The Physics and Applications of High-Efficiency, Ultra-Thin Solar Cells

Jessica Adams

2014-04-11

University of Oklahoma Physics Department Seminar

MicroLink Devices, Inc.

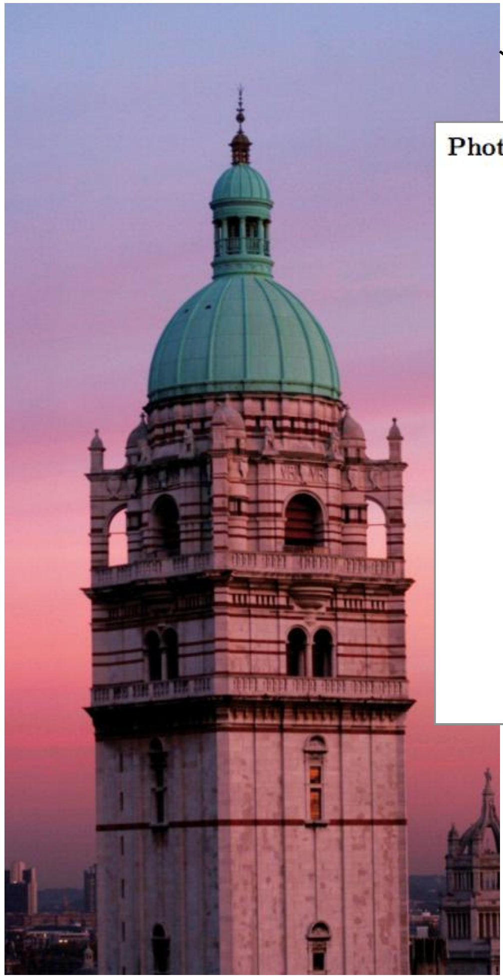
The Physics and Applications of High-Efficiency, Ultra-Thin Solar Cells

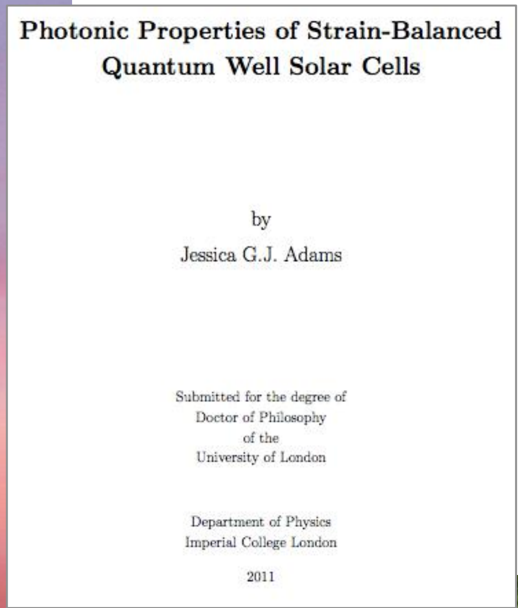
1. Physics of high-efficiency solar cells
2. Manufacturing high-efficiency solar cells
3. Applications for high-efficiency, ultra-thin solar cells

MicroLink Company Background

- Established in 2000 to manufacture heterojunction bipolar transistors
- 30,000 sq ft facility located in Niles, IL
- 2014 ~40 employees
- ~15 employees involved in developing high efficiency solar cells
- Pilot-scale production line manufacturing epitaxial lift-off solar cells

My Background





Photonic Properties of Strain-Balanced Quantum Well Solar Cells

by

Jessica G.J. Adams

Submitted for the degree of
Doctor of Philosophy
of the
University of London

Department of Physics
Imperial College London

2011

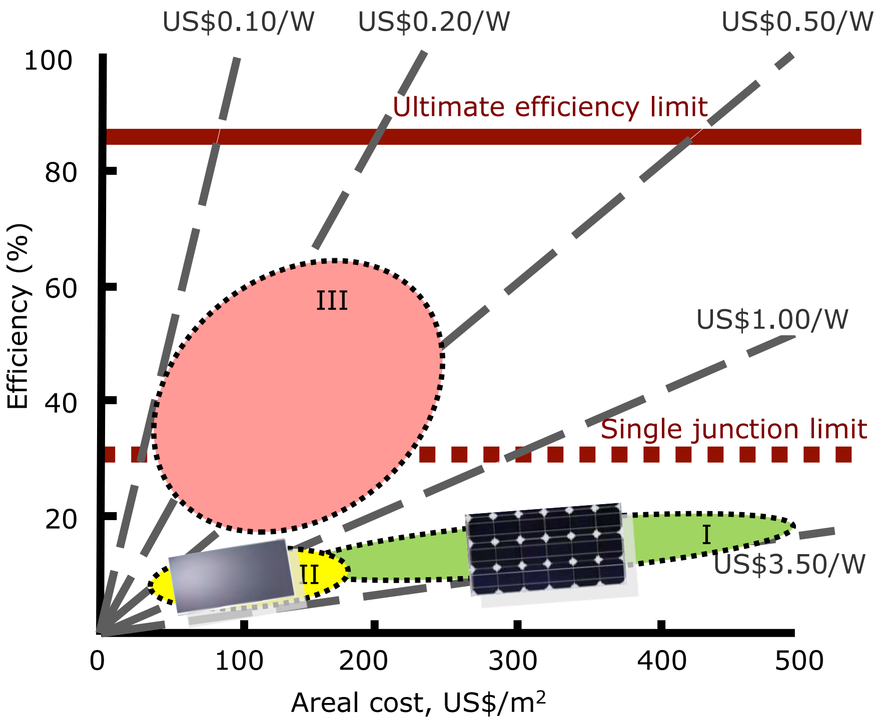
- 2007-2011:
  PhD Experimental Solid State Physics
  (Quantum Photovoltaics Group)
  Imperial College London
- 2011-Present:
  Sr. R&D Engineer
  (Engineering Group)
  MicroLink Devices, Niles IL

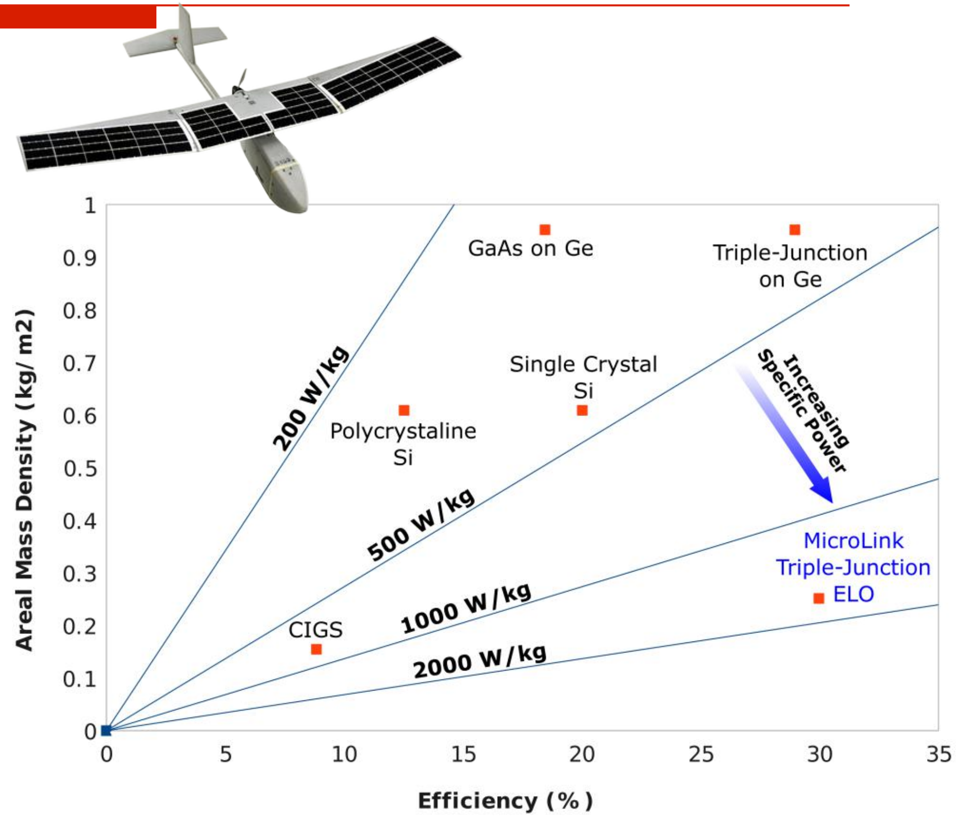
Worldwide power consumption: 16 TW

Incoming solar power: 86,000 TW

1. Physics of High-Efficiency Solar Cells

The Case for Higher Efficiency

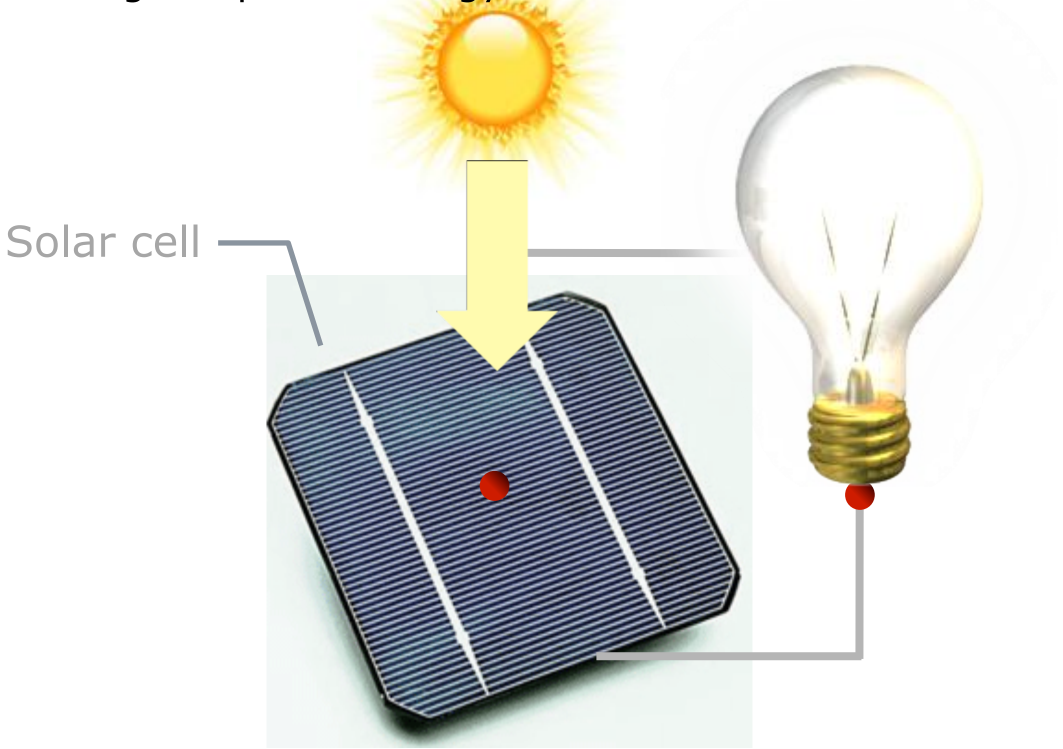




- Solar cells with efficiency >30% are required to enable low $/W and high W/kg applications

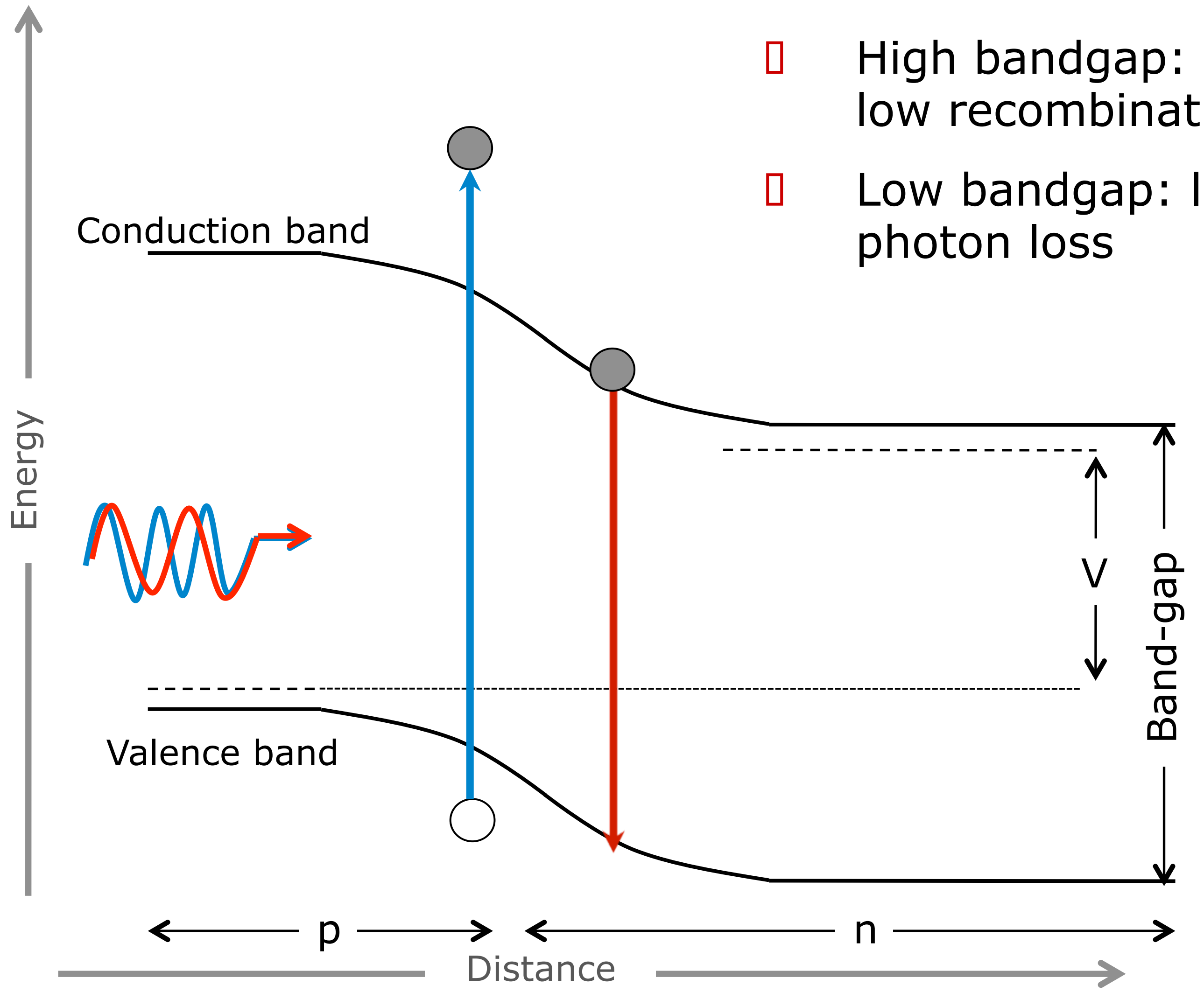
Solar Cell Physics 101

1. Sunlight hits the solar cell and photons are absorbed
2. The energy from the sunlight is given to charge carriers inside the material
3. The carriers are separated by the electric field in the device and travel to metal contacts on the surfaces of the solar cell
4. From the metal contacts, the carriers are extracted to an external circuit
5. The carriers then give up their energy to an external load



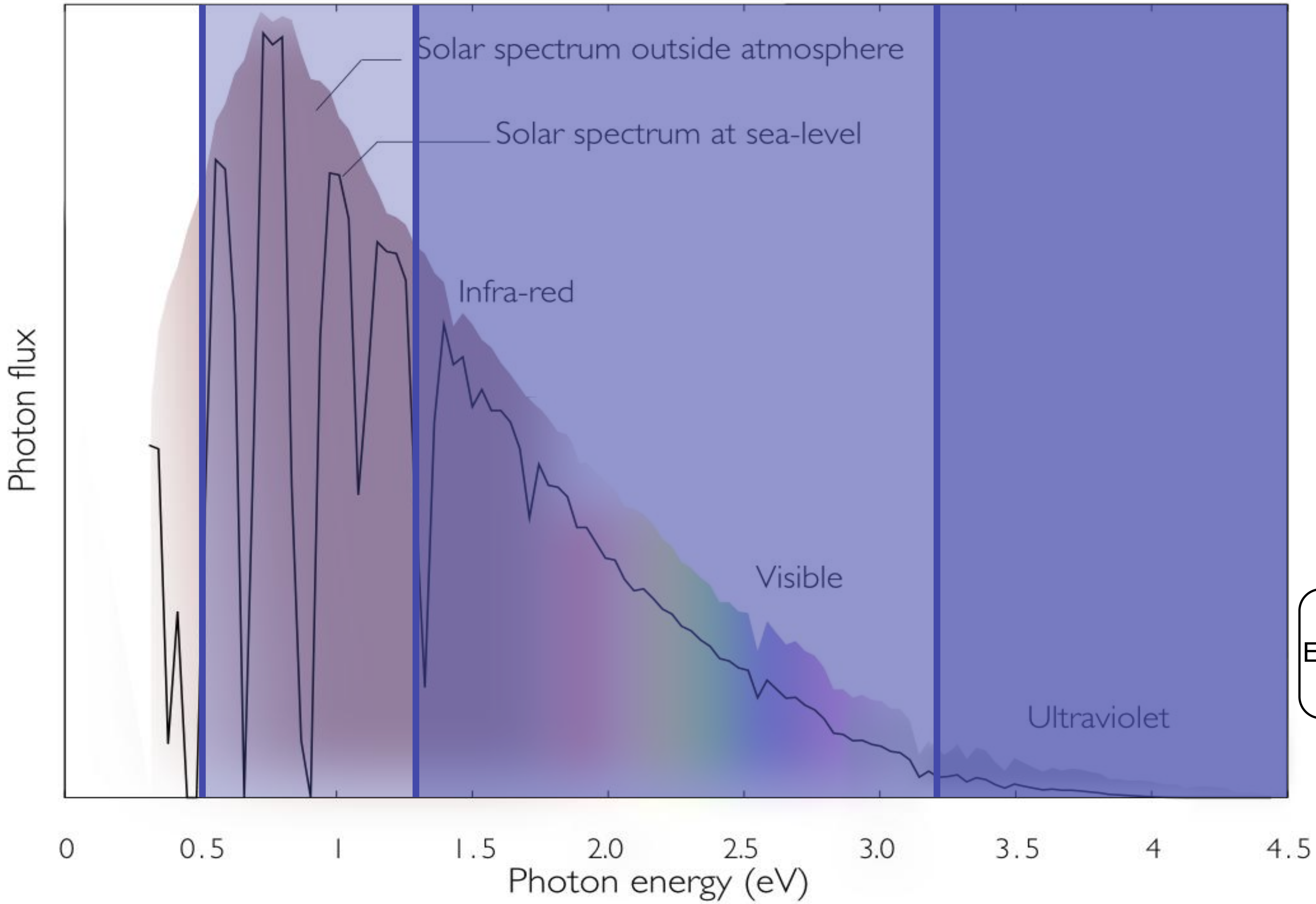
Physics: Power Generation in a Single-Junction Solar Cell

MicroLink Devices, Inc.



- High bandgap: low thermalization loss, low recombination rate
- Low bandgap: low below-bandgap photon loss

Optimizing the Solar Cell Bandgap

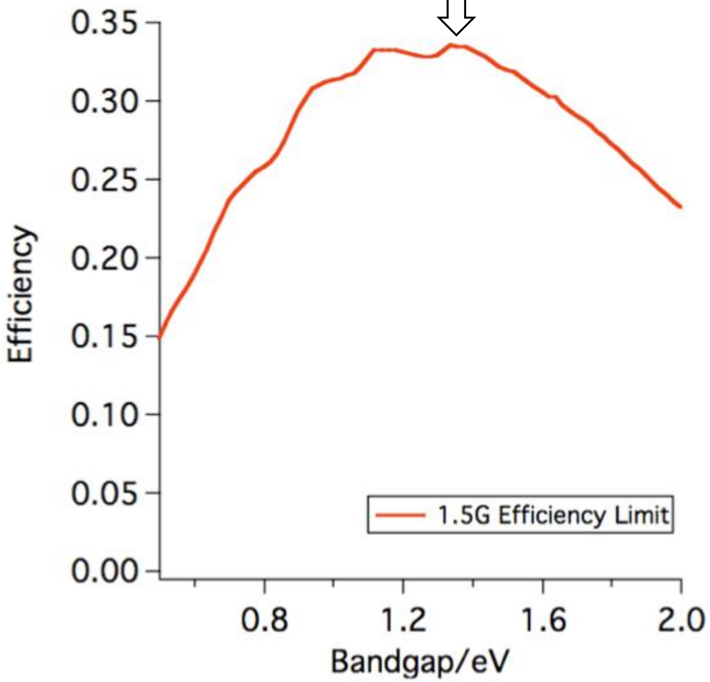


P = V x I

$$\text{Efficiency} = \frac{\text{Power out}}{\text{Power in}}$$

Single-Junction Solar Cell Efficiency Limits

Shockley-Queisser Limit



William Shockley

Hans Queisser

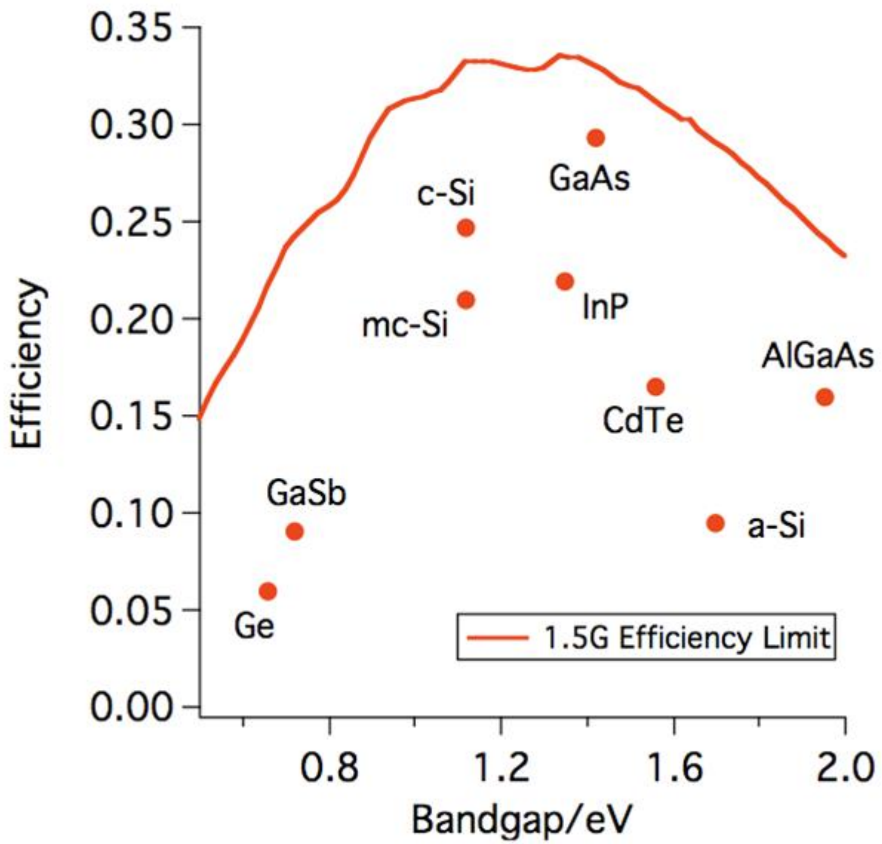
JOURNAL OF APPLIED PHYSICS VOLUME 32, NUMBER 3 MARCH, 1961

Detailed Balance Limit of Efficiency of *p-n* Junction Solar Cells*

WILLIAM SHOCKLEY AND HANS J. QUEISSER
Shockley Transistor, Unit of Clevite Transistor, Palo Alto, California

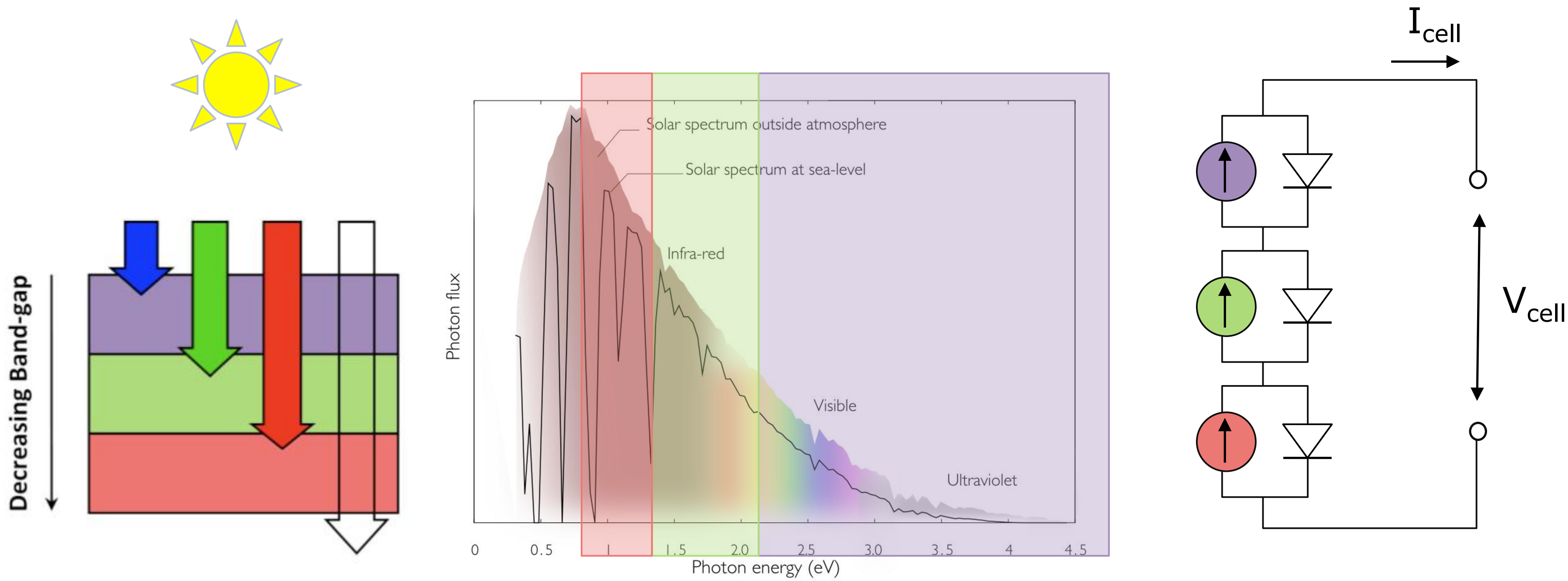
(Received May 3, 1960; in final form October 31, 1960)

Achieved Single-Junction Cell Efficiencies



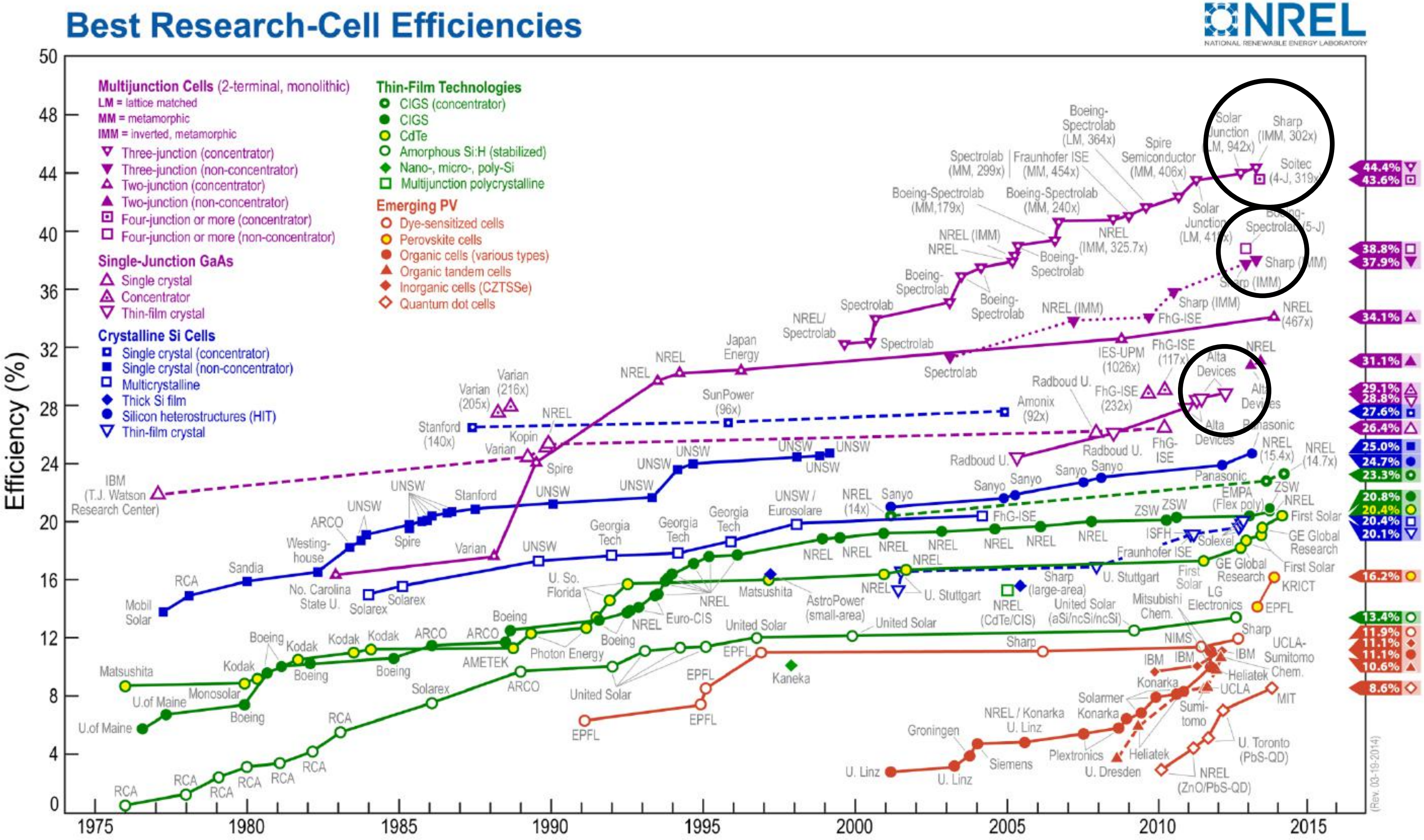
- Max theoretical efficiency for a single-junction solar cell ~33%
- GaAs cell efficiency record: 28.8%
- Si cell efficiency record: 25% (indirect bandgap)

Dividing the Spectrum with Multi-Junction Solar Cells



- Cell voltage is sum of subcell voltages
- Cell current is that of limiting subcell
- Theoretical optimum triple-junction bandgap combination arises from subcell current-matching requirement: 1.7 / 1.2 / 0.7 eV

Best Research-Cell Efficiencies

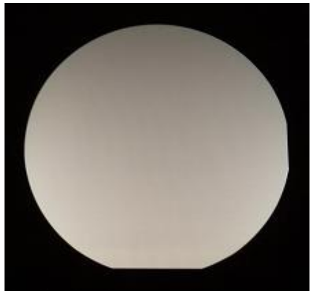


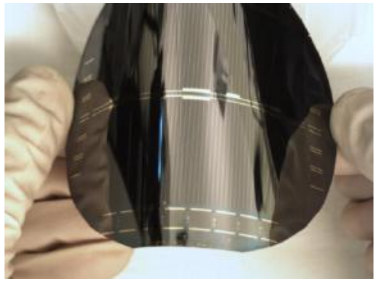
MicroLink Devices, Inc.

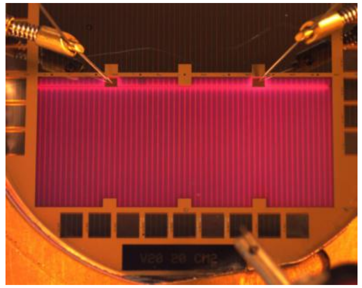
2. Manufacturing High-Efficiency Solar Cells

Making Epitaxial Solar Cells

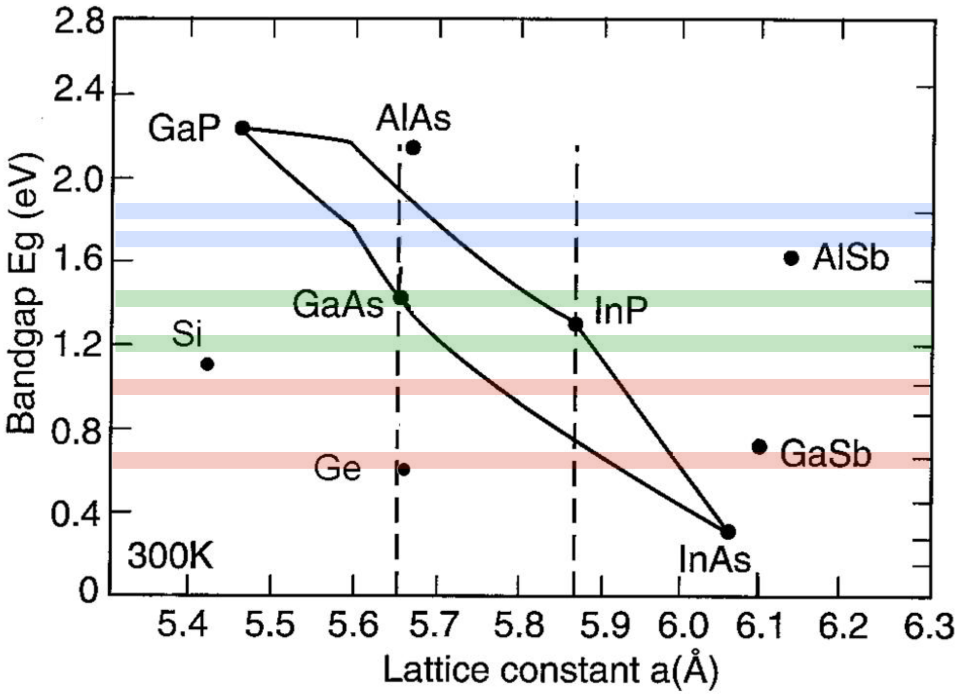
Design → Growth → Fabrication → Test

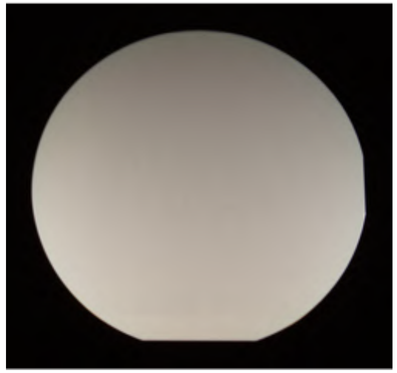






Designing a Multi-Junction Solar Cell

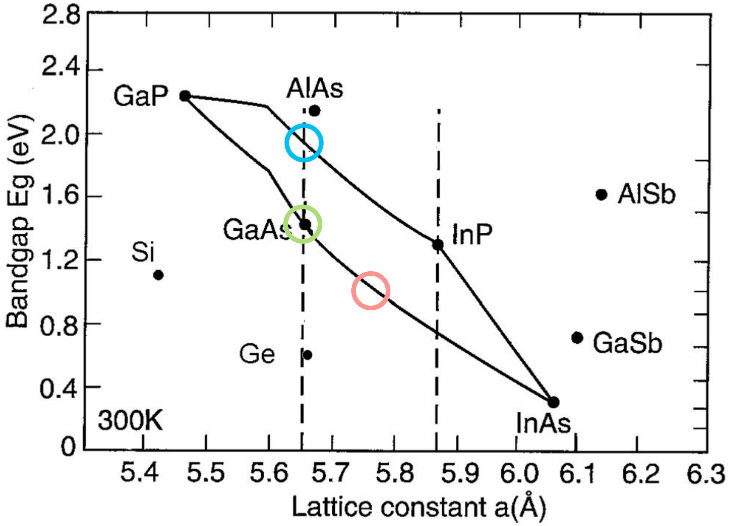


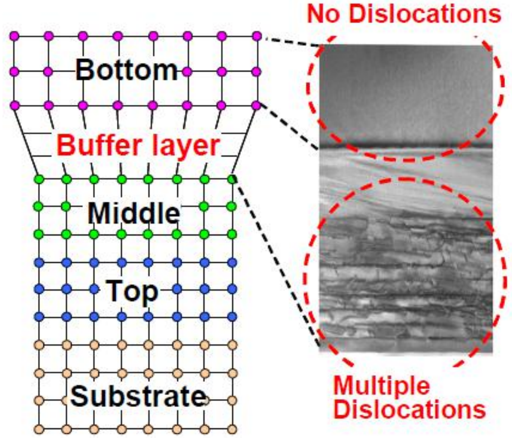


- Epitaxial materials usually grown by:
  - Metal-organic chemical vapor deposition (MOCVD)
  - Molecular beam epitaxy (MBE)
- Layer-by-layer growth on a substrate
- Lattice-matched growth has lowest defect density

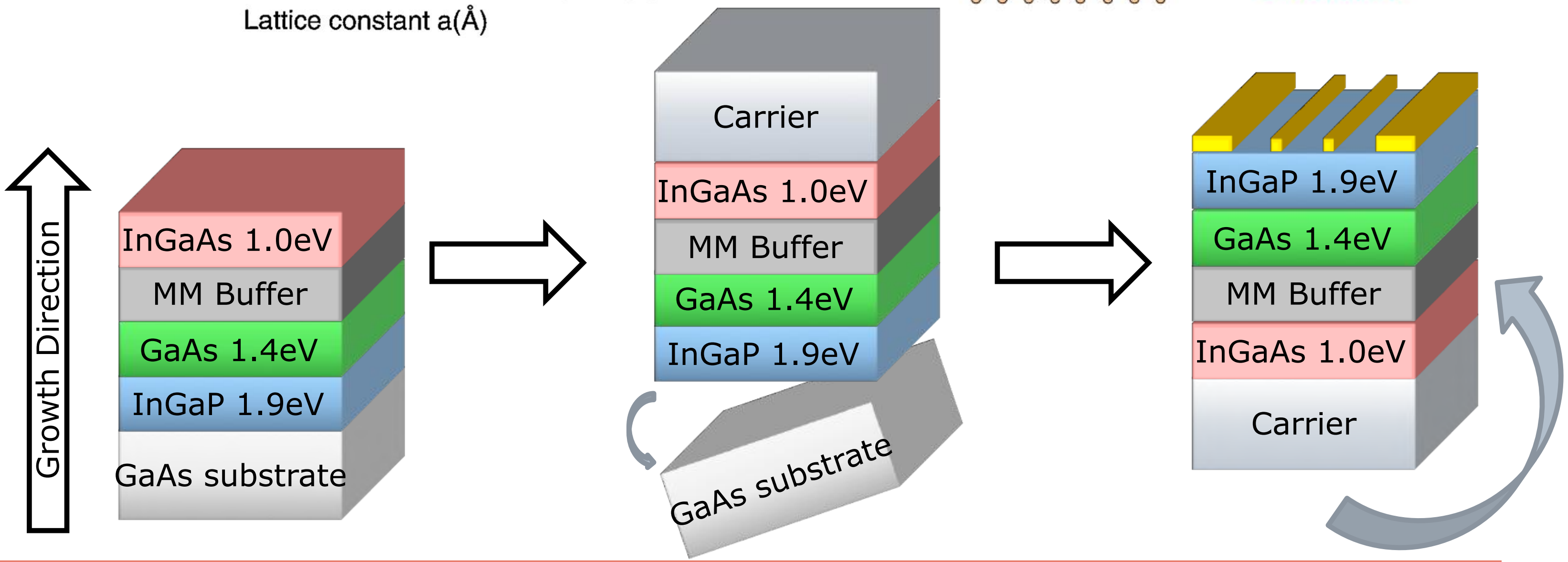
Inverted Metamorphic (IMM) Solar Cell: High Efficiency, Low Weight

IMM: 44.4% (302X), Sharp



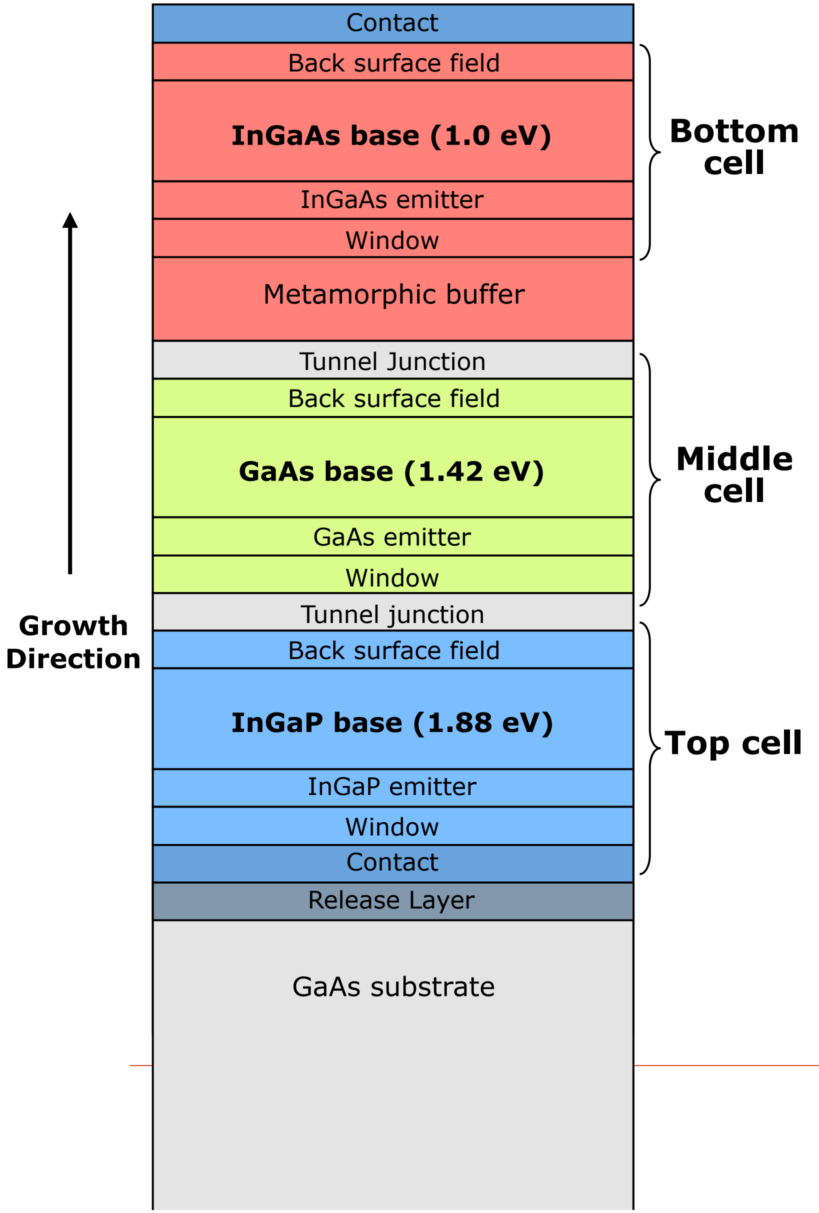


*



*Takamoto et. al., Proc. IEEE PVSC 35, (2010).

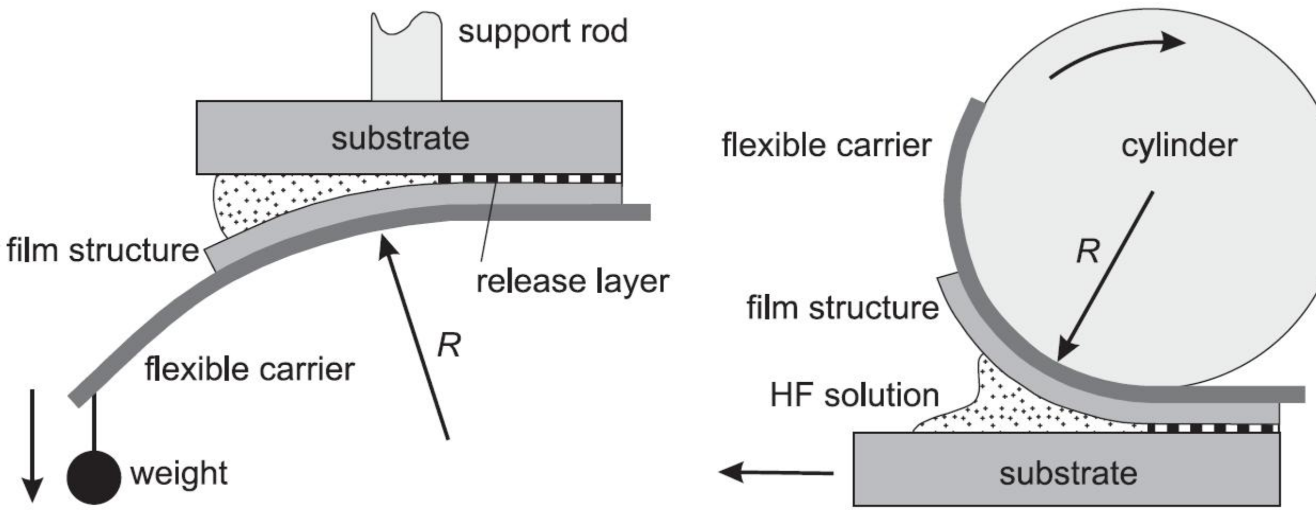
Inverted Metamorphic Solar Cell Structure



- IMM triple-junction structure
- Three subcells series-connected via tunnel junctions
- Transparent metamorphic buffer for growth of lattice-mismatched InGaAs subcell
- Release layer to facilitate removal of epitaxial layers by wet chemical process

History of Epitaxial Lift-Off (ELO)

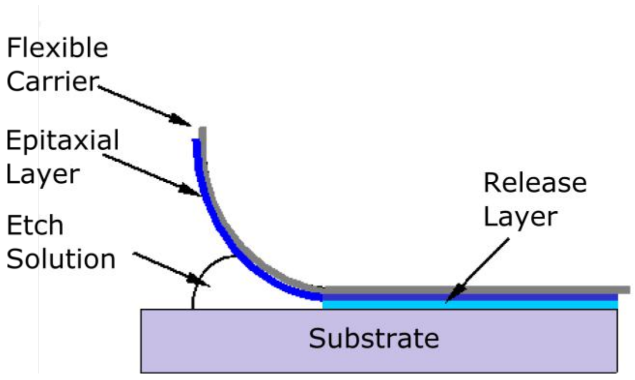
- ELO originally developed in the late 1970s
- Incorporation of sacrificial release layer to remove epitaxial material
- Initially plagued by very slow etch rates, crack formation, difficult to lift off large areas
- More recent work (Schermer, et al.) has improved etch rate (hours instead of days)



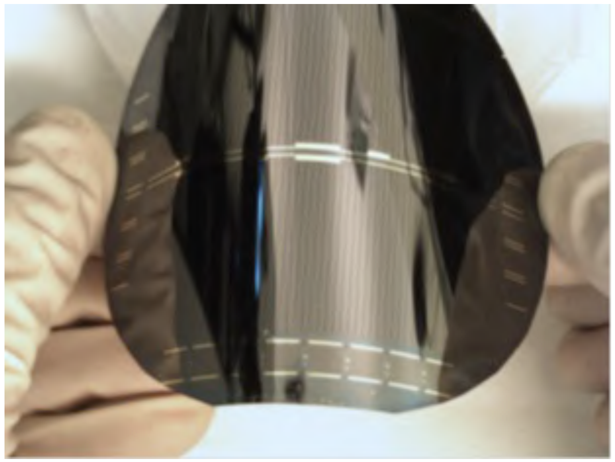
J.J. Schermer, et al., phys. stat. sol. (a) 202, No. 4, 501–508 (2005)

Epitaxial Lift-Off Solar Cells

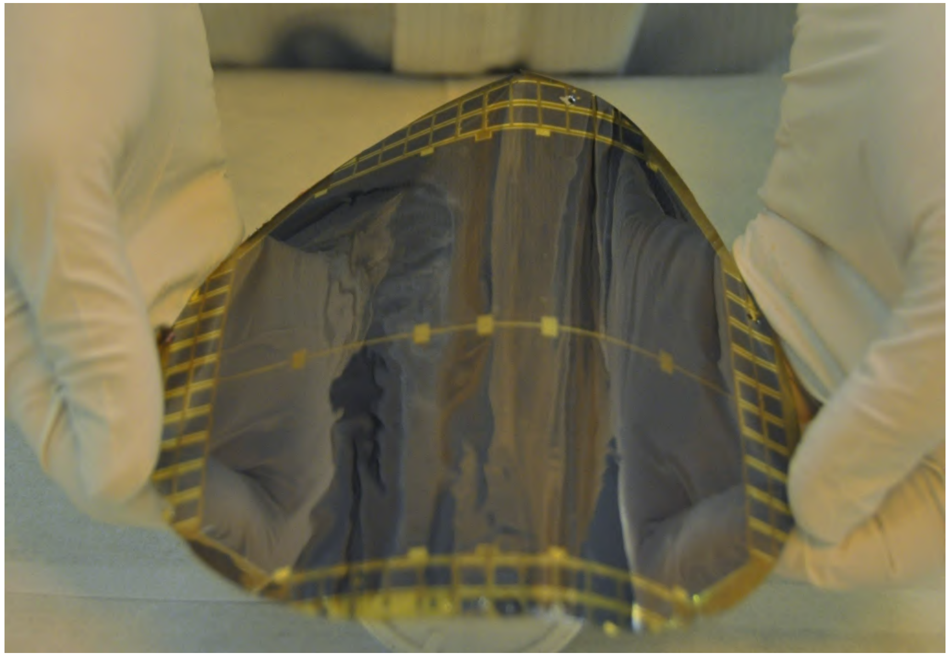
MicroLink Devices, Inc.



- Developed wafer-scale ELO technology
- Compatible with low-cost batch processes
- Substrate intact and reusable



4″ wafer ELO (2x20cm^2 cells)

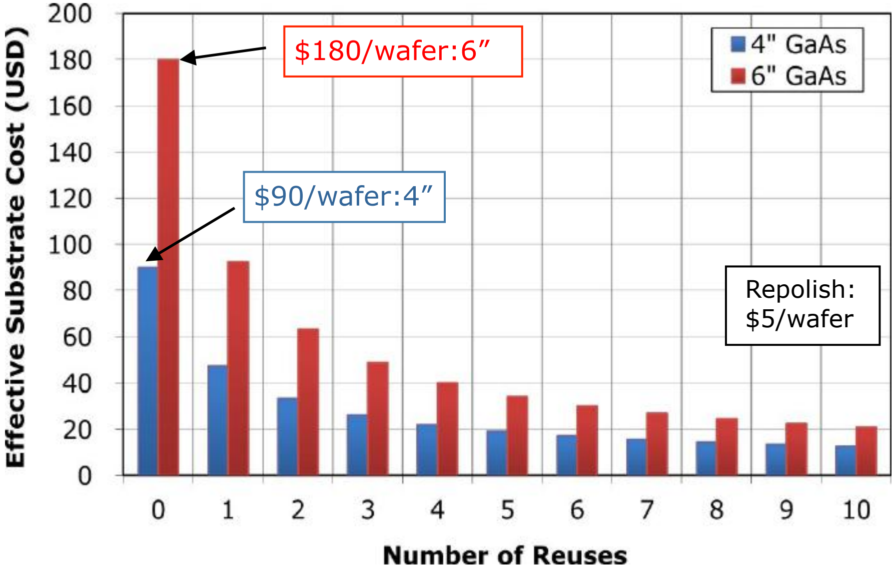


6″ wafer ELO (2x61cm^2 cells)

ELO for Cost and Weight Reduction

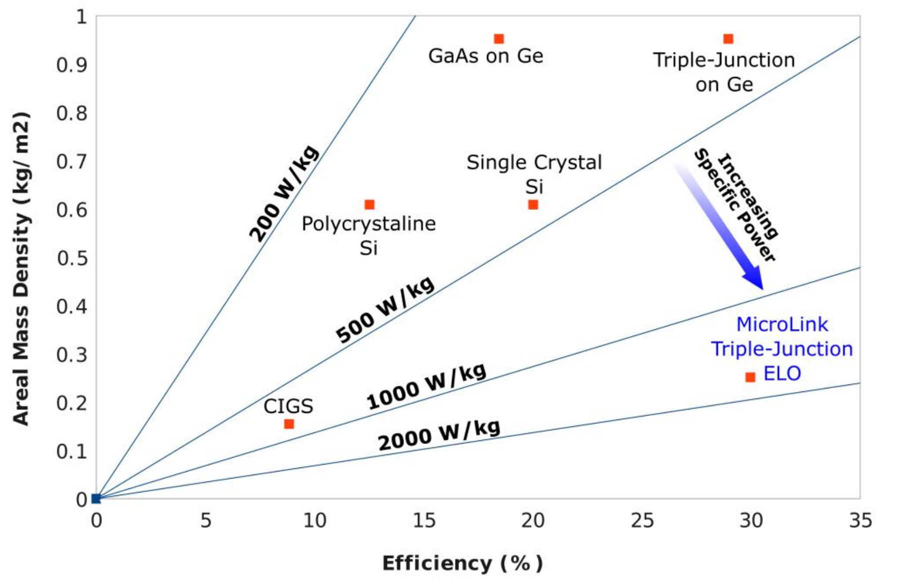
<$/W

Substrate Reuse Cost Reduction



>W/kg

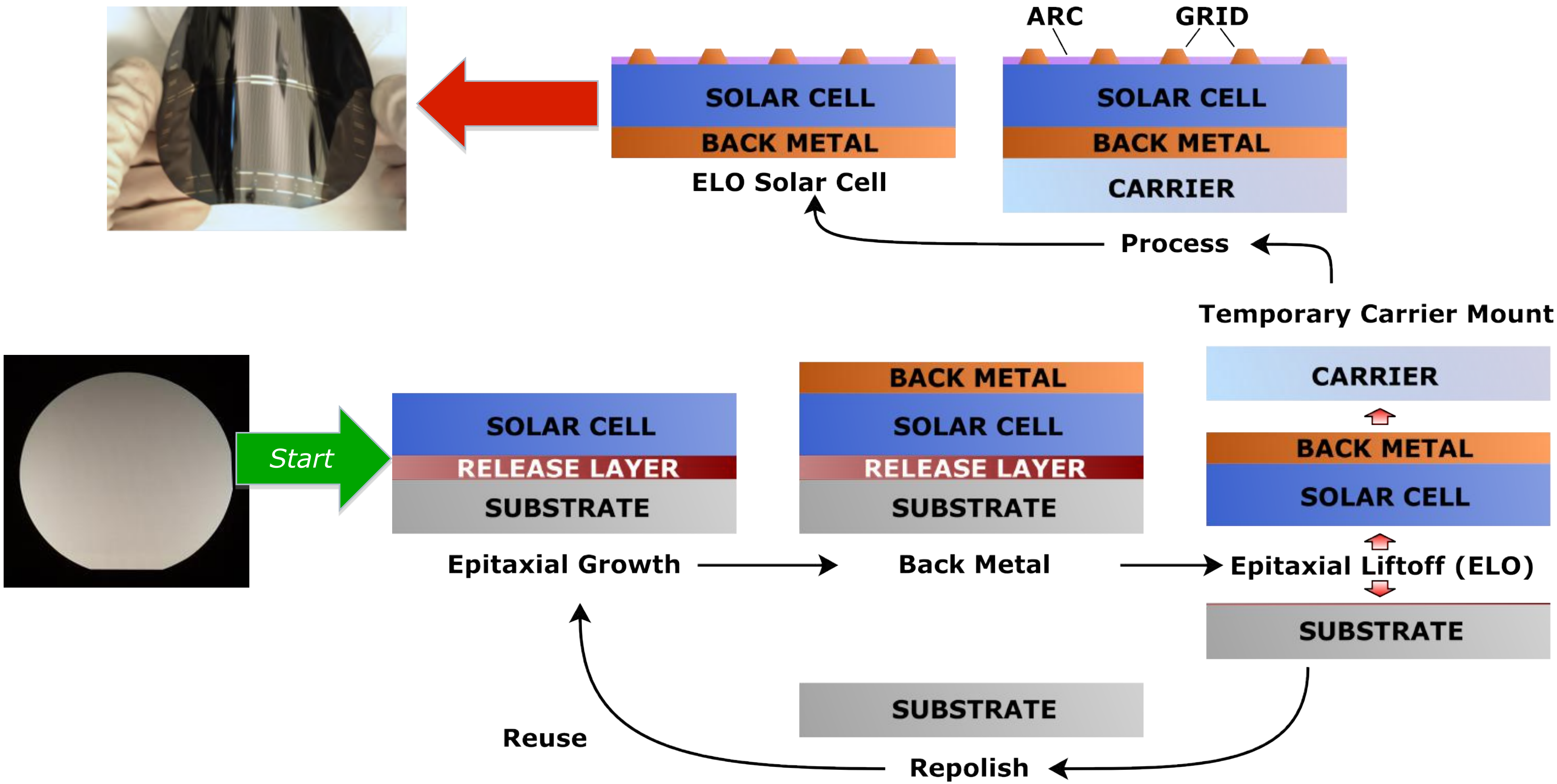
Specific Power Increase



- Reduced cost: Substrate is ~50% of cost of cell bill of materials
- Low weight: Enables airborne and space applications
- Flexibility: Wrap cell around curved objects
- Compatible with high efficiency cell designs (inverted metamorphic)

Fabrication Process by ELO

MicroLink Devices, Inc.

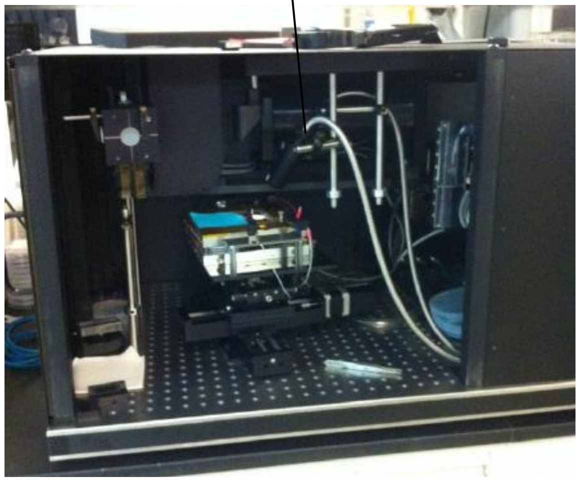


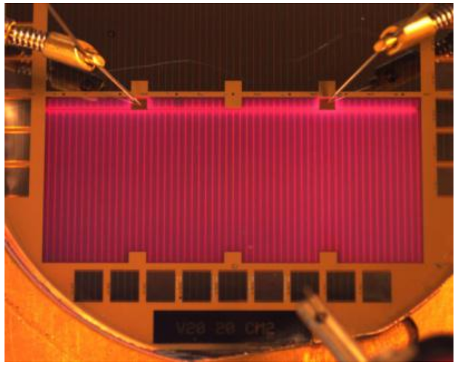
Cell Testing

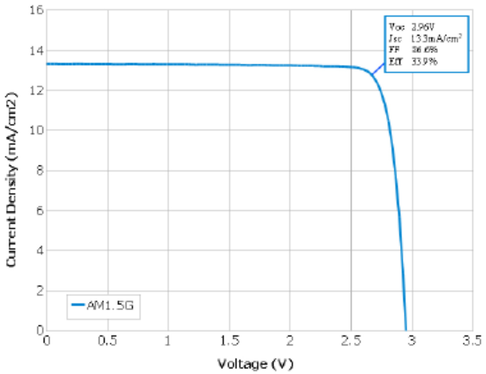
Illuminated current-voltage measurement

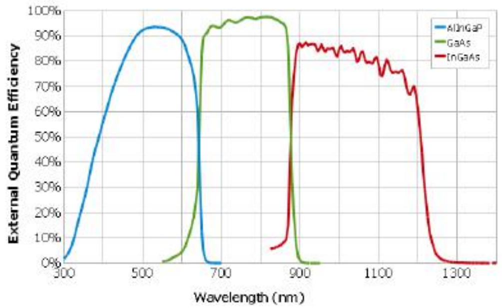
Quantum efficiency measurement

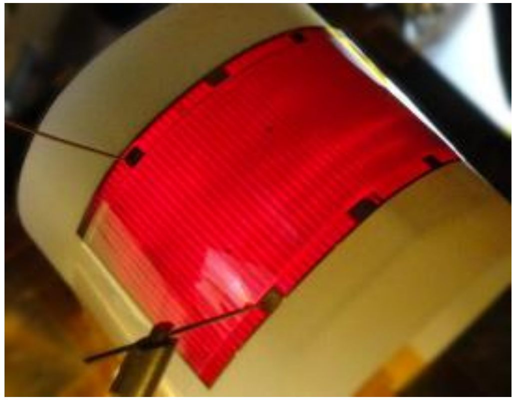
Electroluminescence





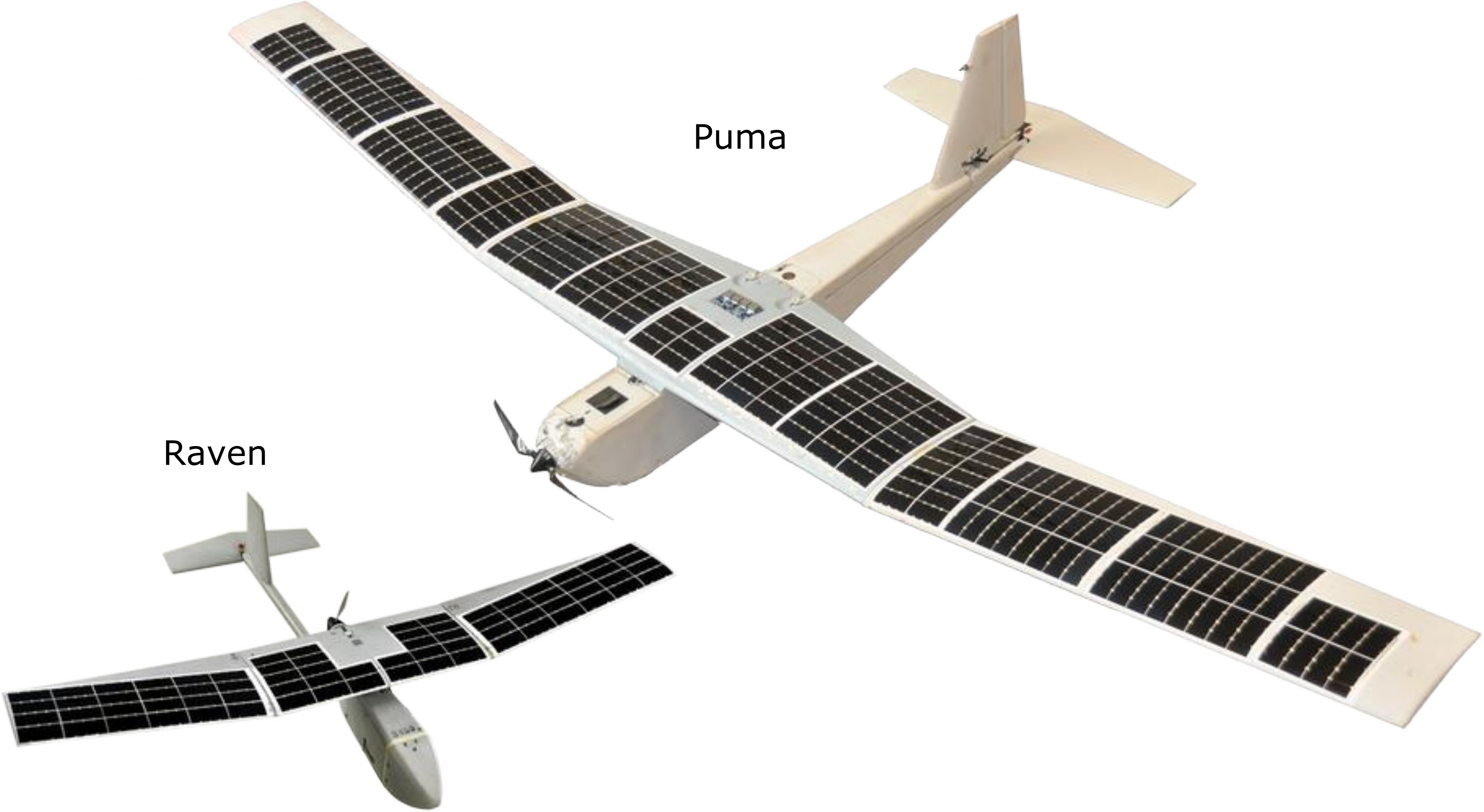






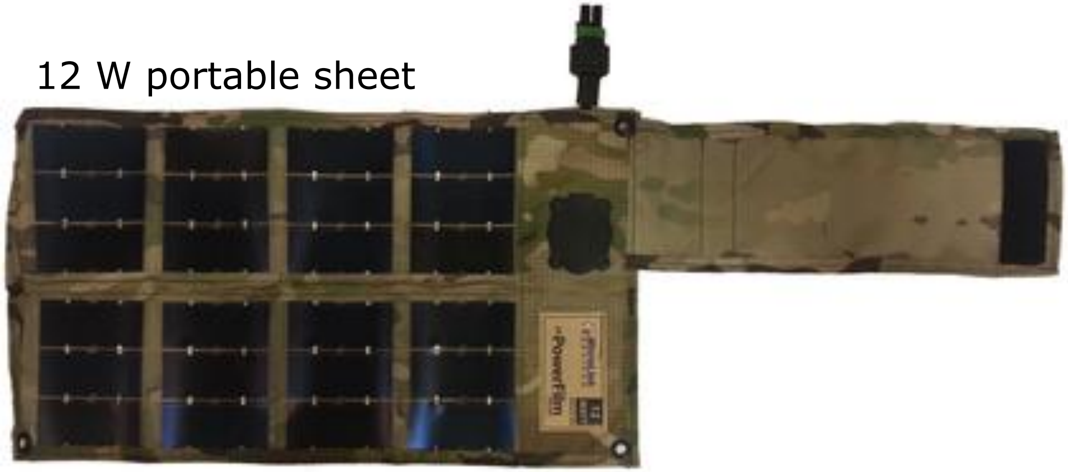
3. Applications for High-Efficiency Ultra-Thin PV

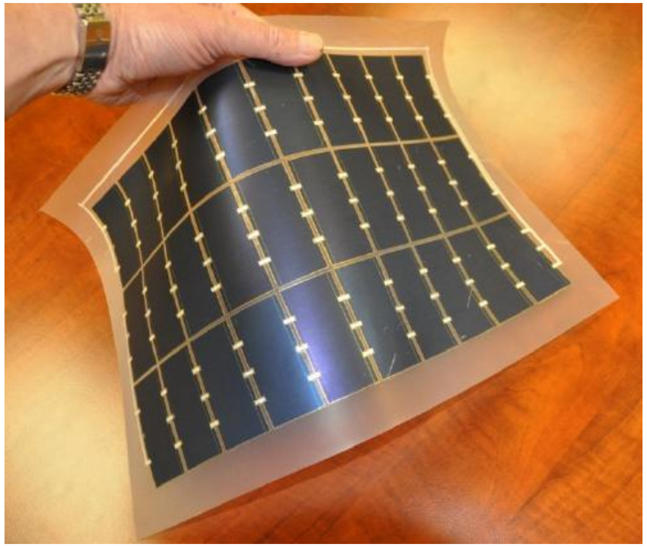
Unmanned Aerial Vehicles



Portable Power

12 W portable sheet

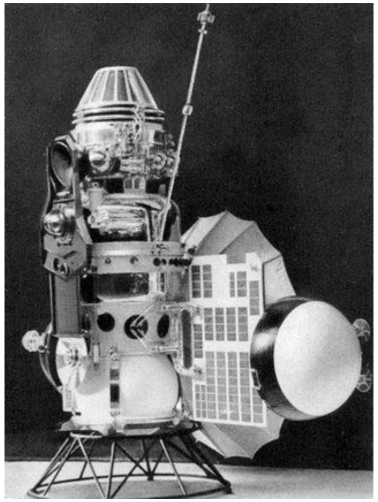


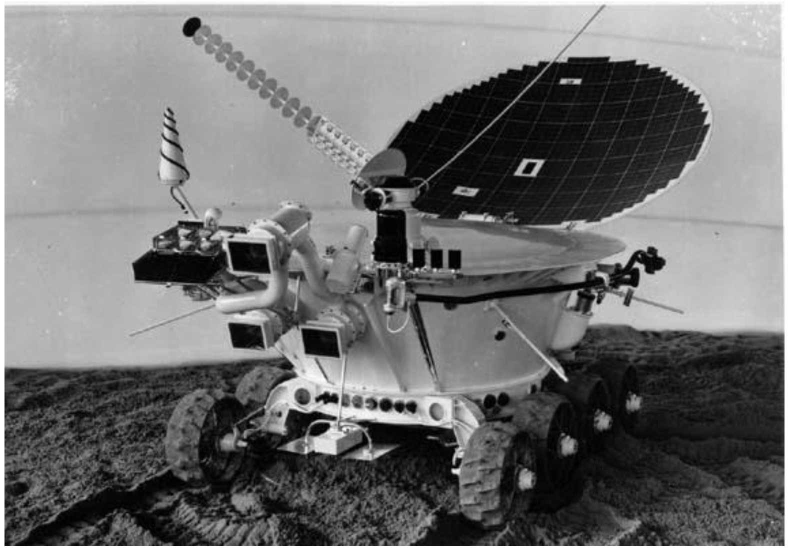


Testing at Limited Objective Experiment

Possible Application: Space

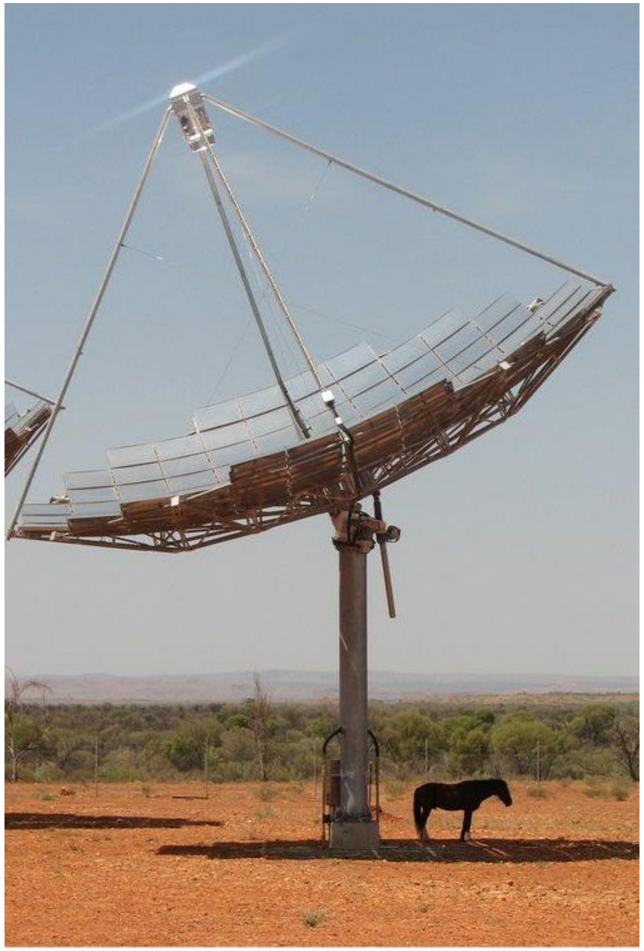
Venera 2 & 3 launched 1965: 2 m^2 GaAs PV
Lunokhod-1 & 2, 1970/72: 4 m^2 GaAs PV, 11% Efficiency


Venera – 3 (1965)


Lunokhod – 2 (1972)


ISS

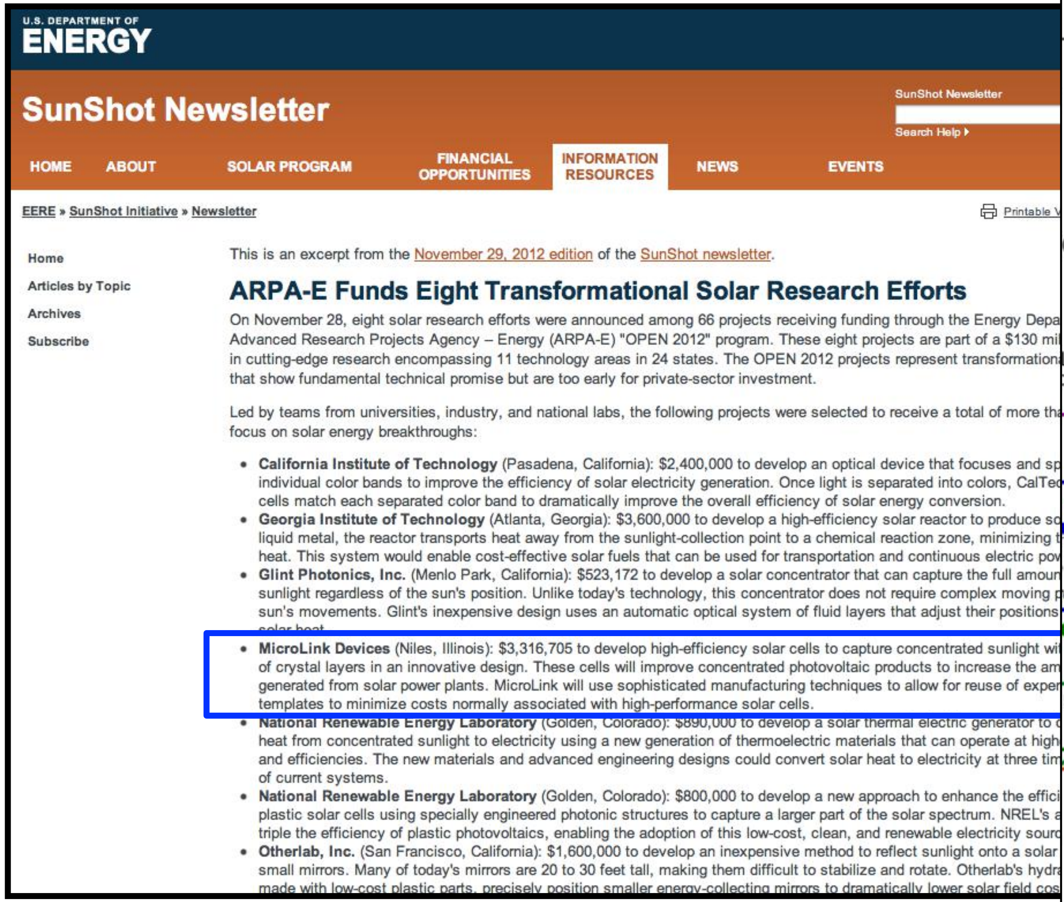
Possible Application: Concentrator PV



Amonix - USA

Solar Systems - Australia

Industry at the Cutting Edge



U.S. DEPARTMENT OF ENERGY

SunShot Newsletter

SunShot Newsletter

Search Help ▸

HOME | ABOUT | SOLAR PROGRAM | FINANCIAL OPPORTUNITIES | INFORMATION RESOURCES | NEWS | EVENTS

EERE » SunShot Initiative » Newsletter

Printable V

Home

Articles by Topic

Archives

Subscribe

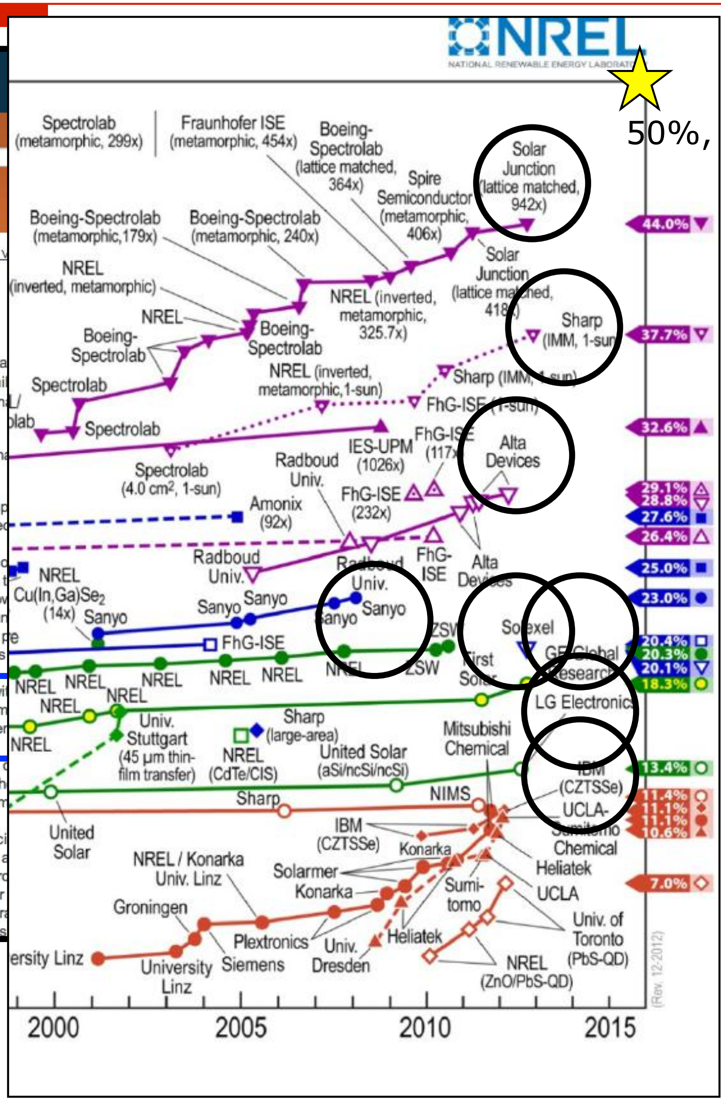
This is an excerpt from the November 29, 2012 edition of the SunShot newsletter.

ARPA-E Funds Eight Transformational Solar Research Efforts

On November 28, eight solar research efforts were announced among 66 projects receiving funding through the Energy Depa Advanced Research Projects Agency – Energy (ARPA-E) "OPEN 2012" program. These eight projects are part of a $130 mi in cutting-edge research encompassing 11 technology areas in 24 states. The OPEN 2012 projects represent transformationa that show fundamental technical promise but are too early for private-sector investment.

Led by teams from universities, industry, and national labs, the following projects were selected to receive a total of more th focus on solar energy breakthroughs:

- **California Institute of Technology** (Pasadena, California): $2,400,000 to develop an optical device that focuses and sp individual color bands to improve the efficiency of solar electricity generation. Once light is separated into colors, CalTe cells match each separated color band to dramatically improve the overall efficiency of solar energy conversion.
- **Georgia Institute of Technology** (Atlanta, Georgia): $3,600,000 to develop a high-efficiency solar reactor to produce so liquid metal, the reactor transports heat away from the sunlight-collection point to a chemical reaction zone, minimizing t heat. This system would enable cost-effective solar fuels that can be used for transportation and continuous electric pow
- **Glint Photonics, Inc.** (Menlo Park, California): $523,172 to develop a solar concentrator that can capture the full amoun sunlight regardless of the sun's position. Unlike today's technology, this concentrator does not require complex moving pe sun's movements. Glint's inexpensive design uses an automatic optical system of fluid layers that adjust their positions solar heat.
- **MicroLink Devices** (Niles, Illinois): $3,316,705 to develop high-efficiency solar cells to capture concentrated sunlight wi of crystal layers in an innovative design. These cells will improve concentrated photovoltaic products to increase the am generated from solar power plants. MicroLink will use sophisticated manufacturing techniques to allow for reuse of expe templates to minimize costs normally associated with high-performance solar cells.
- **National Renewable Energy Laboratory** (Golden, Colorado): $890,000 to develop a solar thermal electric generator to c heat from concentrated sunlight to electricity using a new generation of thermoelectric materials that can operate at high and efficiencies. The new materials and advanced engineering designs could convert solar heat to electricity at three tim of current systems.
- **National Renewable Energy Laboratory** (Golden, Colorado): $800,000 to develop a new approach to enhance the effici plastic solar cells using specially engineered photonic structures to capture a larger part of the solar spectrum. NREL's a triple the efficiency of plastic photovoltaics, enabling the adoption of this low-cost, clean, and renewable electricity sour
- **Otherlab, Inc.** (San Francisco, California): $1,600,000 to develop an inexpensive method to reflect sunlight onto a solar small mirrors. Many of today's mirrors are 20 to 30 feet tall, making them difficult to stabilize and rotate. Otherlab's hydra made with low-cost plastic parts, precisely position smaller energy-collecting mirrors to dramatically lower solar field cos



Summary

- The solar resource is huge: >5000x more power falls on Earth's surface from sun than we consume
- For terrestrial applications it is critical to reduce the solar cell $/W
- For airborne applications it is necessary to increase the solar cell W/kg
- Both of these are achieved via the epitaxial lift-off and substrate reuse process

Thank You.