Two and Three Terminal Photovoltaic Cells Based on InP Using Lattice-Matched InGaAs and InGaAsP

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PVSAT 4: 2nd April 2008

Outline

1. Thermophotovoltaics

2. Device design

3. Single junction device performance

4. Double junction, three terminal device performance

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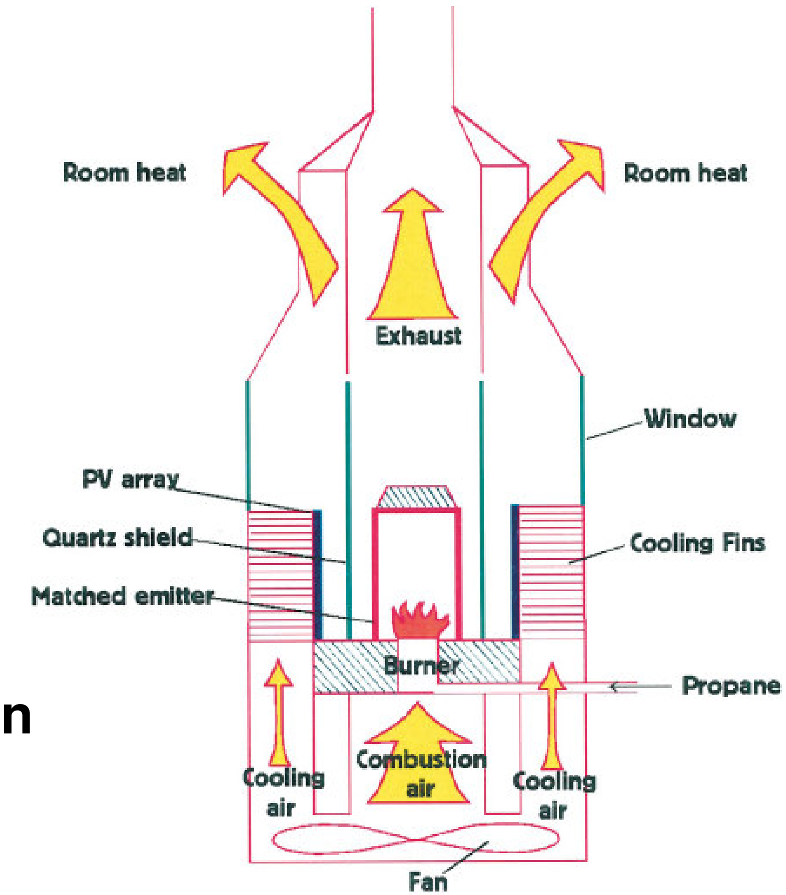
Thermophotovoltaics

A thermophotovoltaic (TPV) system consists of:

- artificially heated source (1200 – 2000K)
- spectral control
- photovoltaic cells
- cooling system.

Applications:

- combined heat and power generation
- industrial waste heat recovery
- deep-space power sources.

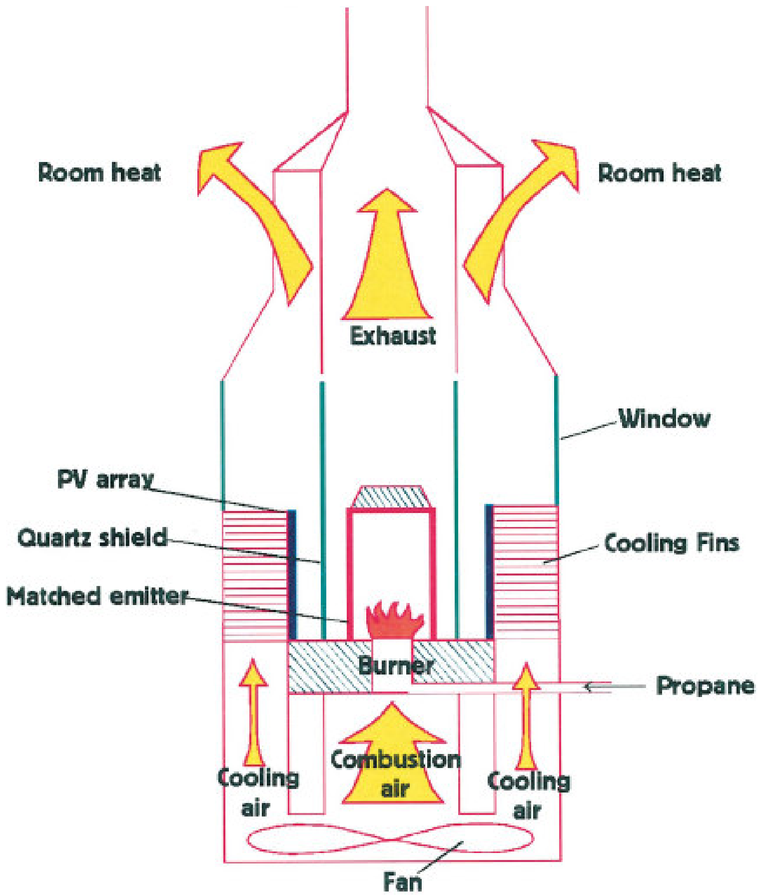


JX Crystals TPV system (GaSb cells)

Thermophotovoltaics

Advantages:

- high power densities (≥1Wcm^{-2})
- quiet
- no moving parts
- supply and demand is in phase
- versatile fuel source.



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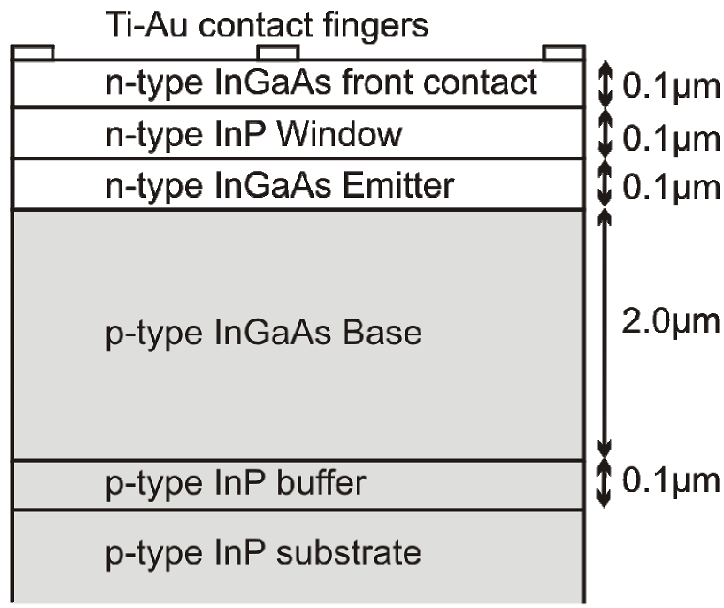
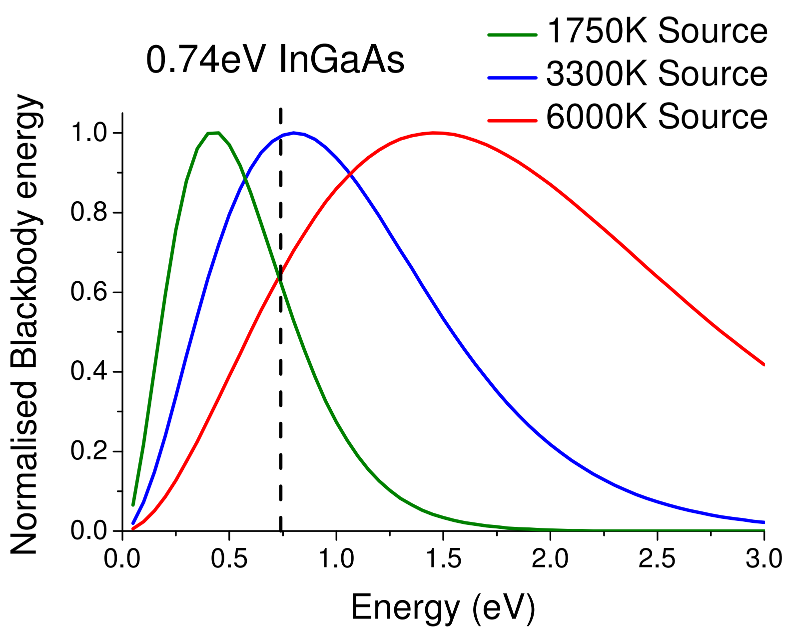
Device Design: Single Junction

- InGaAsP lattice matched to InP allows 0.74eV to 1.34eV bandgaps ($In_{0.53}Ga_{0.47}As$ to InP)
- InP substrate:
  - potential high efficiency
  - lower cost than GaSb.

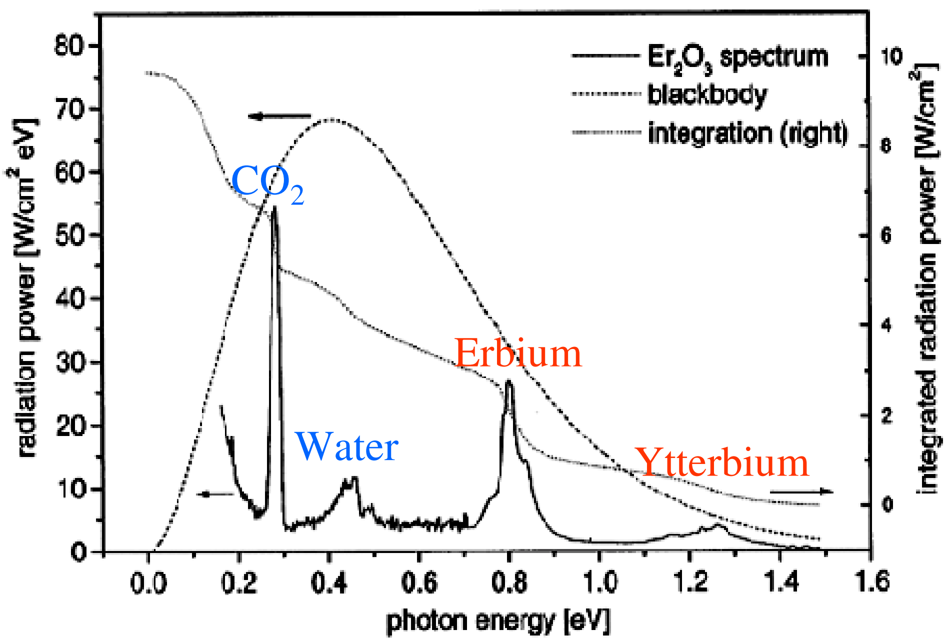




- Pure blackbody TPV source requires lower bandgaps.
- Higher bandgaps useful with:
  - spectral control
  - higher temperatures.

Device design: Selective Emitters

- A selective emitter can greatly enhance the efficiency of the device by reducing losses both above and below the bandgap.



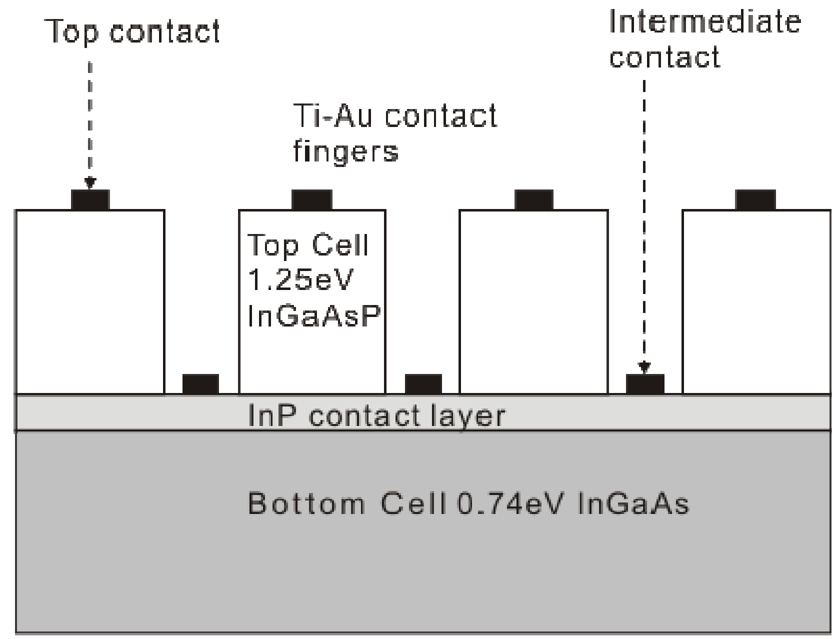
- E.g. a porous Erbium and Ytterbium Oxide selective emitter reported by Bitnar et al. [1]

- Suggests combination with a higher bandgap cell at 1.25eV.

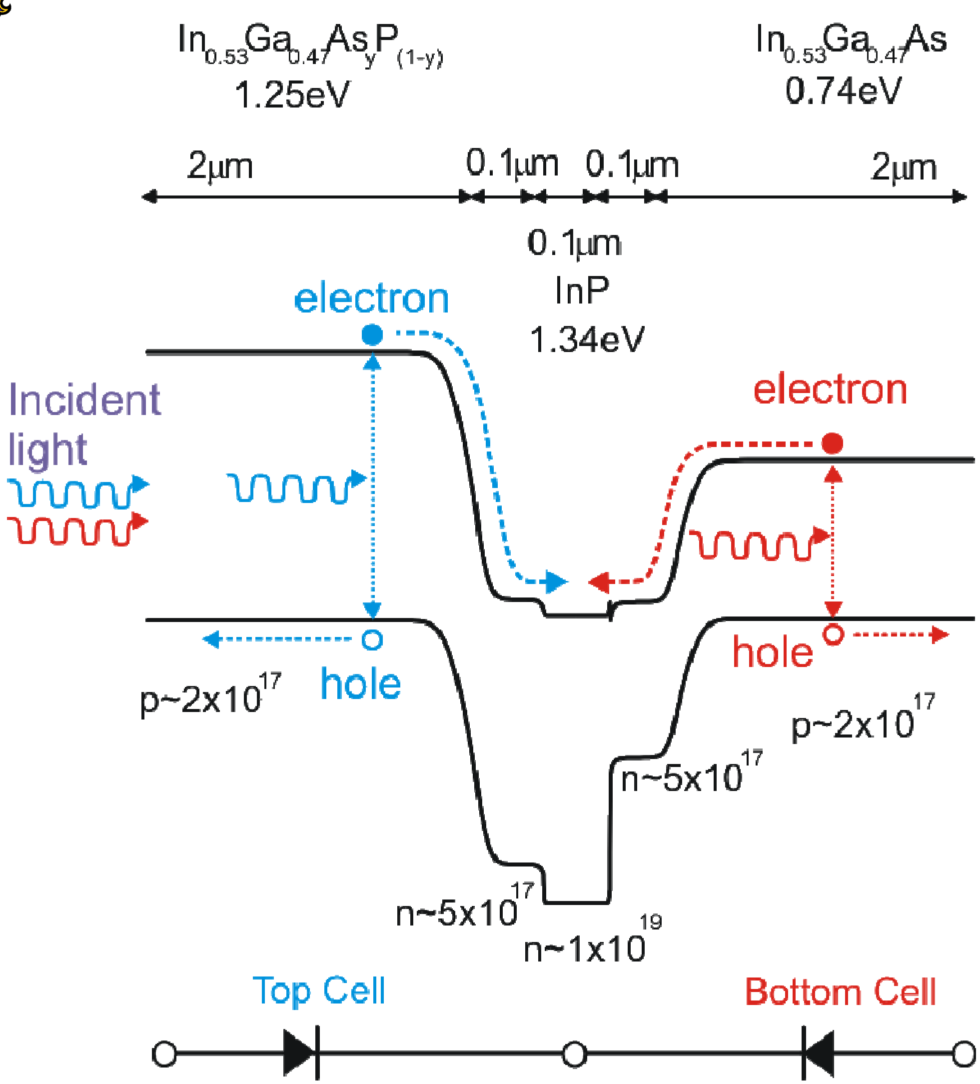
[1] Bitnar, W. Durisch, J. C. Mayor, H. Sigg, and H. R. Tschudi, Solar Energy Materials and Solar Cells 73 (2002) 221.

Device design: Double Junction

- **Double junction device:**
  - **InGaAsP top cell 1.25eV**
  - **InGaAs bottom cell 0.74eV.**
- **Intermediate contact created by etching through small areas of the top cell.**
- **Three terminal device:**
  - **no current matching required**
  - **flexibility in source spectrum with no loss in efficiency.**

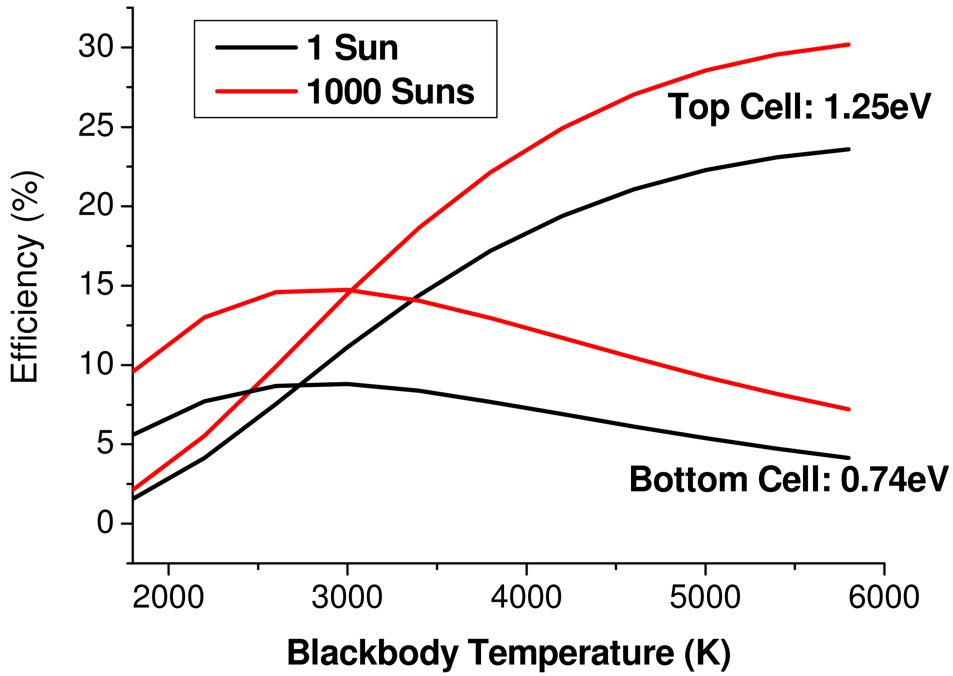


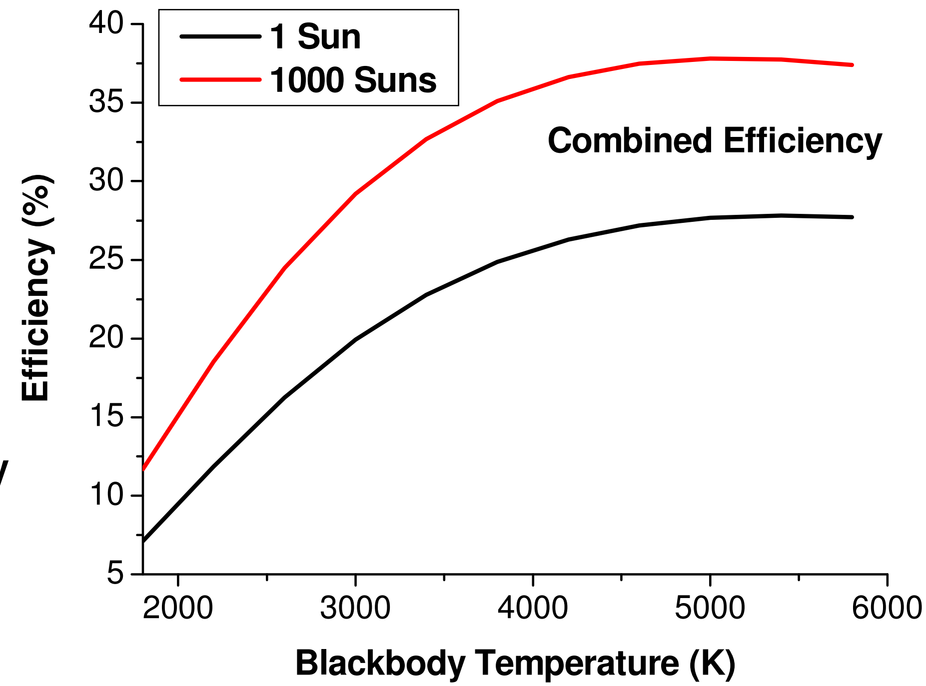
Double Junction Bandstructure



- A pn - np structure removes the need for a low resistance tunnel junction.
- Current collection occurs at all three terminals.
- Multiple devices can be connected together by voltage matching.

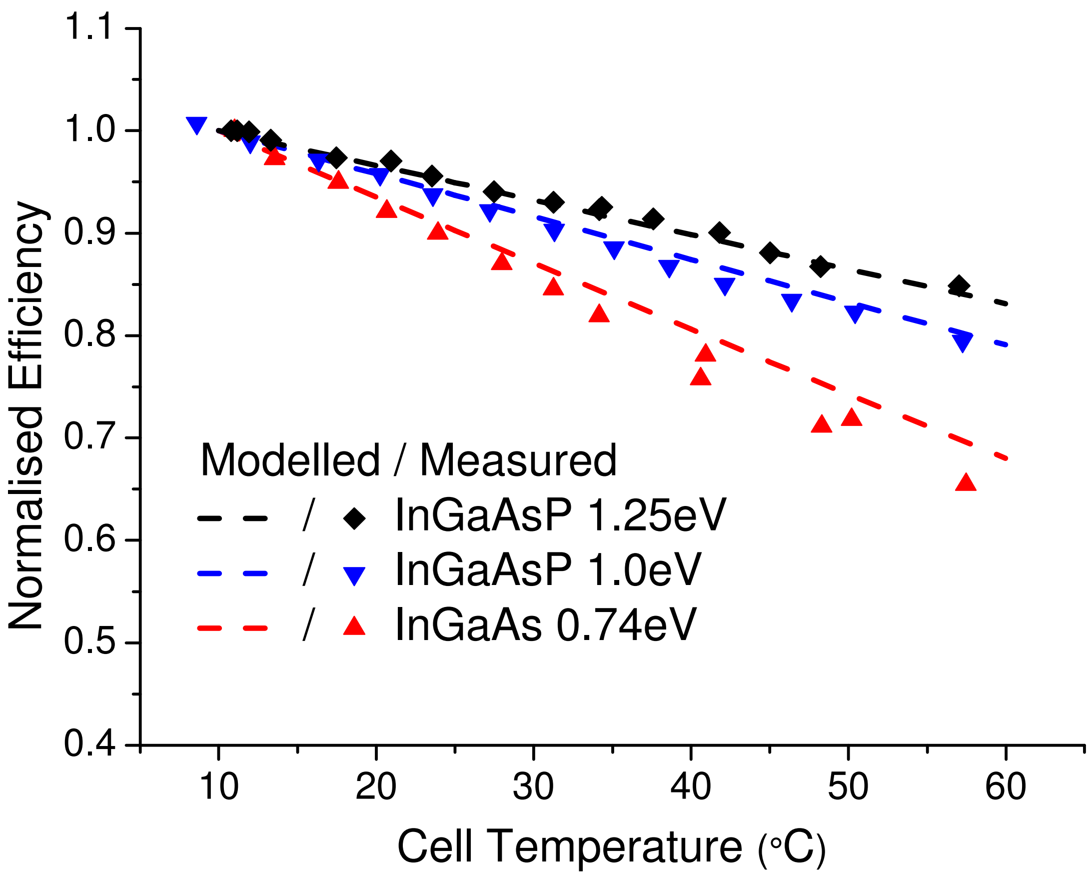
Device Design: Solar Concentrators





- **Also suitable for solar concentrator systems.**

Cell Temperature Dependence



- **Higher bandgap devices are less sensitive to temperature variations.**
- **Cell cooling improves performance.**
- **Combined heat and power can recover energy from cooling – improves system efficiency.**

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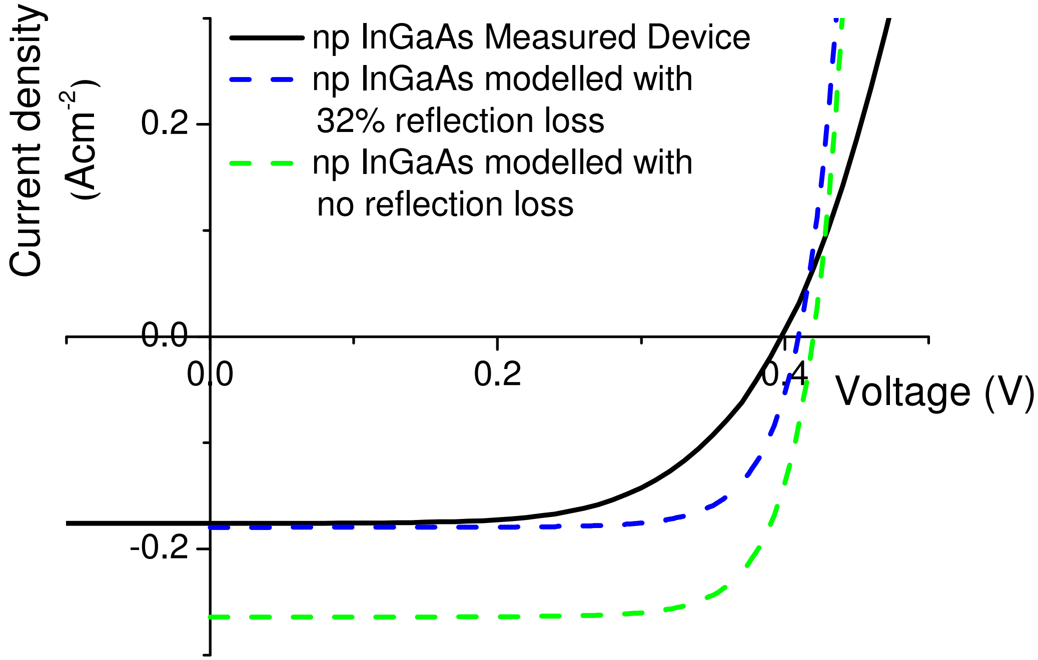
Single Junction Device Performance: InGaAs 0.74eV

- **The two junctions forming part of the three terminal device were first fabricated and measured individually.**

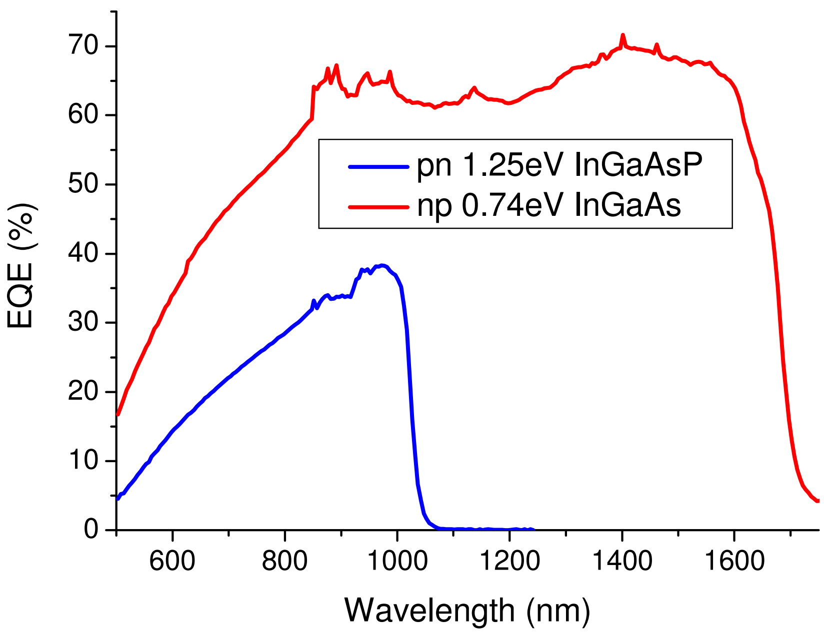


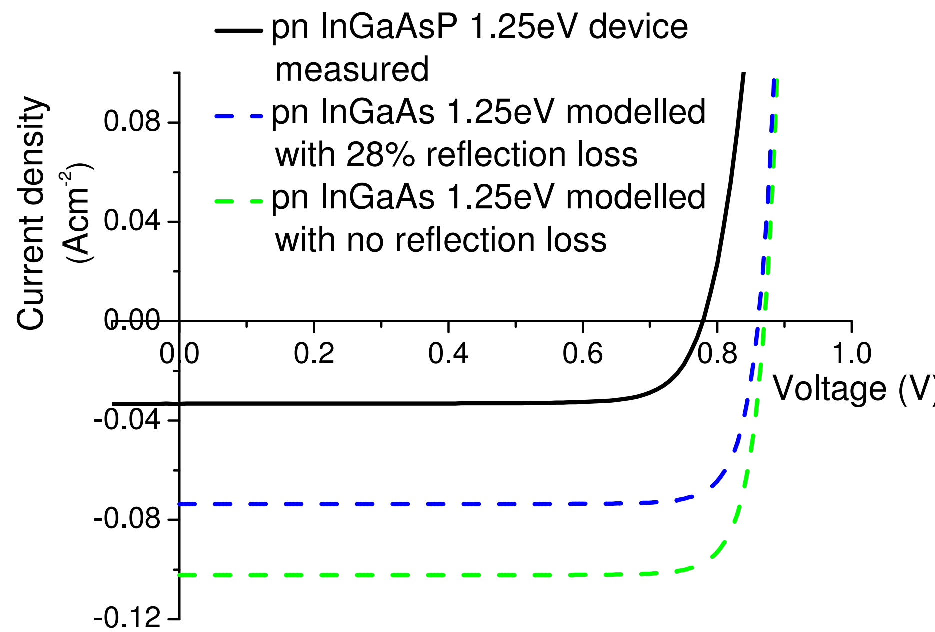
- **Measured under 0.5Wcm^{-2} 3300K blackbody source.**
- **Single junction InGaAs performance is limited by:**
  - **reflection losses**
  - **series resistance.**

- **Measured efficiency at 3300K, 0.5Wcm^{-2} = 8.6%**
- **Predicted efficiency with anti-reflection coating and minimal R_s > 14%**
- **Predicted efficiency with anti-reflection coating, minimal R_s with Erbium emitter spectrum at 0.5Wcm^{-2} >20%**

Single Junction Device Performance: InGaAsP 1.25eV

- **The pn 1.25eV InGaAsP shows a significantly lower J_{sc} than expected.**





- **Confirmed by the lower EQE**
- **pn devices generally out-perform np devices, though not well understood.**

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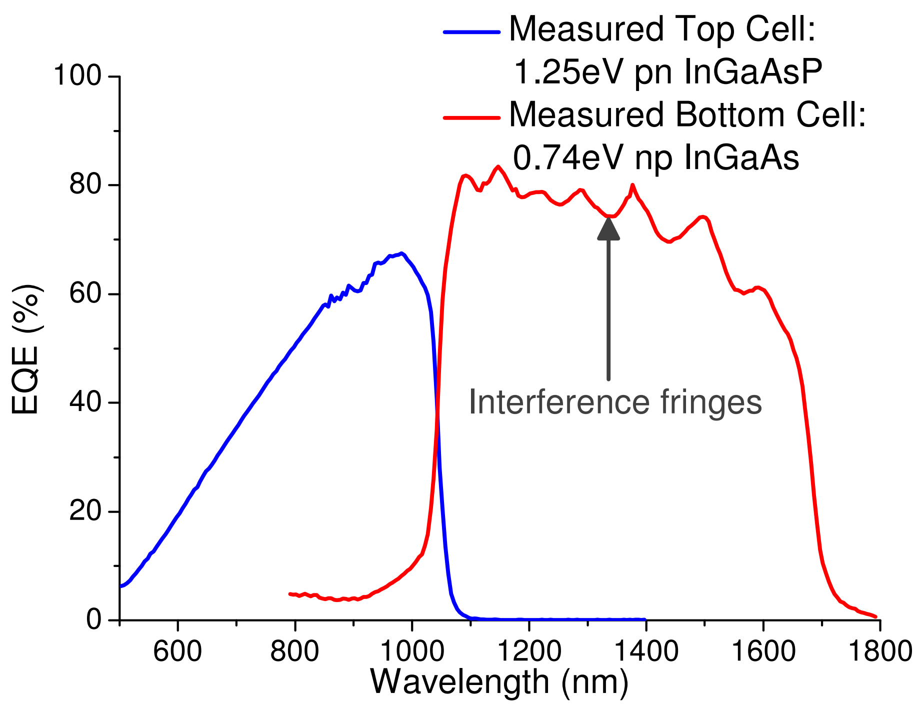
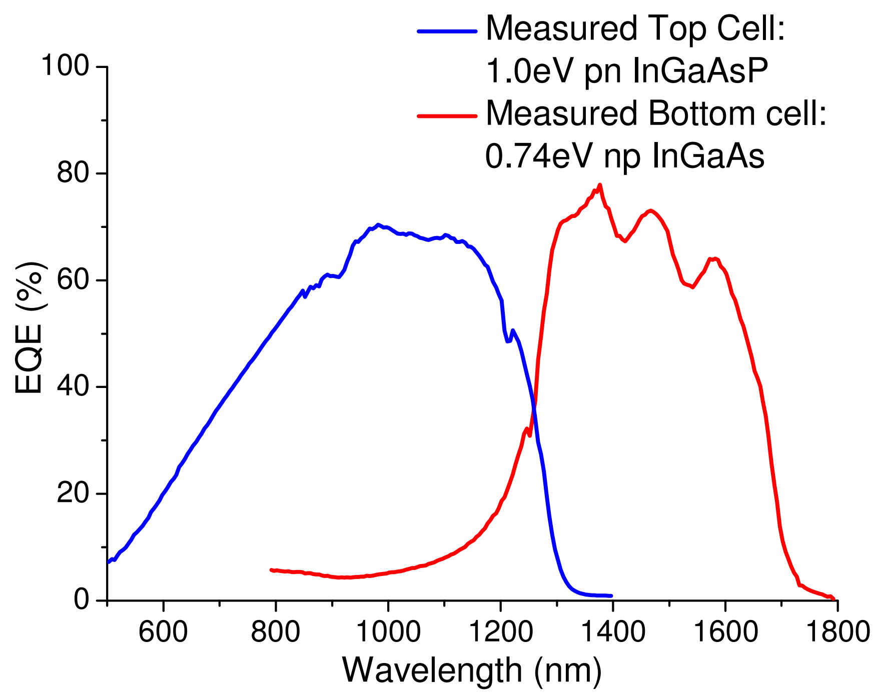
Three terminal performance

- **Both 1.25eV / 0.74eV and 1.0eV / 0.74eV devices have been fabricated, with an anti-reflection coating.**
- **Initial fabrication issues resulted in significant shunting, especially in the top cells.**
- **Short circuit current performance preserved.**





- **Low wavelength fall off due to absorption in contact layer**

Summary

- Single junction 0.74eV devices have been measured with 8.6% efficiency for a 3300K source. 14% is straightforward to achieve.

- Potential for >20% efficiency in a TPV system.

- Three terminal, double junction devices produce efficient spectral coverage with flexibility to incident spectrum.