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MICROSYSTEMS ENABLED PV

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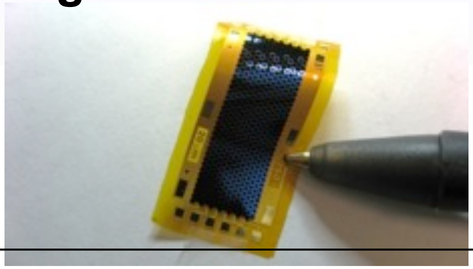
OUTLINE

- **Technology benefits**
- Process flow/assembly examples
- Cost analysis
- From R&D to commercialization
- 3DIC/hybrid assembly and new functionality

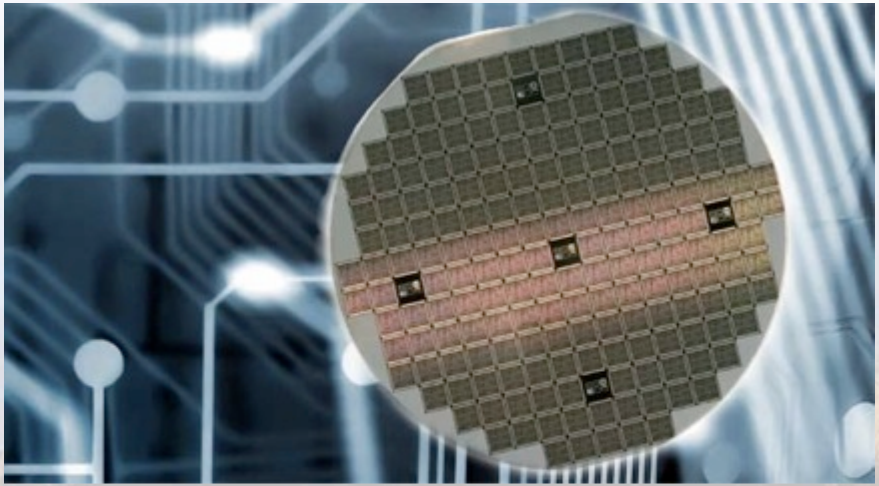
MEPV CORE COMPETITIVE ADVANTAGE

MEPV leverages concepts and technologies from existing successful microelectronics industry (IC, MEMS, LED, LCD, etc.):



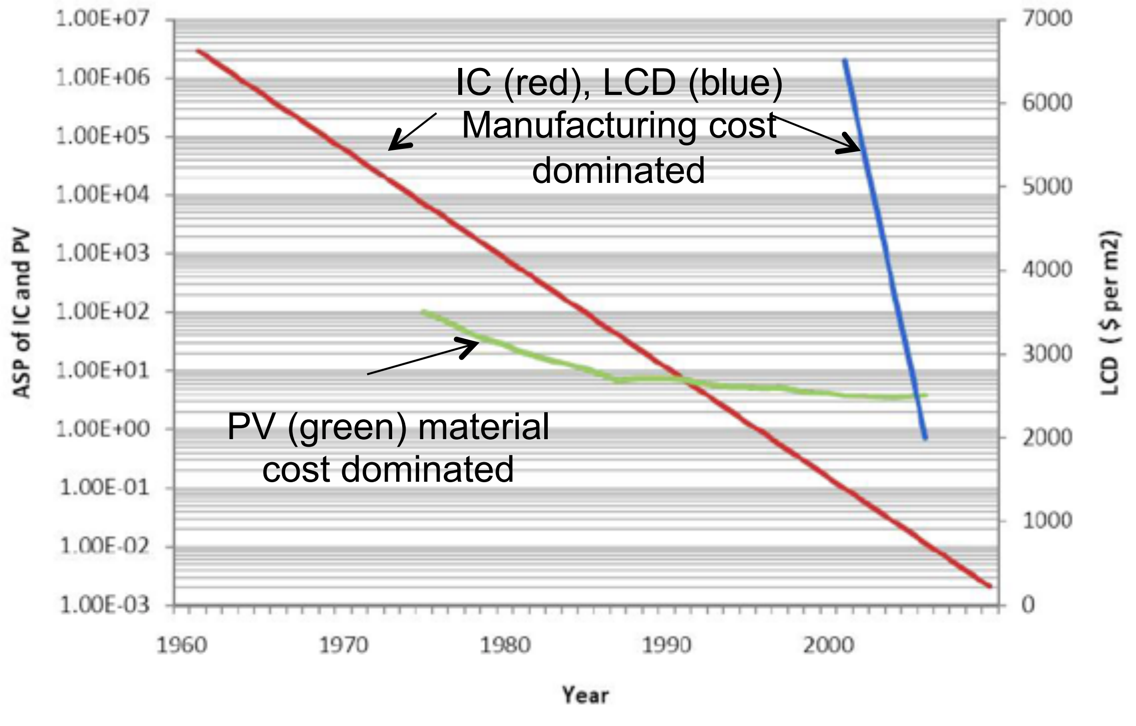
- Take advantage of beneficial scaling effects
  - Improved performance
  - Reduced cost
  - New functionality
- Parallel vs. serial manufacturing
- Increased integration - system vs. cell (component) paradigm
- Utilize established manufacturing supply chain and infrastructure (reducing CapEx)

No other PV technology benefits from similar industry synergies



- *Integrated Circuit Market Size: $300B*
- *LCD Market Size: $102B*
- *LED Market Size: $12.5B*
- *MEMS Market Size: $10B*
- *PV Market Size:*

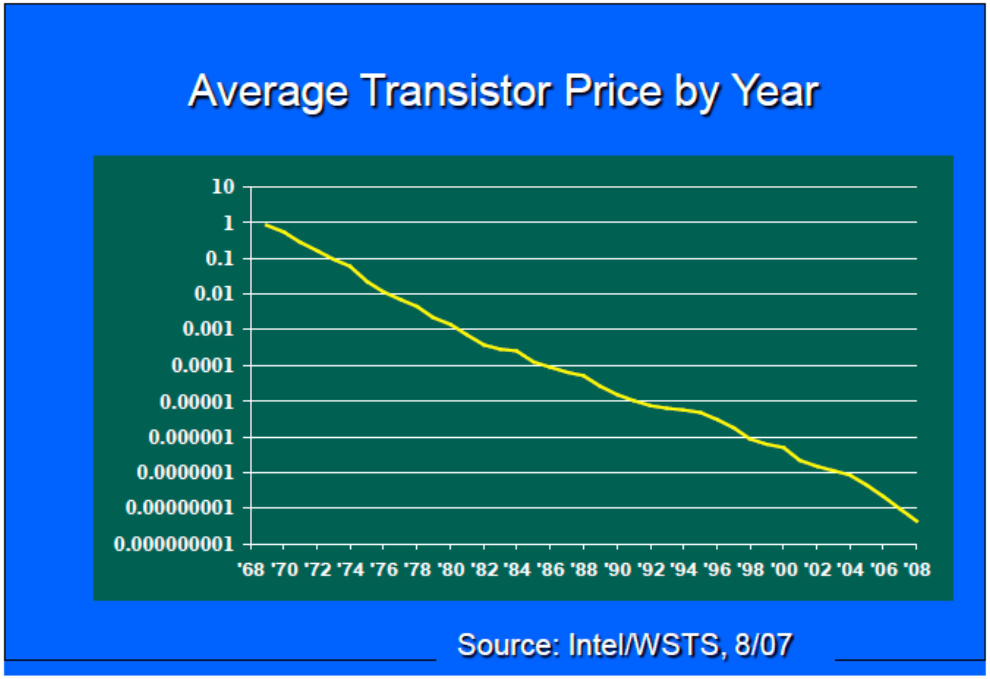
Potential for Cost Reduction



Future cost reductions are much more likely for MEPV than wafered silicon PV since manufacturing costs are a much larger component of the module costs relative to material costs. (Typically manufacturing costs are driven down more rapidly than materials costs.)

Rajendra Singh, "Why silicon is and will remain the dominant photovoltaic material," Journal of Nanophotonics, vol. 3, 032503 (2009), p. 4.

Manufacturing Tools Have Driven ~500x Price Reductions in Processed Silicon



- In 1975, the average price per transistor was ~$0.02 (4-μm features).
- In 2008, the average price per transistor was ~$ 5×10^{-9} (45 nm features)
- This is a 4,000,000x reduction in cost
  - Device scaling accounts for ~8,000x cost reduction ($/transistor)
  - ***Manufacturing efficiencies** account for ~500x reduction in the price of processed Silicon.*

Scalability

Established Polysilicon supply (9-9s purity)

2010 >100,000 metric tons (Hemlock, Wacker, REC, MEMC)

2011 >120,000 metric tons
2012 - OCI (S.Korea) – 62,000 metric tons
GCL Poly (China) – 65,000 metric tons
world total > 200,000 metric tons

[Bloomberg Energy Finance]

Standard Si wafered PV
~ 5-6 grams Si/W_{peak}

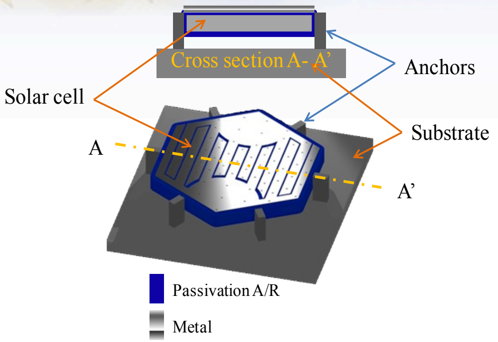
MEPV - < 0.1 gram Si/W_{peak}
Silane/TCS main feedstock
10x thinner cells
no kerf loss (usually 50% for standard Si PV)
>10x optical concentration

200 MW_p/year unit line

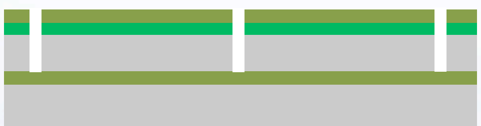
- Small IC Fab: 5,000 8'' wafers/week
  (@30 wfr/hr, IC industry standard = 60 wfr/hr)
- 10 pick-and-place tools: 130,000 parts/hr
- 2,900 m^2 PV modules produced per day (0.7 acres)
- 200W x 2,900 = 0.58 MW_p/day

Scalability > 100GWp/year
US generation capacity ~1TW

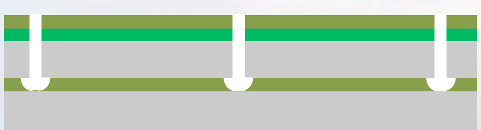
Solar Cell Fabrication: Suspended Cells



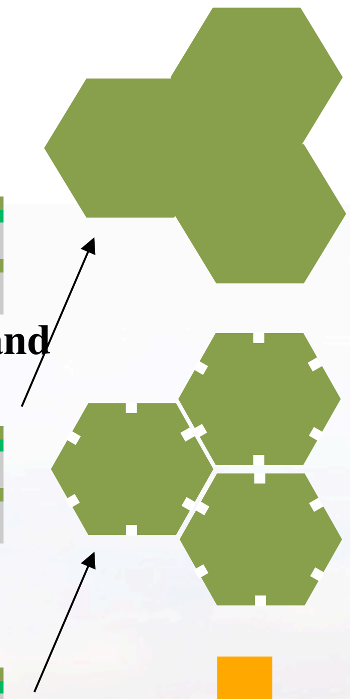
A) SOI cell with nitride and oxide

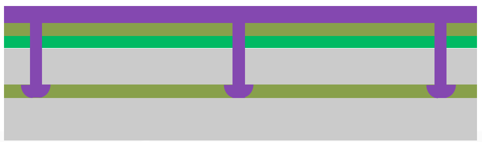


B) First deep etch reaching the BOX layer

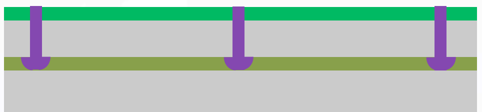


C) wet etch to reach the handle wafer

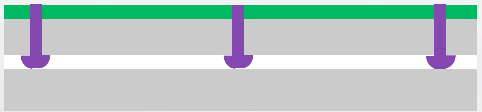




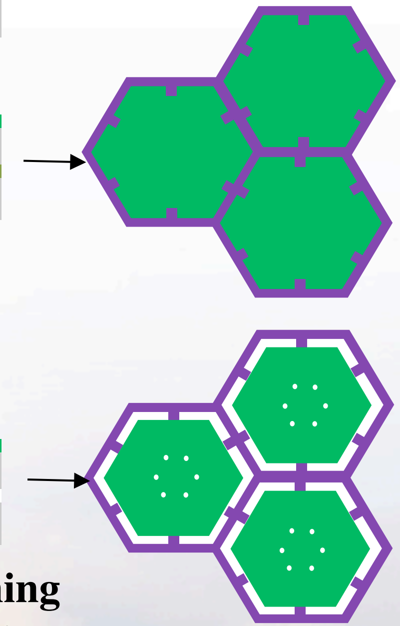
D) polysilicon fill



E) Chemical mechanical polishing

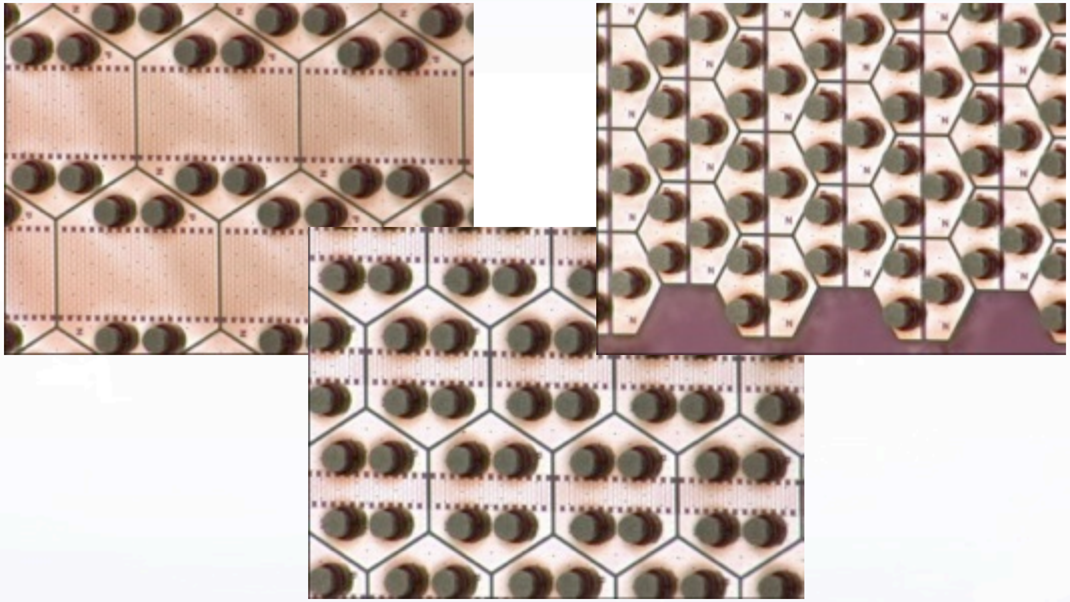


F) Second deep etch defining the cell and 2nd wet etch to suspend the cell



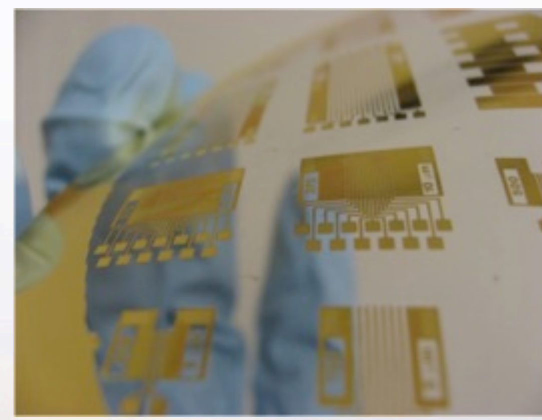
Assembly

copper/solder bumps



pick-and-place (Universal Instruments)

flex receiver substrate (with cells)

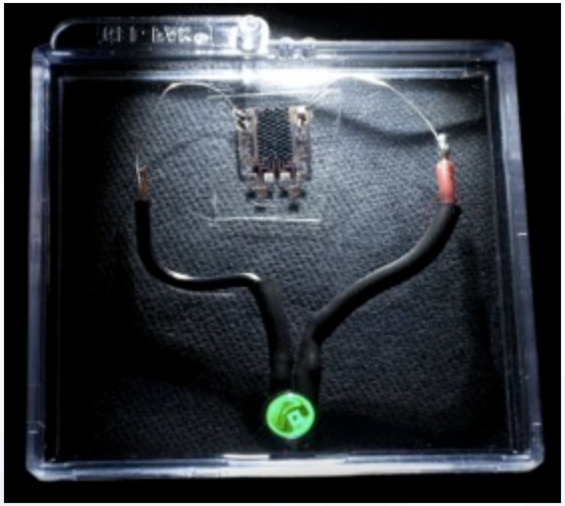


Corning® Willow^{TM} Glass

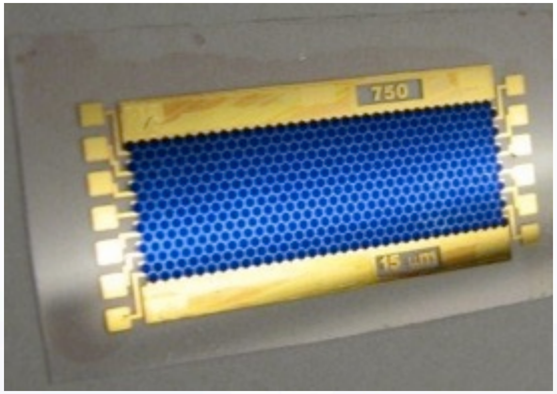
CORNING Sandia National Laboratories

Prototype Examples

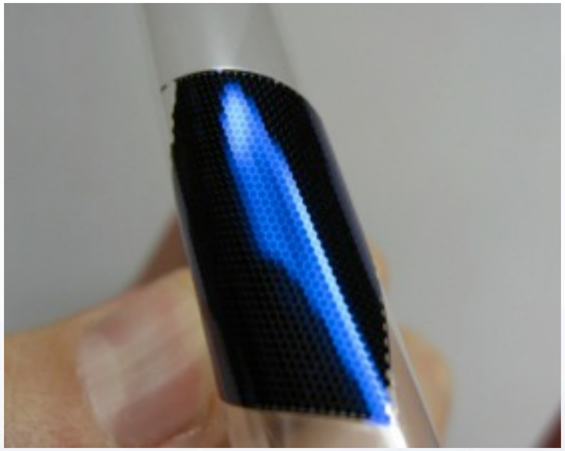
750um cell flexible prototypes on glass and polymer substrates



Corning® Willow™ Glass Substrate

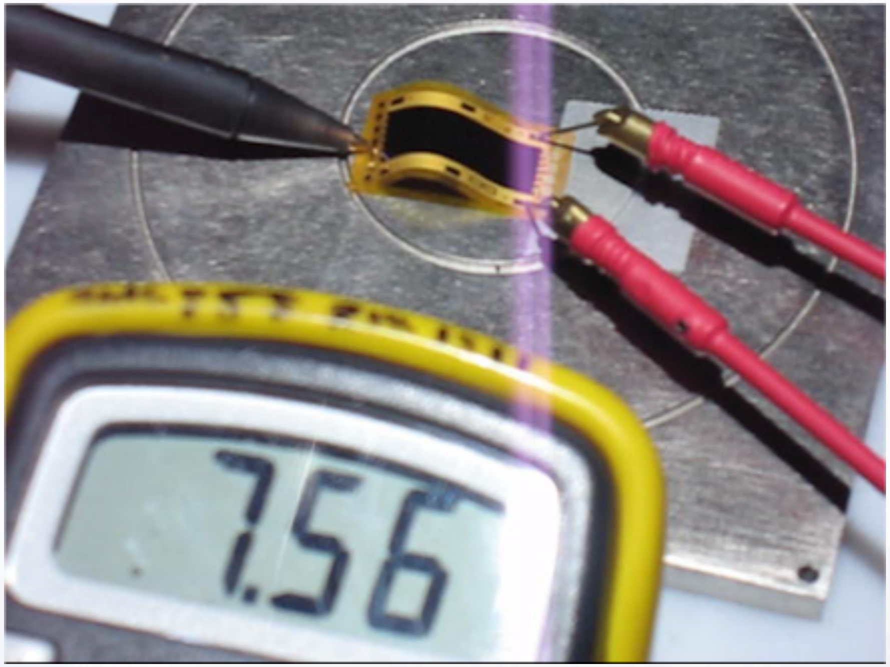


Polymer Substrate



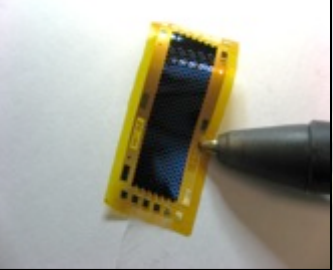
Prototype Examples
750um cell flexible prototype on polymer substrate

- Bend radius < 2mm without damage/ degradation.
- <100um as assembled.
- Demonstrated 14.9% array efficiency with single junction Si
  - >20% Si target
  - >35% multi-junction
- >1000 W/kg target (single junction).
- 10 kW array stowable into poster tube ("kW-in-a-can").
- 10s of W in a pencil dimension tube.



MEPV

> 400 Watts/kg



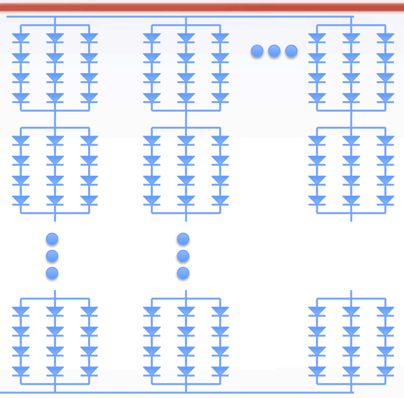
The Competition

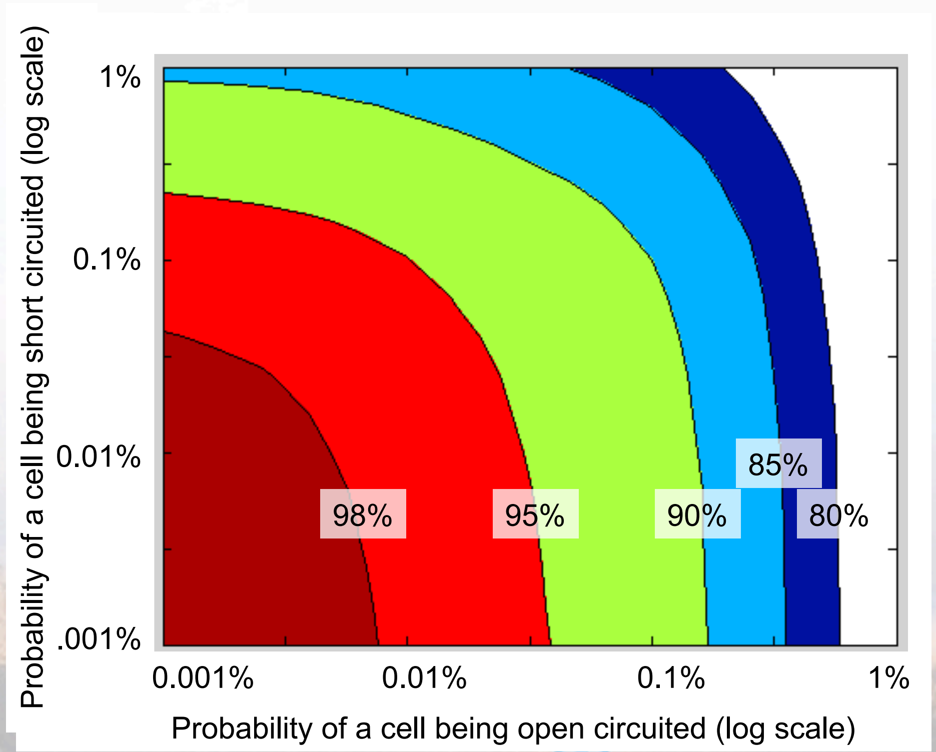
< 40 Watts/kg

New Functionality

- Better performance in partial shading without the need for bypass protection diodes.
- Inherently robust (open/short, damage resistance).
- High-voltage DC (600 – 1000 V) in minimal footprint (5cm x 5cm).
- Integrated power management for on-the-fly optimization, voltage selection, state-of-health monitoring, logging.
- Reduced mechanical stresses and fatigue due to smaller cell/interconnect size.
- Integration of III-V layers/cells, independently connected junctions for highest performance possible.
- …

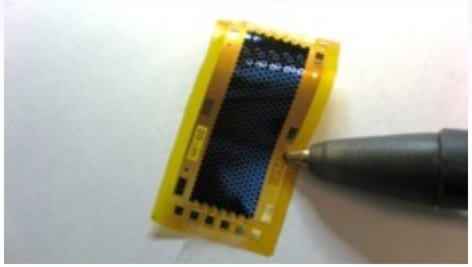
With thousands of solar cells per square meter available, increasing levels of series-parallel-series-parallel connection networks of solar cells allow for improved performance (contour plot illustrates relative efficiency of module with different percentages of opens or shorts within the module).





Broad Application: Power Markets

MEPV solar cells can be integrated into flexible and/or moldable polymer substrates for high-efficiency and flexible or 3D conformal applications



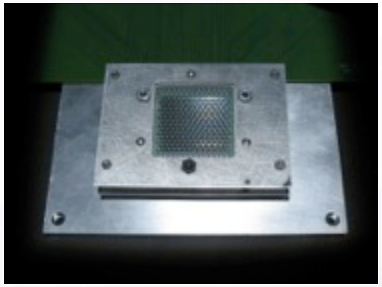
Space (500 kW/yr)
\$500 – 1000/W_{peak}

Defense (~100 MW/yr)
\$50/W_{peak}

Consumer-Logistic (>100MW/yr)
\$50/W_{peak}

Consumer-Mobile
(AA battery = \$100-200/kWh)

MEPV solar cells can be built into a thin concentrator module and sold for solar power applications



Residential Solar Power (>100 GW/year)
\$0.10 – 0.20/kWh = ~\$2/W_{peak}

Commercial (>100 GW/yr)
\$0.10 – 0.20/kWh = ~\$2/W_{peak}

Utility (>100 GW/yr)
\$0.5 – 0.10/kWh = ~\$1/W_{peak}

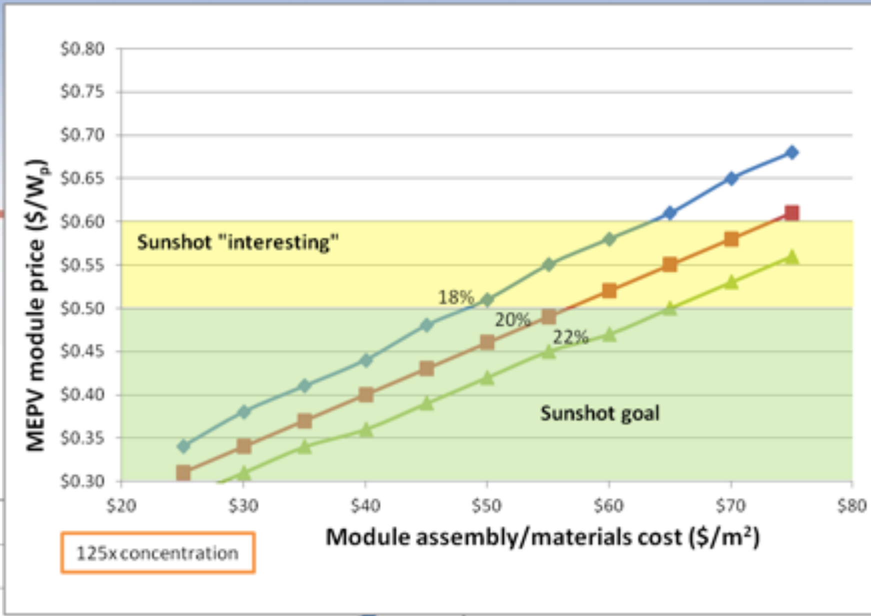
Value of Power

Market Size

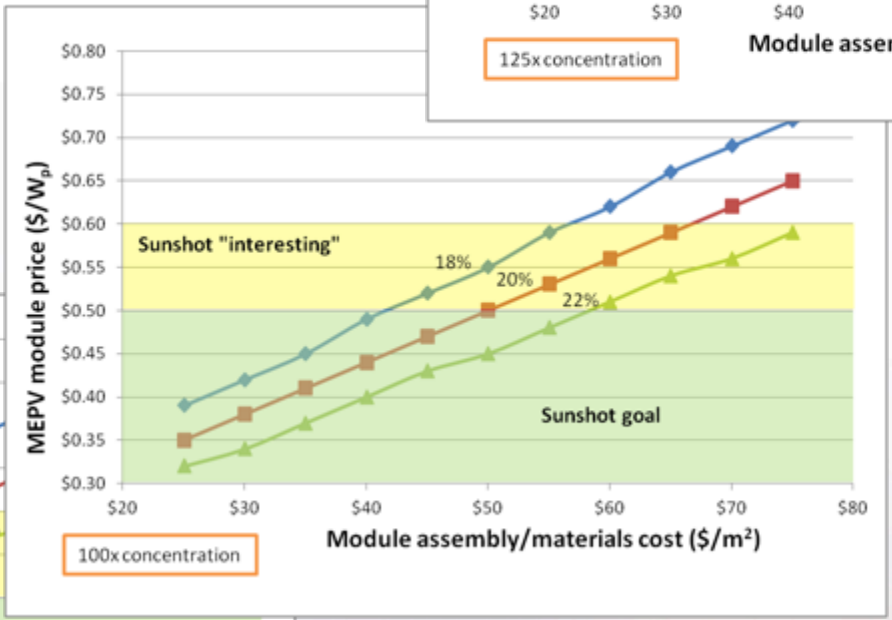
MEPV Cost Models

18% margin
200mm wafers

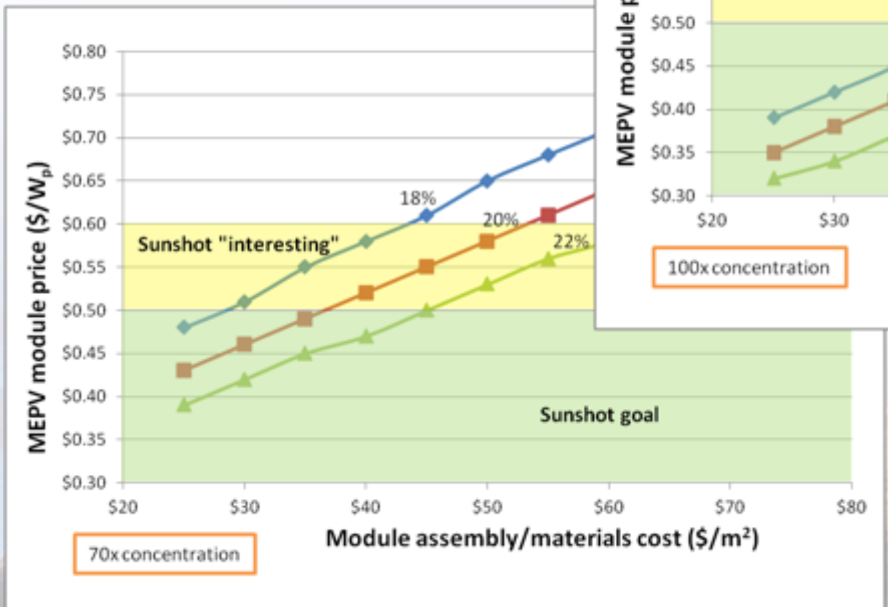
$100/8'' wafer
cell fab cost



125x



100x



70x

BOS costs are another $0.50/W_p$ – MEPV approach has the potential to reduce those costs as well (integrated power management, easier install, cheaper trackers, etc.)

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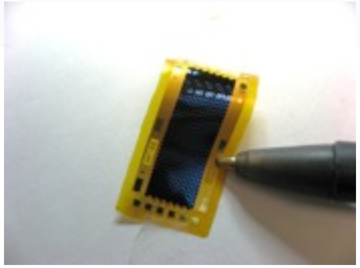
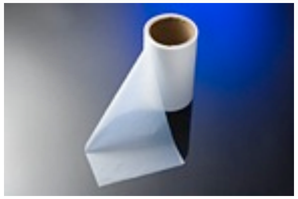
Where will we be in 2 years?

Now



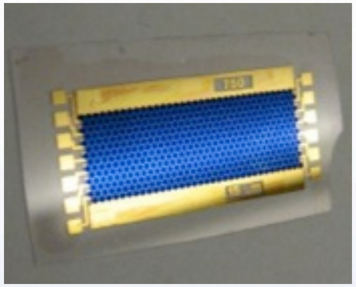
In 2 Years

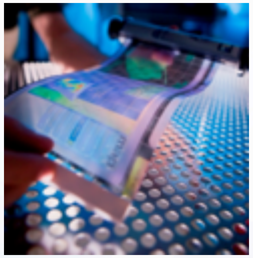


Highly flexible prototype with 20% efficient, >1000 Watts/kg

Next Steps

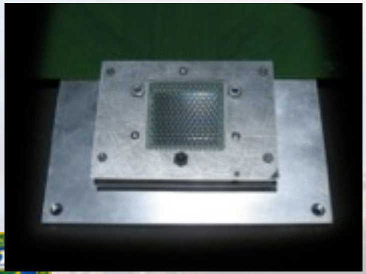
Identify defense systems integrators, for high margin, differentiated applications of MEPV in a flexible format





Small prototype integrated system for charging mobile devices

Identify electronics manufacturers for partnering opportunities, focused on mobile charging/energy harvesting applications. Requires either flexible or conformal MEPV capabilities with high-efficiency.



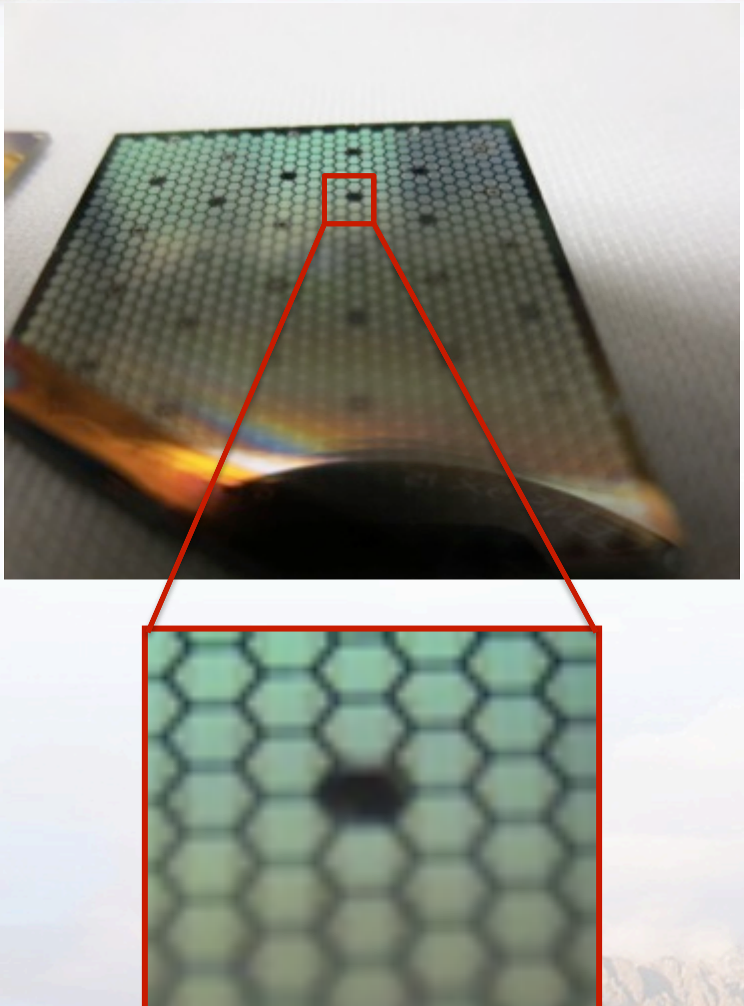
Low-Cost, High-Efficiency MEPV concentrator prototype

Continue working with solar companies: both supply chain and system integrators

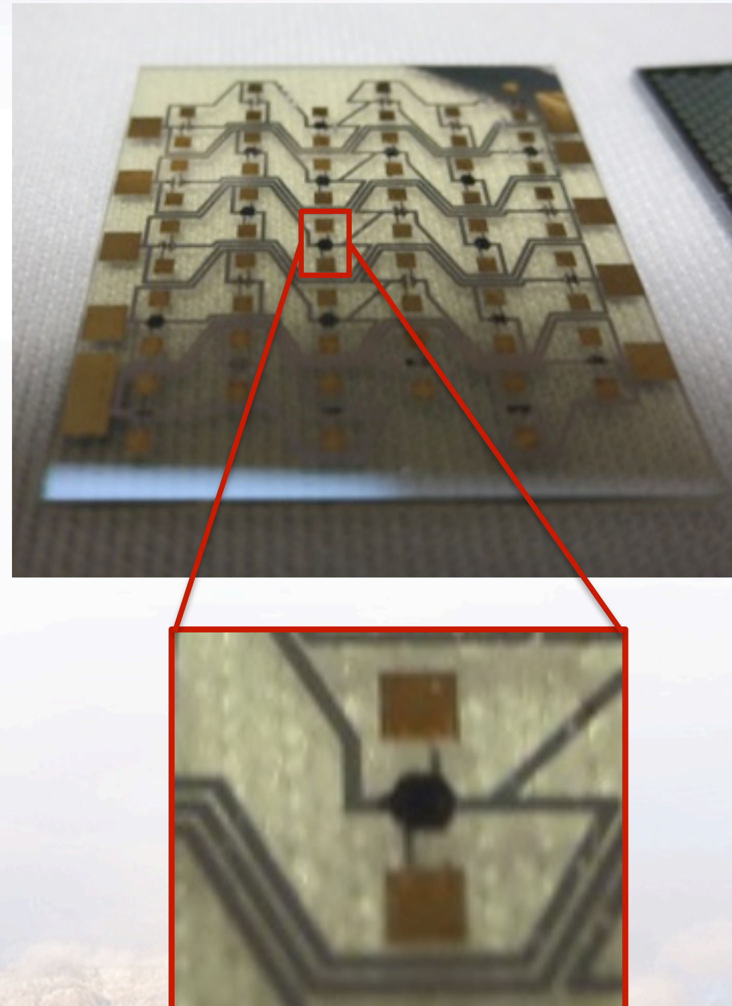
3DIC / Hybrid Integration

- Same technology base enables hybrid integration of dissimilar materials/processes with high throughput and high yield.
- Additional functionality integrated at chip or assembly level.
- Multiple assembly substrates possible.
- Current 3DIC approaches have significant issues with thin wafer handling, which is eliminated with this approach.

Sparse/Parallel Transfer



Donor Substrate with cells (ICs)



Receiver with cell transferred

Acknowledgements

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