NREL
NATIONAL RENEWABLE ENERGY LABORATORY

III-V Multijuntion & Concentrator Photovoltaics Research at NREL

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SUN UP webinar
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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

III-V multijunctions used in high value applications

Space: Large, flat panels

- High efficiency at 1-sun AM0
- Light weight is critical
- High radiation resistance
- Cost not so important

Terrestrial: Small cells, high concentration

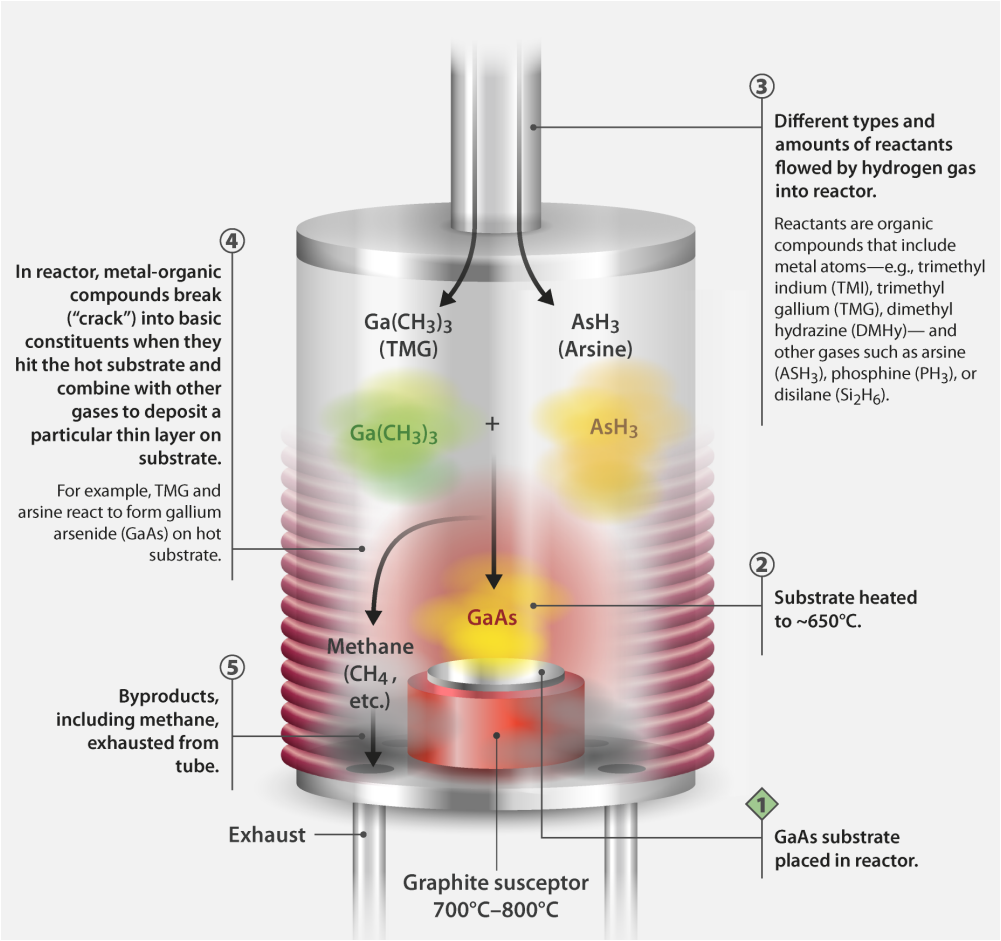
- High efficiency under concentration
- Low system cost
- Balance of system (optics, tracking…)
- Sensitivity to spectral changes

Efficiency is critical!

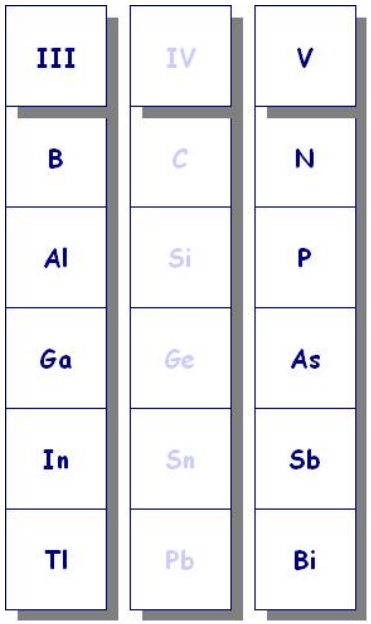
Proven Strategies for High Efficiency Solar Cells

- Multijunctions – reduce thermalization losses
- Concentration – efficiency and economics
- Radiative efficiency – material science and optics
- III-V alloys – high quality and versatile

Metalorganic Vapor Phase Epitaxy (MOVPE)

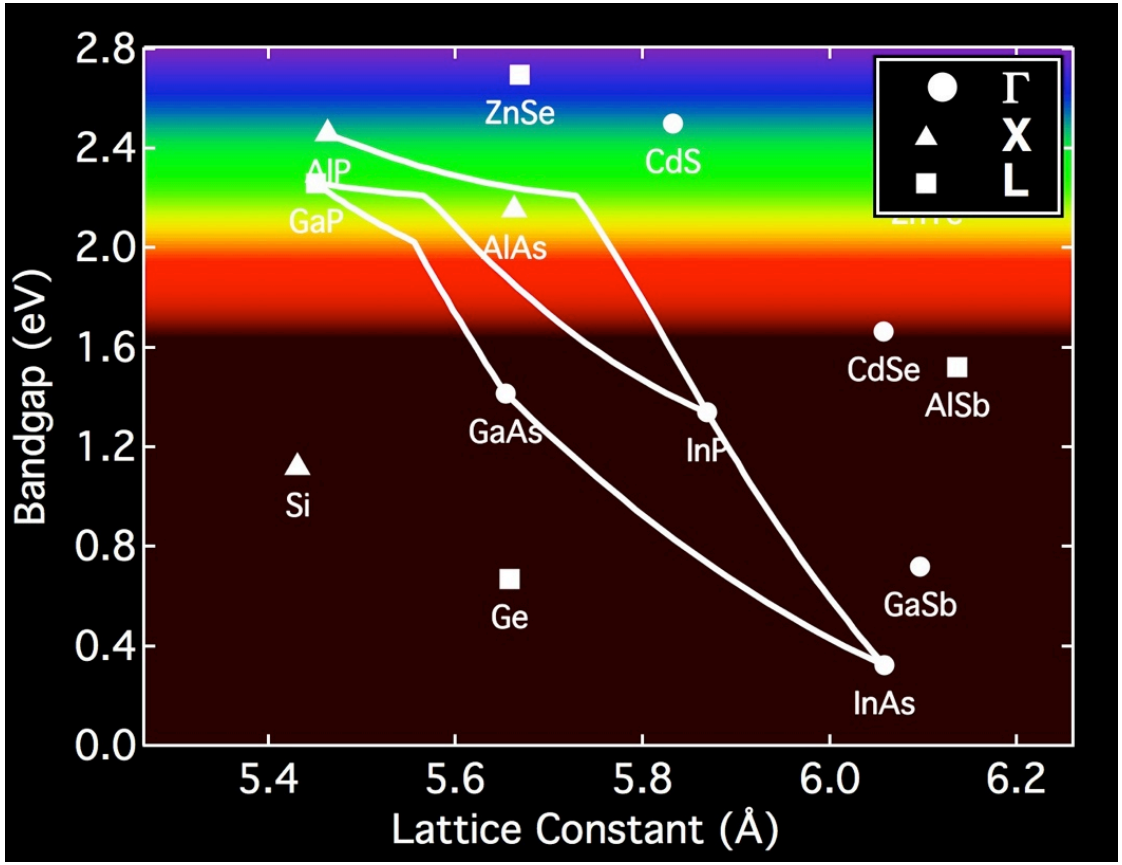


Easy to grow complex structures with many alloys using elements in Group III and V columns



Used in solar cells, lasers, LEDs, transistors, power electronics

III-V material system

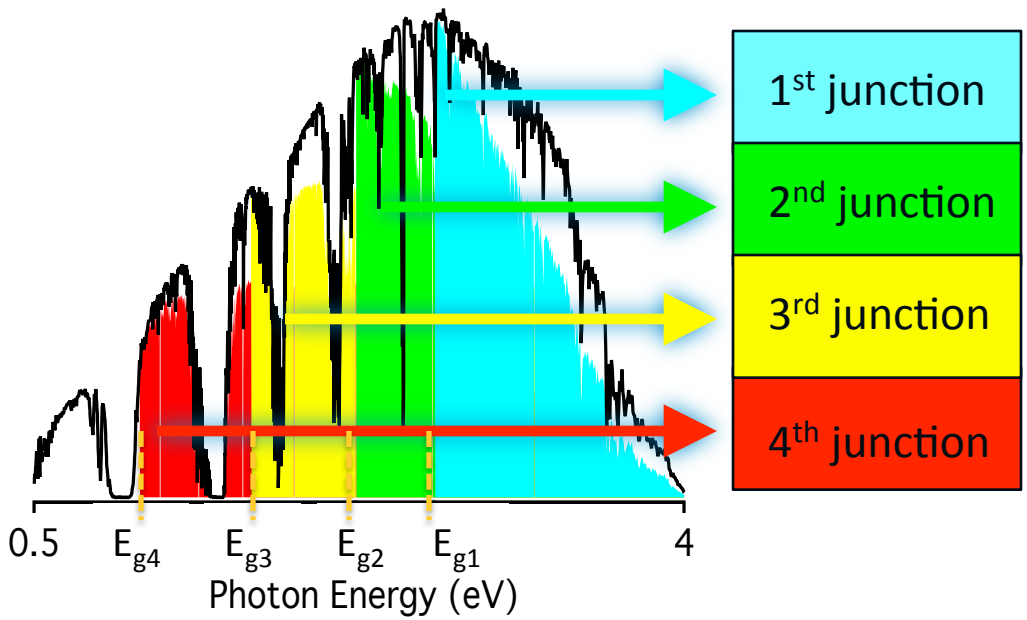


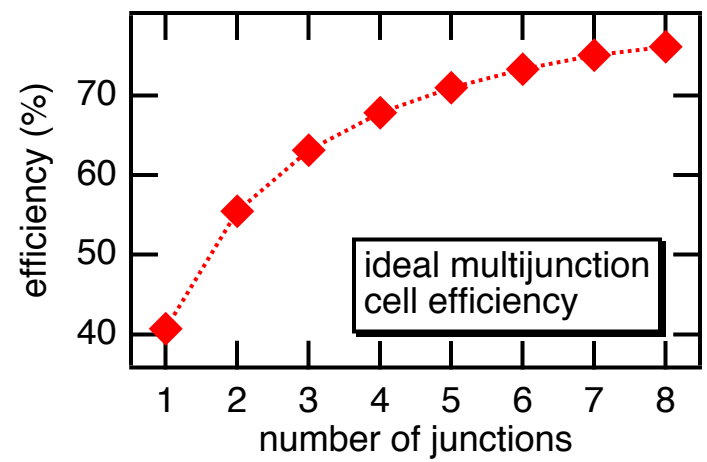
- Highly crystalline
- Lattice-matched alloys
- Direct bandgaps
- Wide range of bandgaps
- N-type and P-type doping
- Confinement layers
- Stable

Multijunction solar cells

Multijunction strategy:

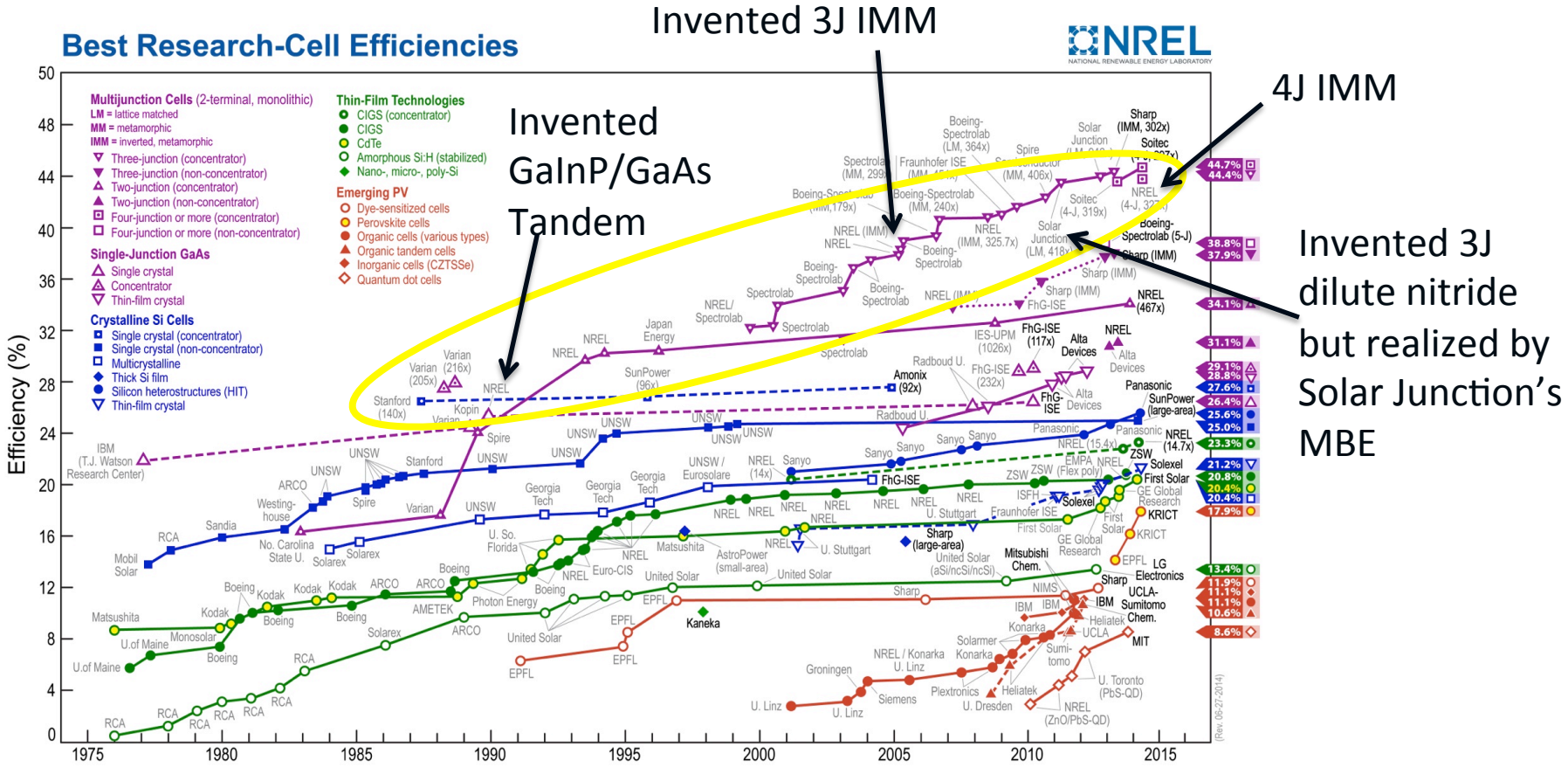
- Absorb a broad portion of the spectrum
- Use multiple junctions with different bandgaps to minimize thermalization





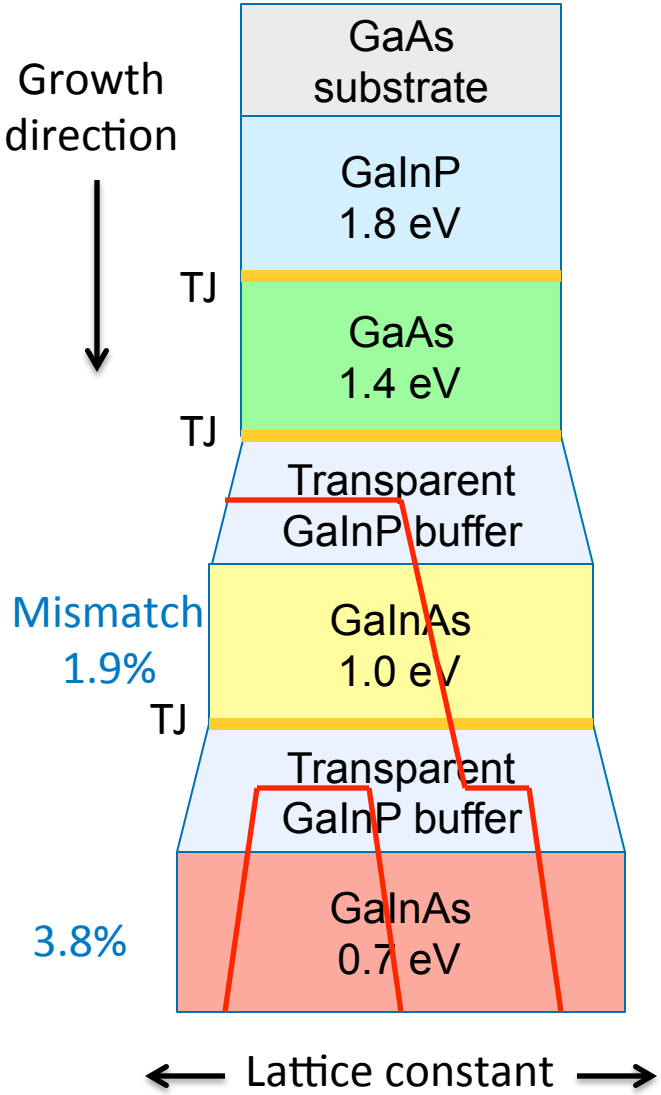
History of Solar Cell Efficiency

Multijunction concentrators are highest and still climbing!

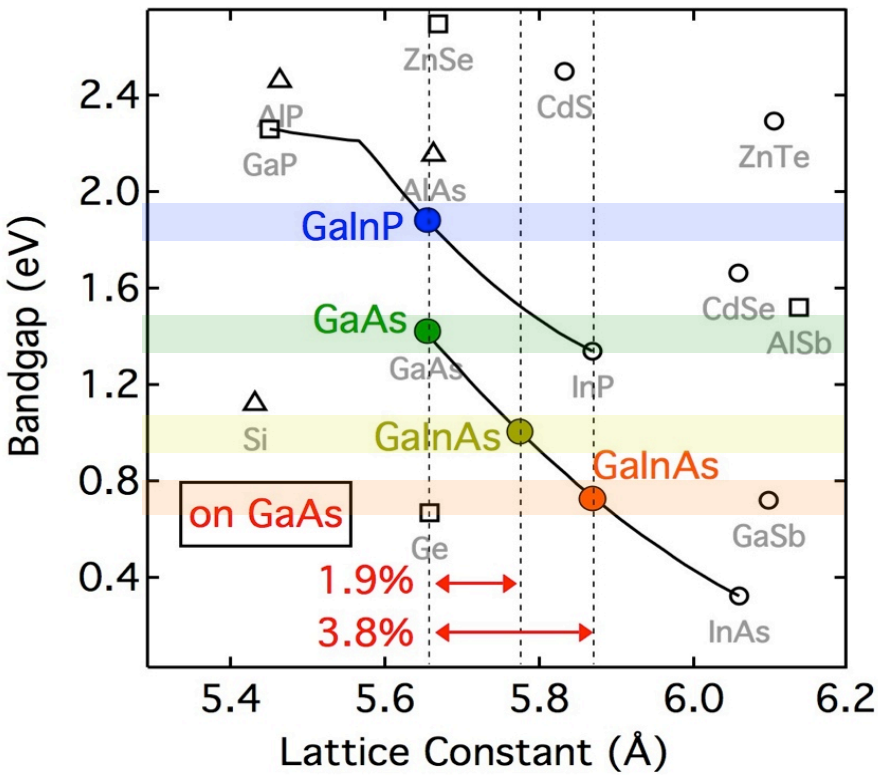


NREL multijunction team leading efficiency gains through research

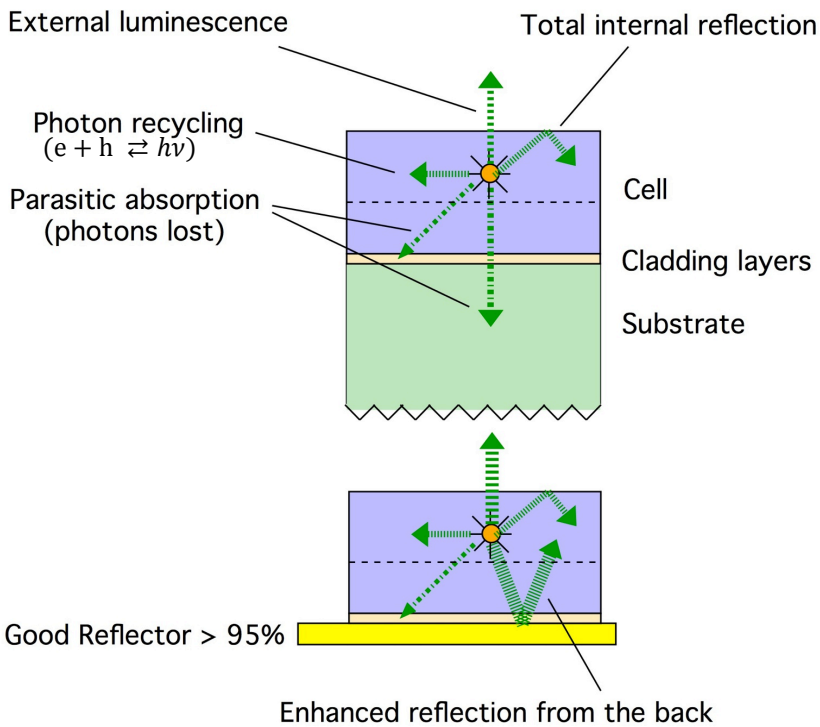
Inverted Metamorphic Multijunction (IMM) Solar Cell



- Near-optimum bandgaps can be achieved by changing the lattice constant
- Inverted growth has many advantages
- World record 40.8% with 3J IMM (now in production)
- Demonstrated 45.6% with 4J IMM
- Target of 50% with 5J or 6J IMM in near future



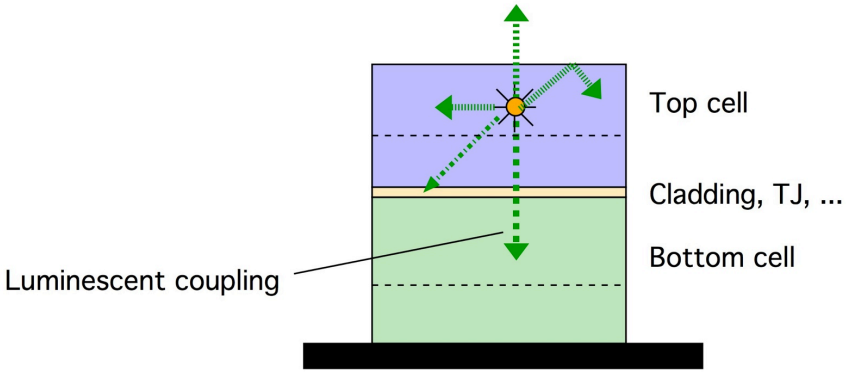
Understanding role of optics in solar cells



- Some photons escape out the front
- Some photons are re-absorbed in the bulk
- Most photons directed downward toward the substrate are lost

(Enhanced) photon recycling:
Photons directed downward are reflected back into the cell, enhancing the photon recycling
INCREASES VOLTAGE

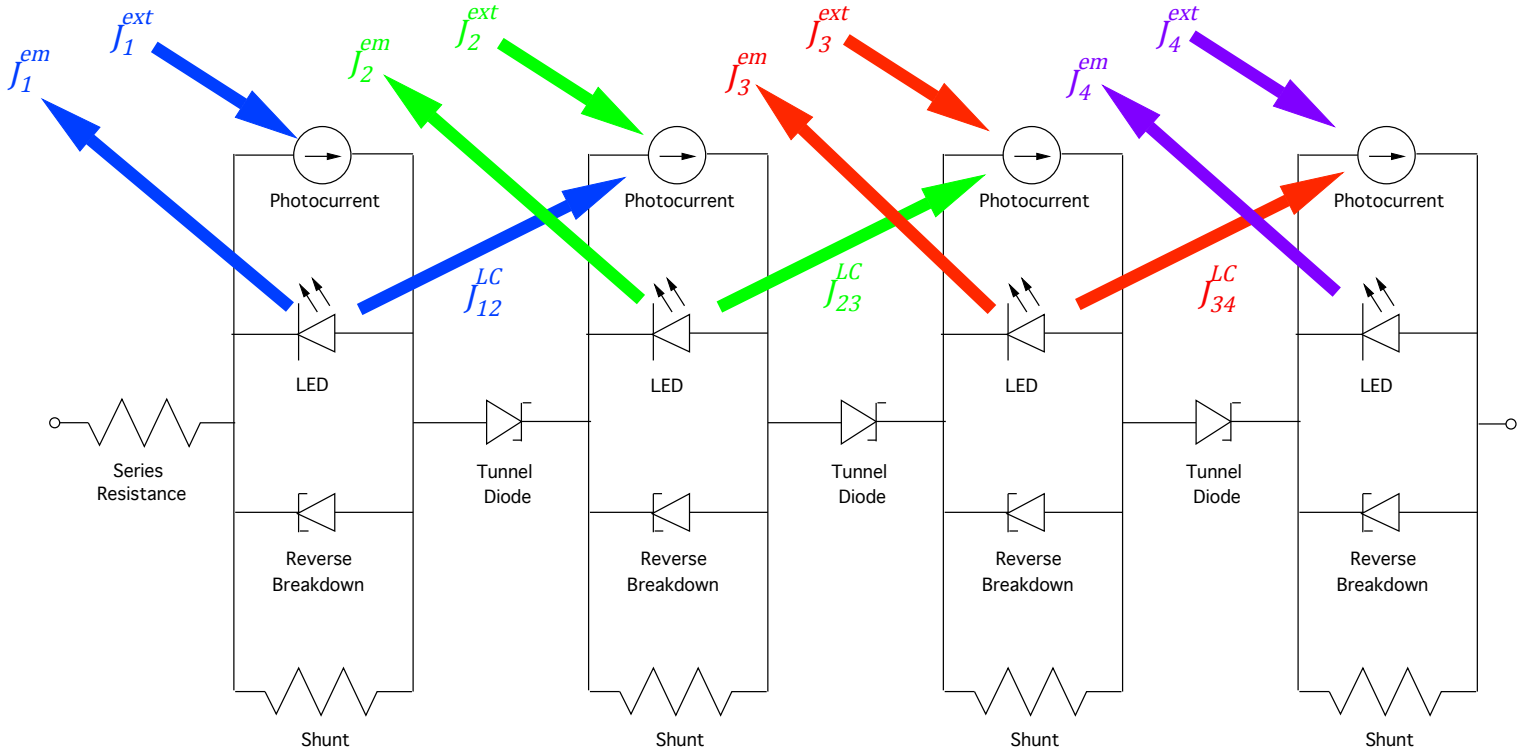
Steiner et al., JAP **113**, 123109 (2013)



Luminescent coupling in a multijunction:
Photons directed downward can be coupled to a lower bandgap junction
INCREASES CURRENT bandgap junction

Steiner et al., APL **100**, 251106 (2012)

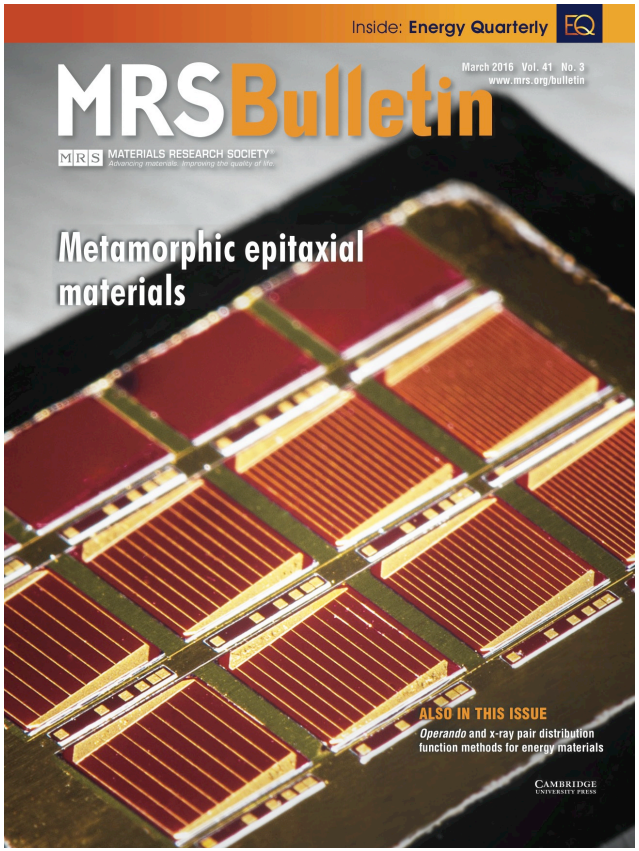
Multijunctions - Complex optoelectronic circuit



Advanced characterization and understanding for improved design

Geisz et al., "Generalized optoelectronic model of series-connected multijunction solar cells", IEEE JPV, **5**, 1827 (2015)

High performance devices through material science solutions

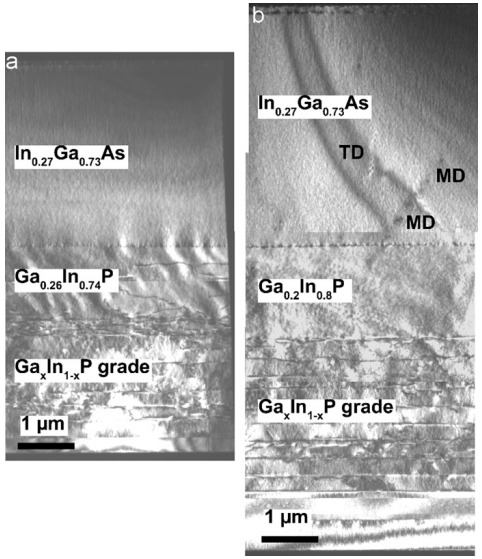


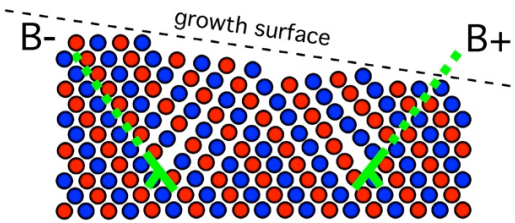
- Solar cells that glow
- High quality layers with different crystal lattice

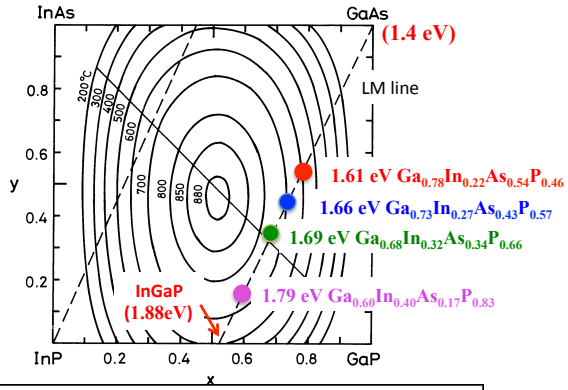
France et al., MRS Bulletin, **41**, 202 (2016)

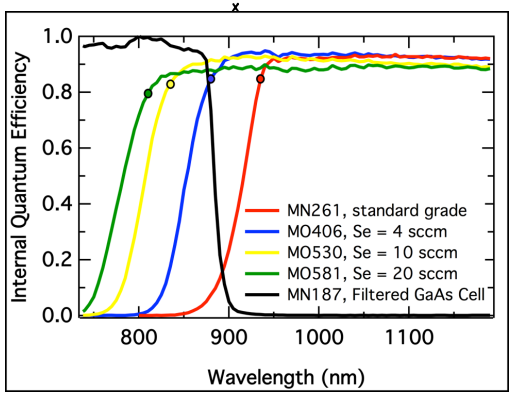
Material science challenges

- Reduction of dislocations in metamorphic alloys
- Effects of alloy ordering
- Transparency of layers using Burstein-Moss shift
- Reduction of non-radiative recombination
- Metastable alloy combinations



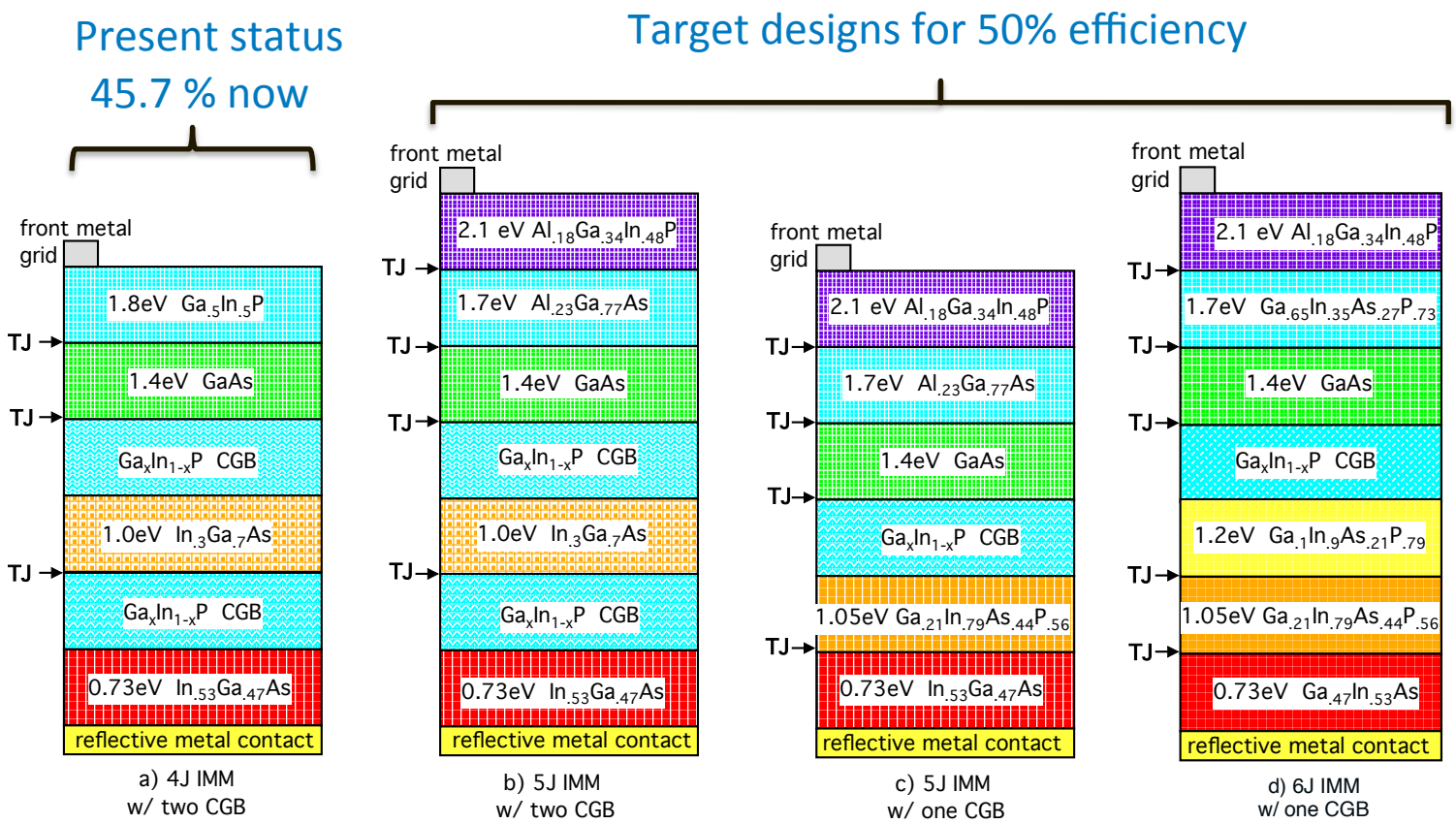






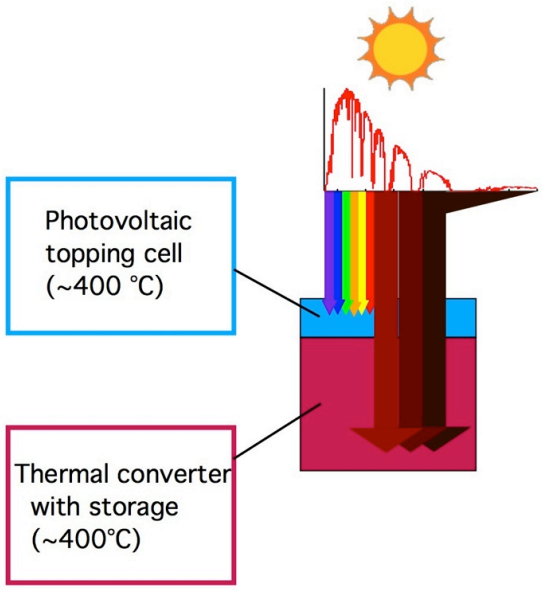
Multijunction solar cells for 50% efficiency

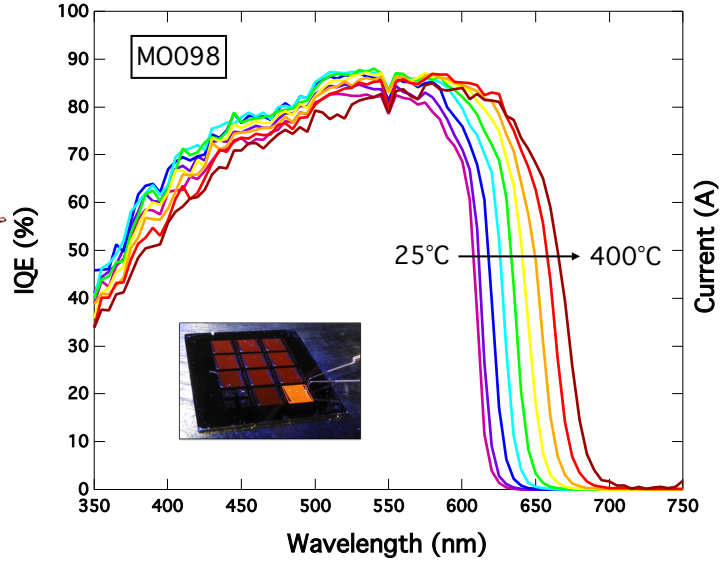
- Funding: DOE EERE SETO SunLamp
- Goal: 5J – 6J inverted metamorphic solar cells for high concentration



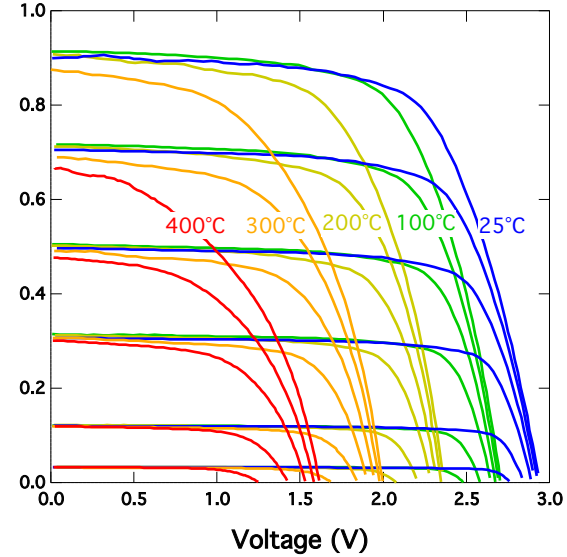
High Temperature Solar Cells for Hybrid Energy

- Funding: ARPA-E FOCUS
- Collaborators: Yale, NREL, SolAero
- Goal: High temperature tandems for solar-thermal hybrid cogeneration





Higher RT E_g for optimal high temperature E_g

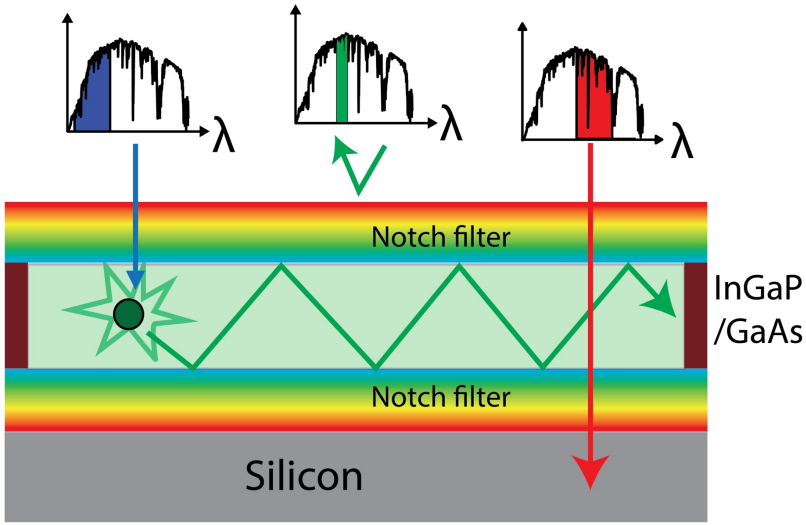


2J solar cell operating at 400°C and 1000X

Perl et al, IEEE JPV, **6**, 1345 (2016)

Luminescent Solar Concentrators

- Funding: ARPA-E MOSAIC
- Collaborators: Caltech, UIUC, LBNL, NREL
- Goal: Tracker-free, low-profile concentrator using high radiative efficiency quantum dots in polymer waveguide coupled to GaInP microcells and Si cells



Opportunities for research

Contribute to advancing the state-of-the-art in multijunction solar cell efficiencies!

- MOVPE crystal growth
- III-V semiconductor material science
- Multijunction solar cell design
- Concentrator and Space applications
- Optical modeling
- Device processing
- Physics of optoelectronic devices

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