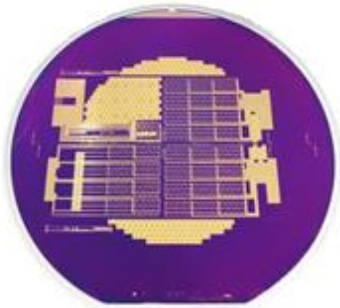
Masked cell

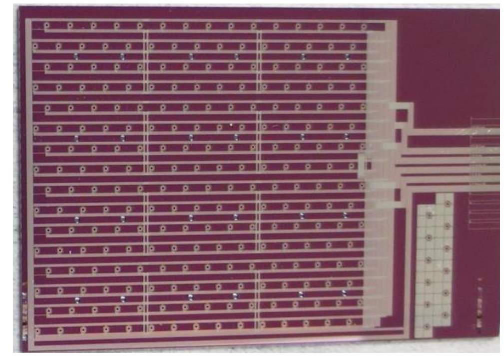


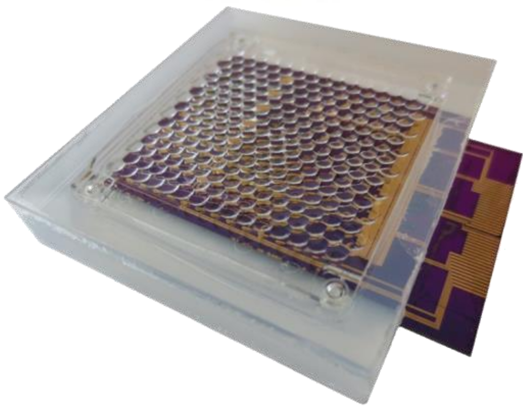
Unmasked cell

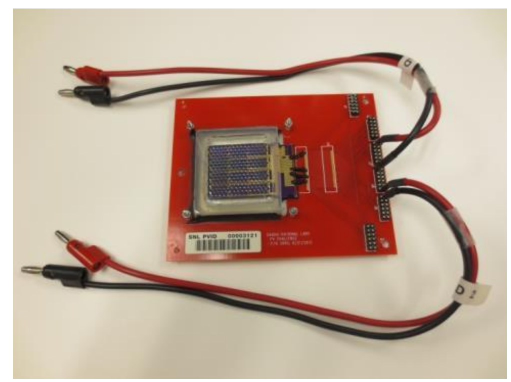
efficiencies > 21% (III-V side) with an active silicon efficiency of about 1-2%

Packaging of active cells into modules was achieved yielding optical efficiencies above 90%

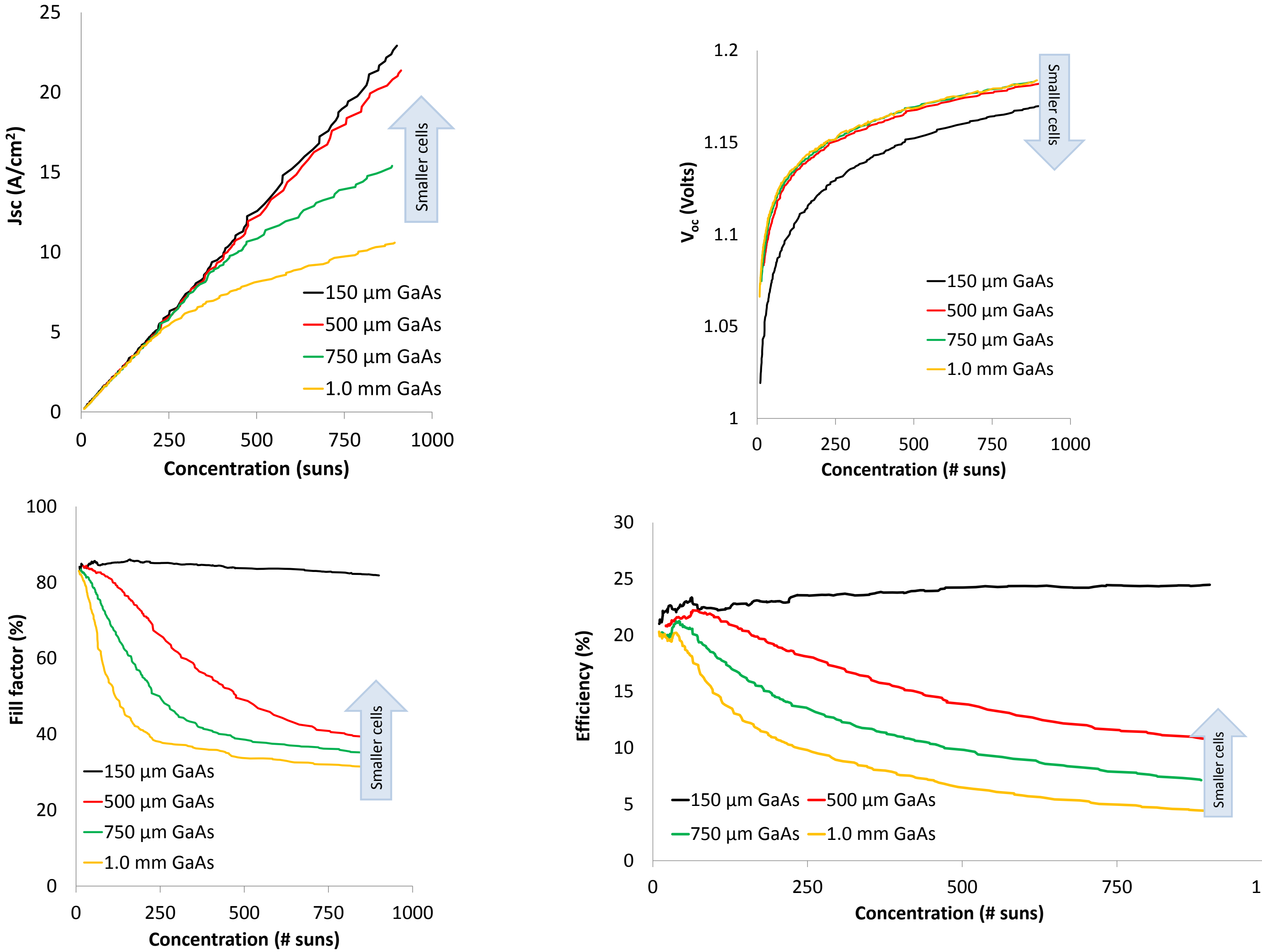




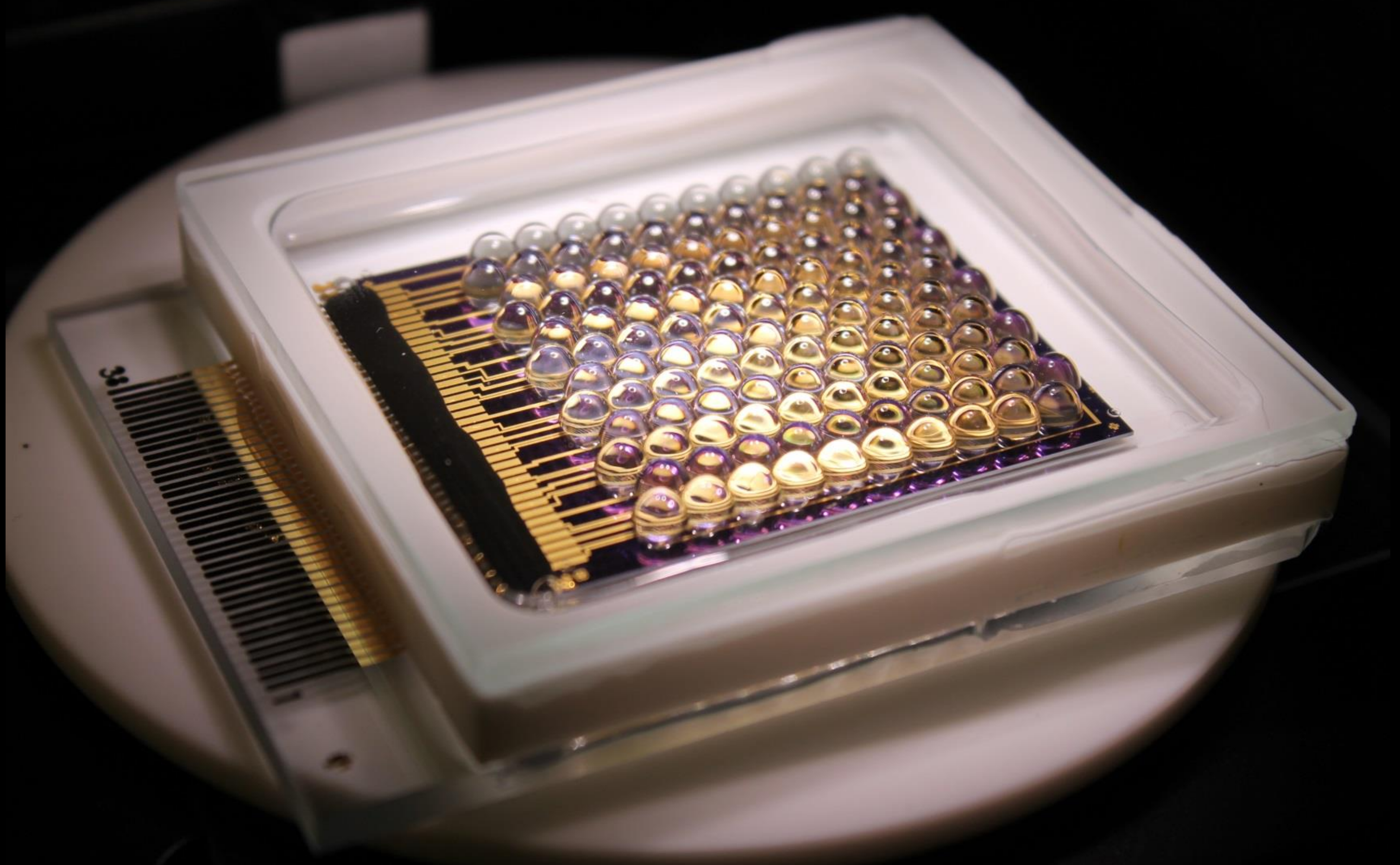




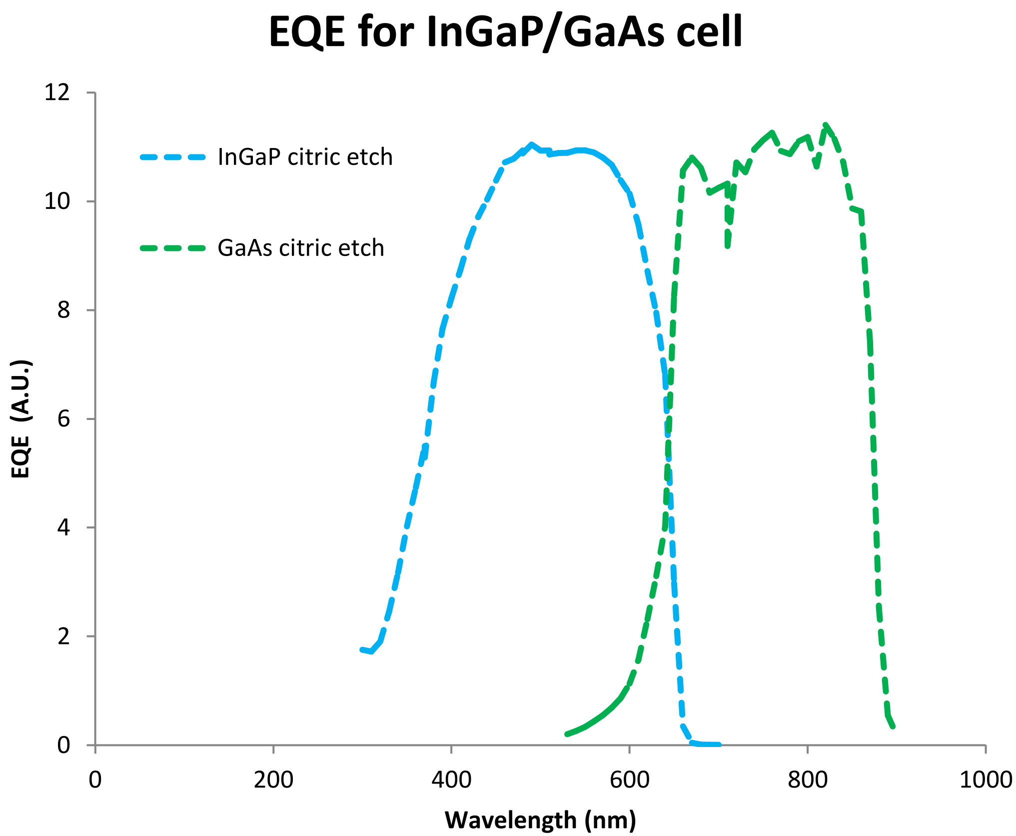
Smaller cells optimize efficiency at higher concentrations

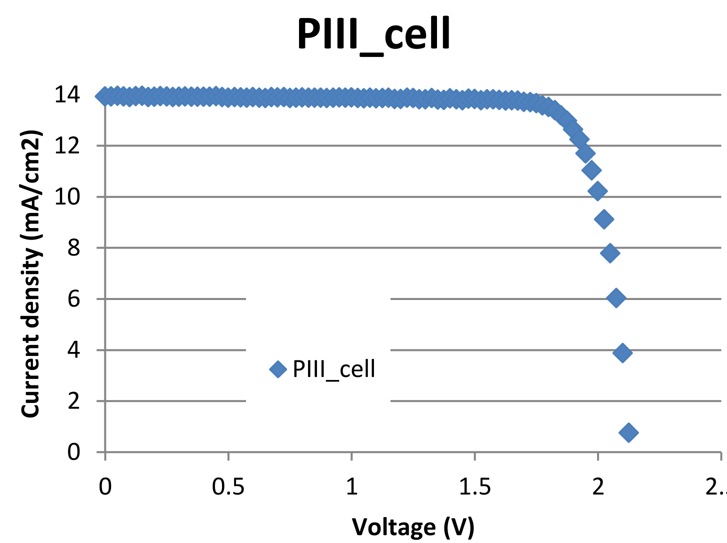


Jose L. Cruz-Campa, Anna Tauke-Pedretti, Jeffery G. Cederberg, Carlos A. Sanchez, Gerald R. Girard, Charles Alford, Brandon A. Aguirre, Ian E. Addington-Luna, Murat Okandan, Jeffrey S. Nelson, Gregory N. Nielson, Power maximization in III-V sub-millimeter, radial front contacted cells for thin micro-concentrators , PVSC proceedings, 2014



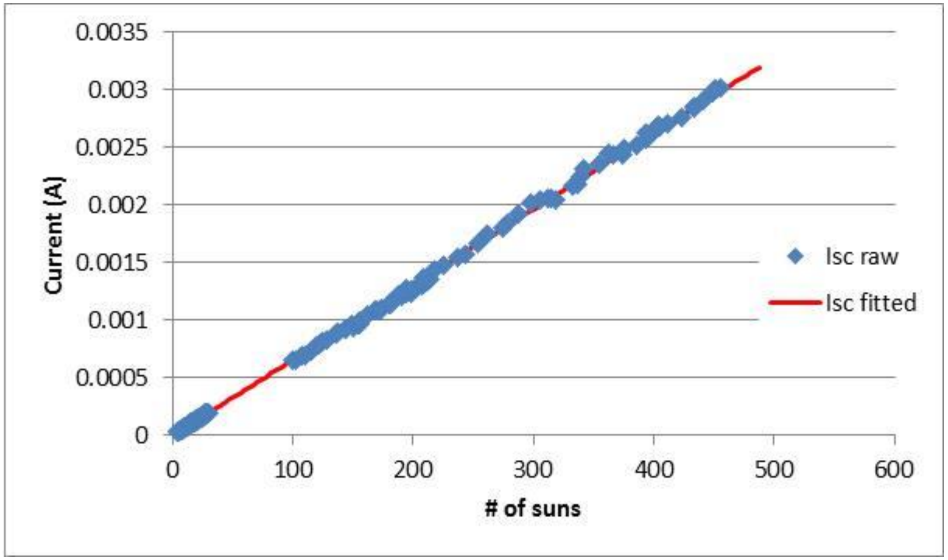
Prototype III had a great performance with only 6um of thickness bonded onto silicon

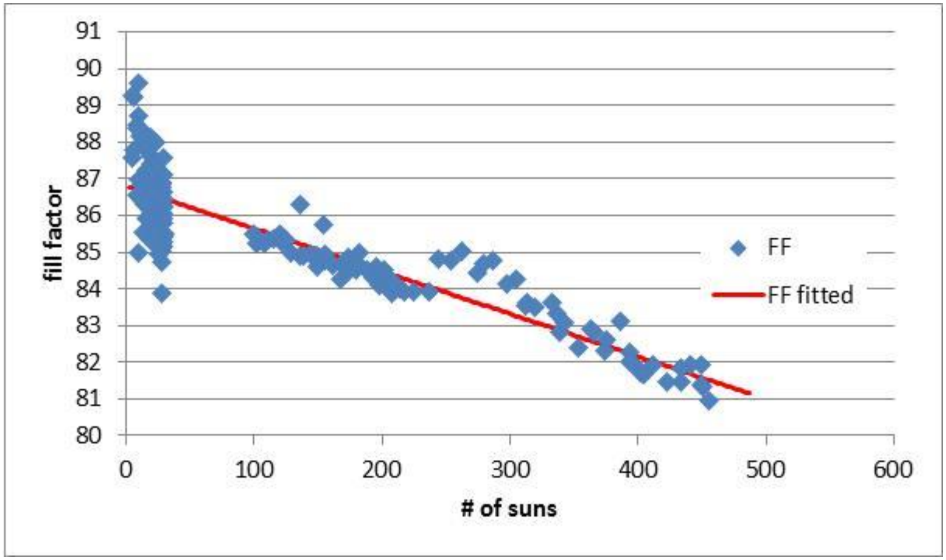


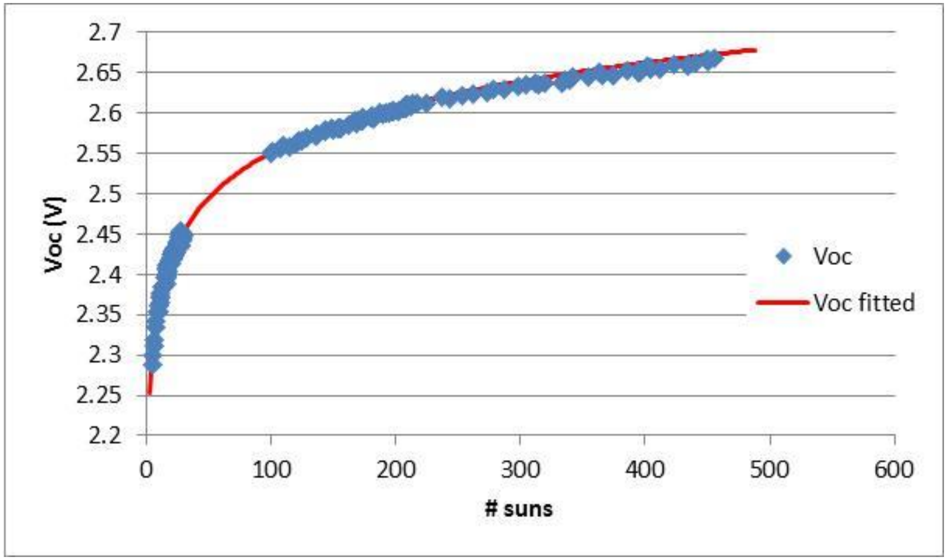


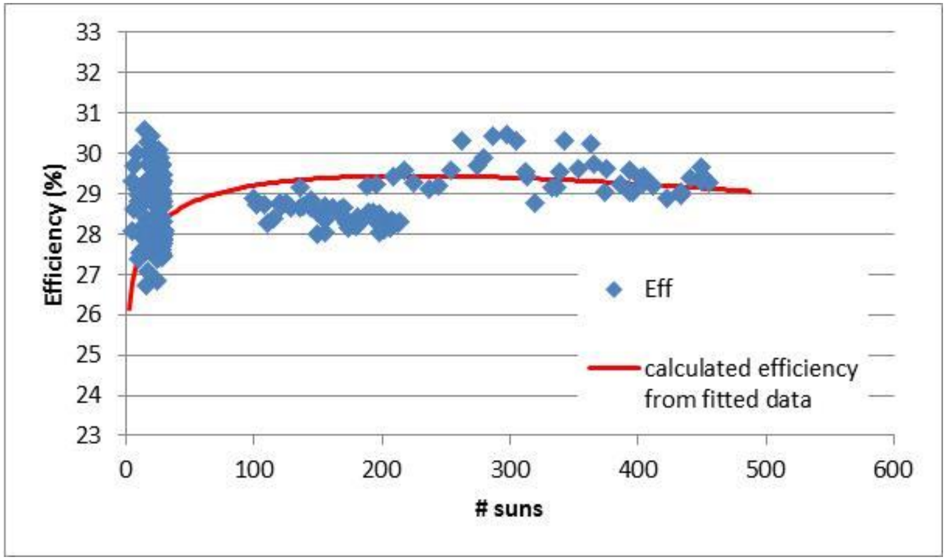
- PIII InGaP/GaAs cell efficiency: 26%

Concentration tests (flash tester) PIII InGaP/GaAs cell at 22°C









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Concentrated PV

Lowers price
Improves performance

Crystalline silicon PV

Improves functionality
(flexible films)

Thin Film PV

Improves material quality

This is an exciting time for solar!

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www.nmsea.org/

Thank you for your attention
Questions?