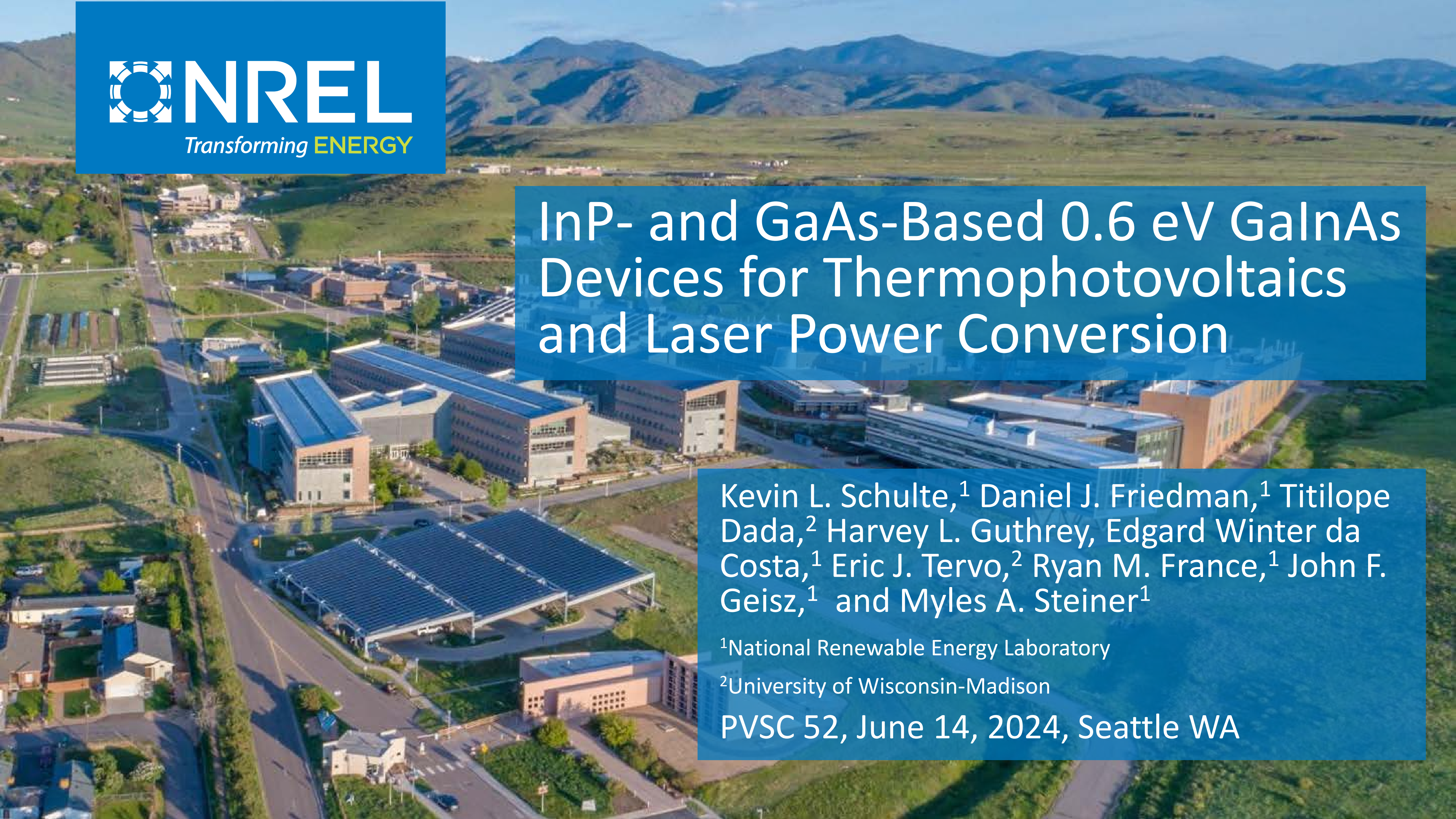


InP- and GaAs-Based 0.6 eV GaInAs Devices for Thermophotovoltaics and Laser Power Conversion

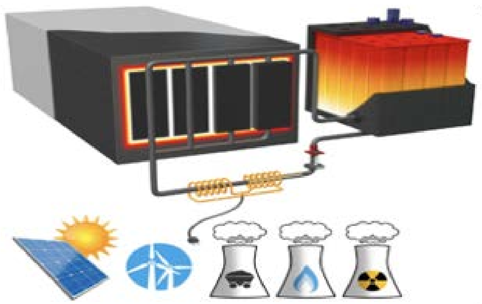
Kevin L. Schulte,[1] Daniel J. Friedman,[1] Titilope Dada,[2] Harvey L. Guthrey, Edgard Winter da Costa,[1] Eric J. Tervo,[2] Ryan M. France,[1] John F. Geisz,[1] and Myles A. Steiner[1]

[1]National Renewable Energy Laboratory

[2]University of Wisconsin-Madison

PVSC 52, June 14, 2024, Seattle WA

Applications of Thermophotovoltaics

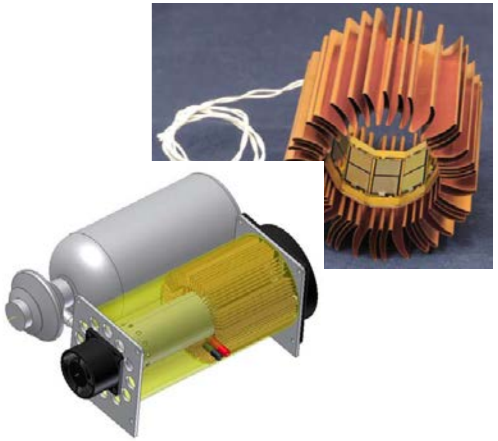


Utility-scale energy storage

- Store energy as high temperature heat

Industrial waste heat recovery

- Steel
- Cement
- Glass



Power generation

- Portable power (eg. military)
- CSP plant
- Use with combusting hydrogen

Military vehicles

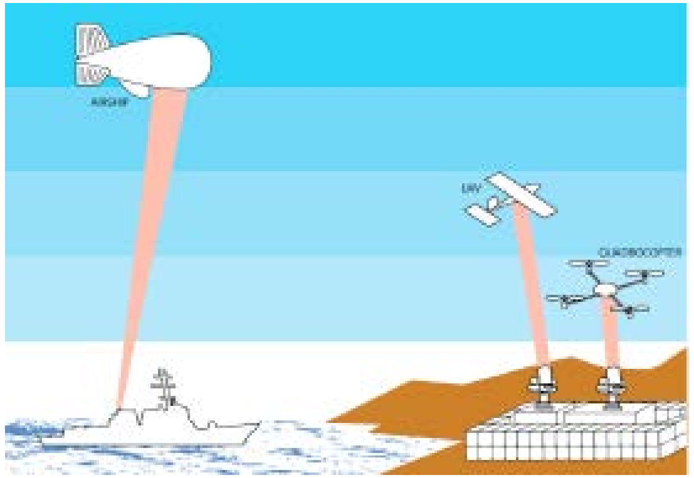
- Quiet power generation from a nuclear reactor
- Hypersonic aircraft

Space Fission

- Surface power for Moon and Mars (NASA concept)

Laser Power Beaming Applications

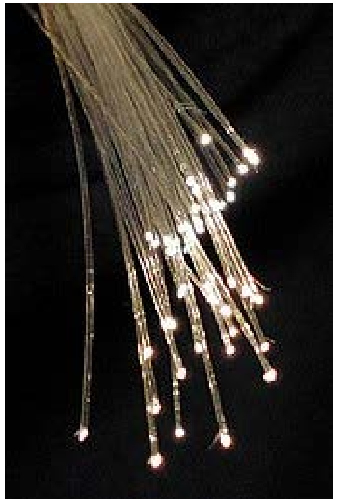
Remote Sensors



UAVs or Drones

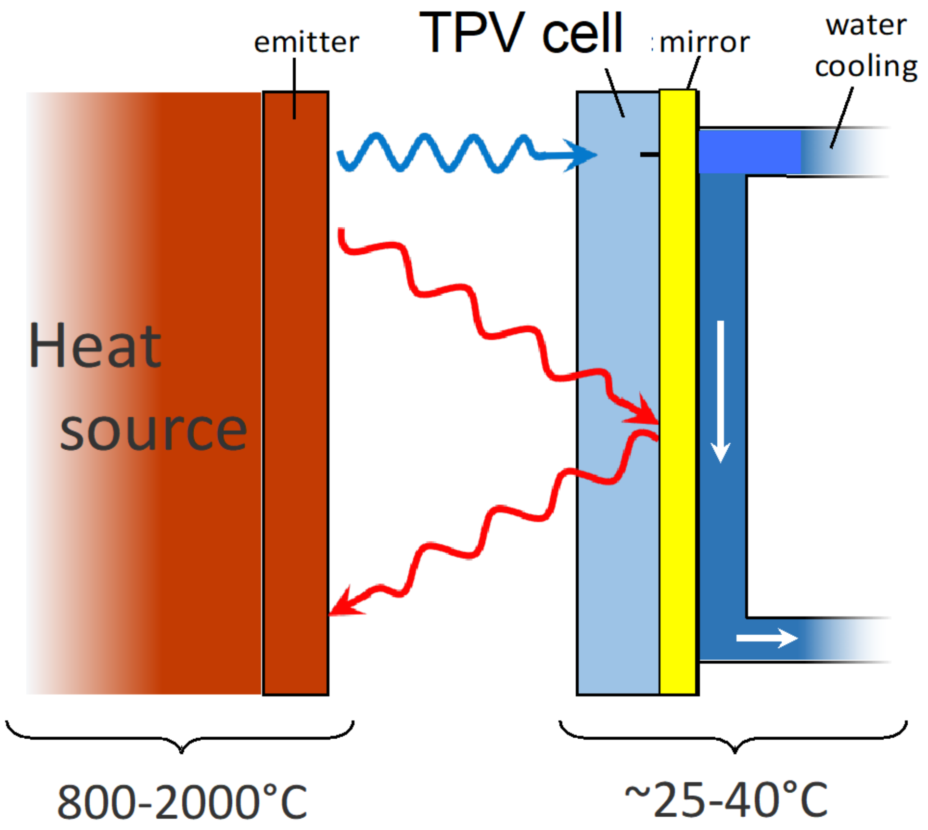
Tethered Underwater Vehicles

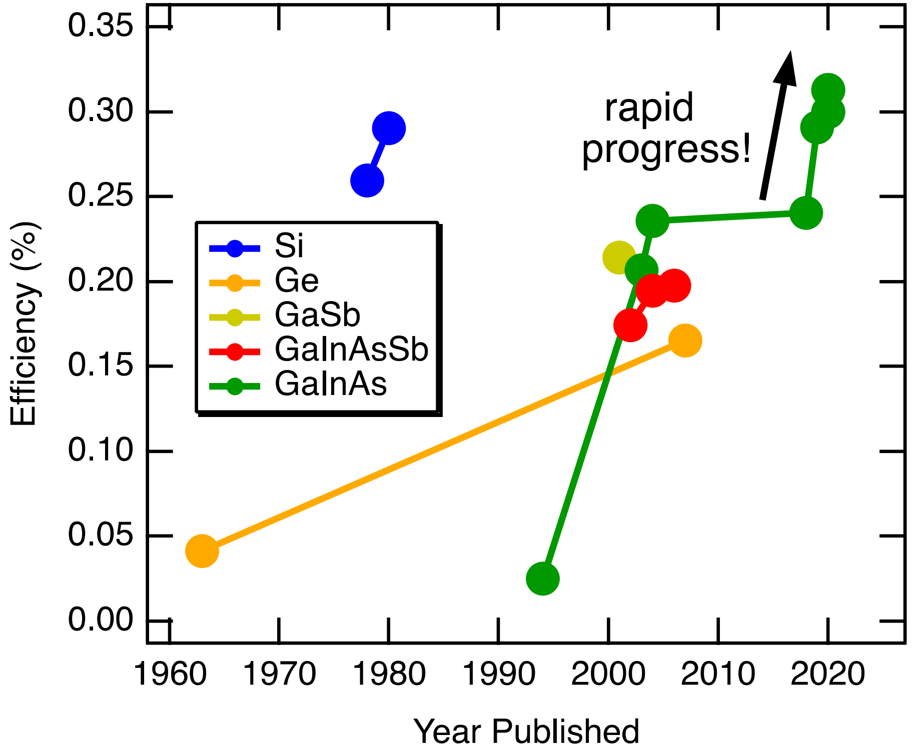
Powering
Distributed
Components



Fiber Optical Power
For Electrical Isolation

Modern III-V PVs Enable High TPV Efficiency

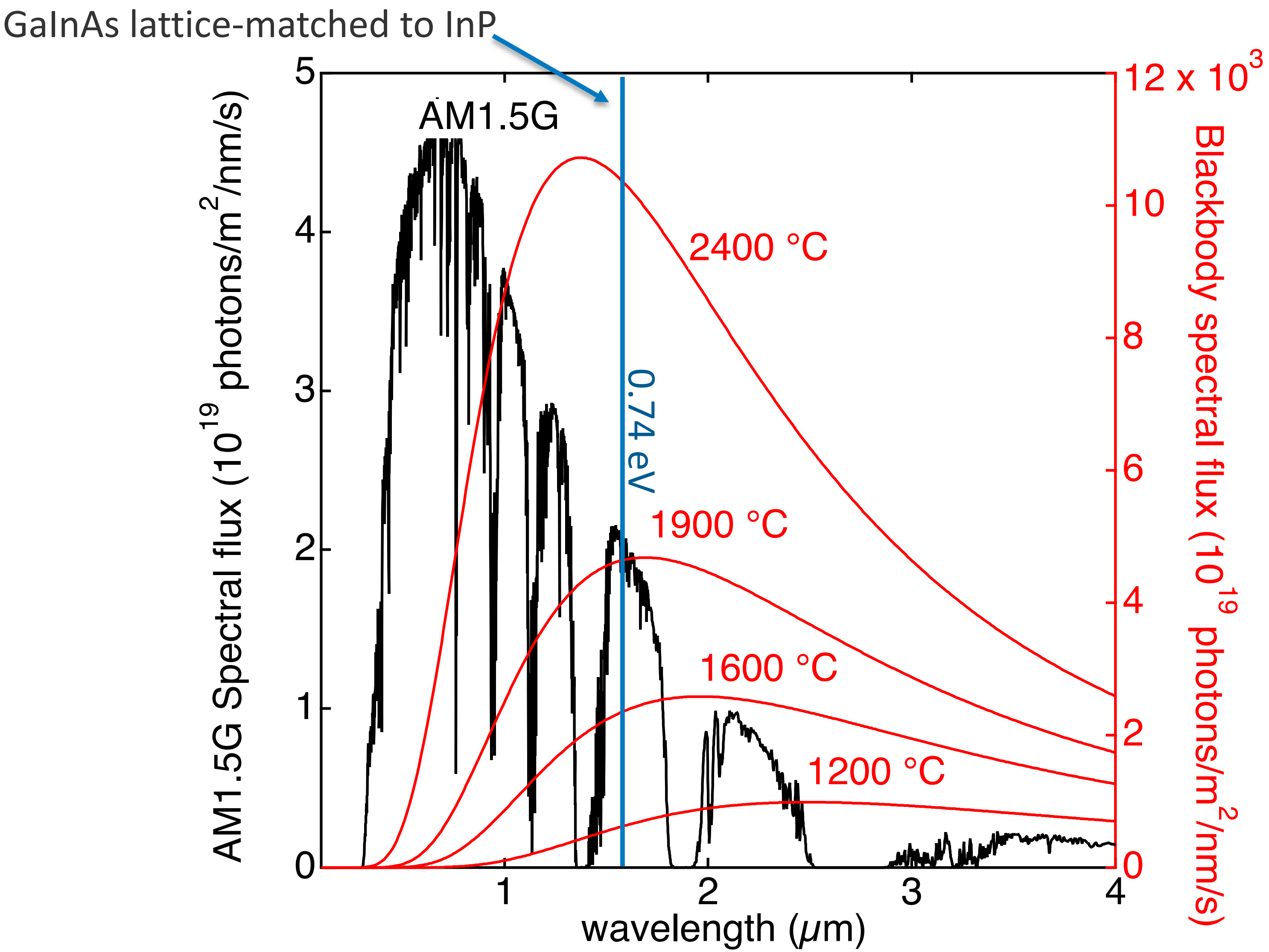




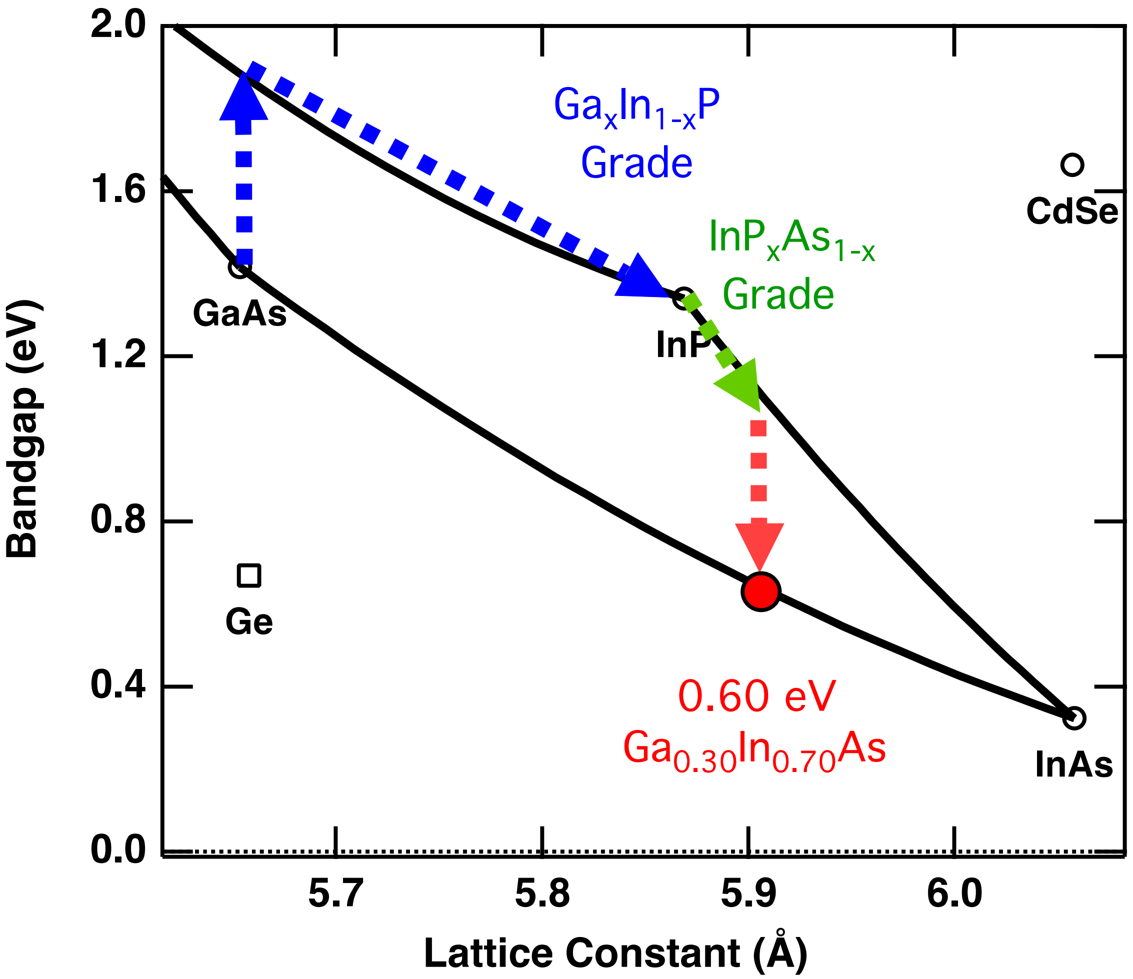
adapted from Burger et al, *Joule* **4**(8), 1660-1680 (2020).

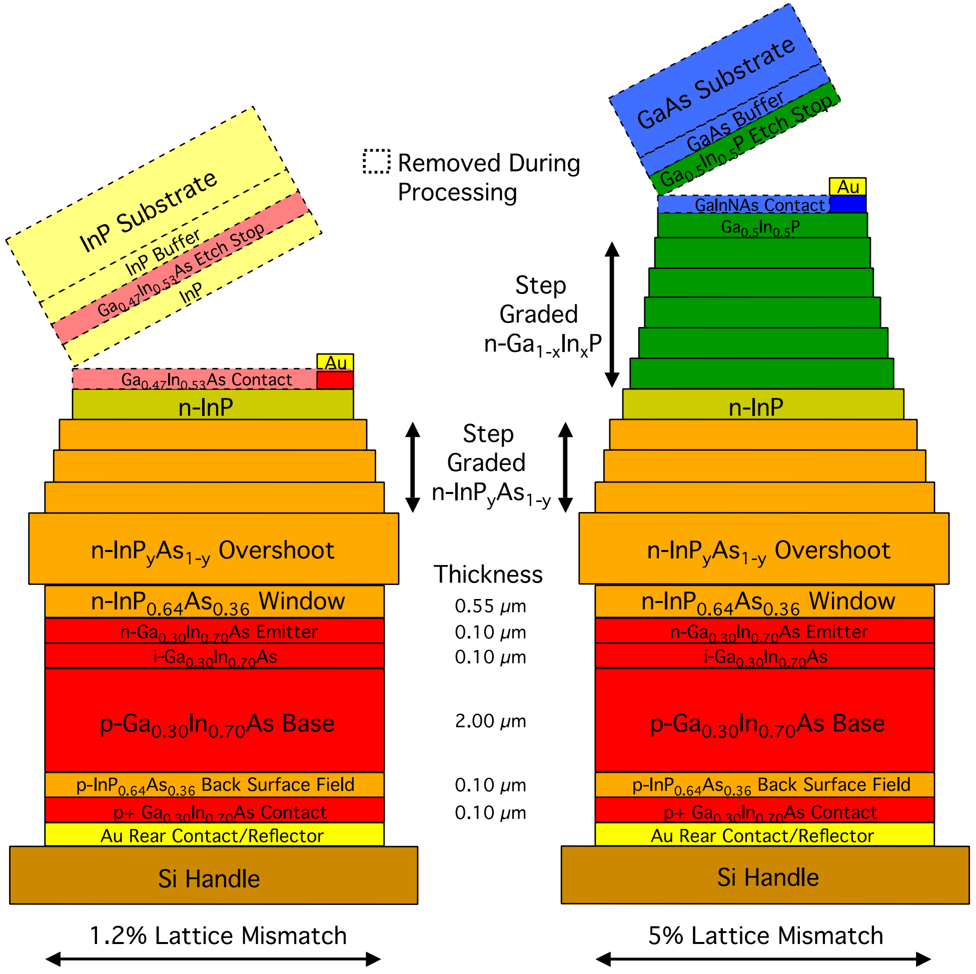
$$\text{TPV Efficiency} = \frac{\text{Power Output}}{\text{Power Incident} - \text{Power Reflected}}$$

Lower Bandgaps Necessary to capture Lower Temperature Radiation



Extending Past InP Using InPAs Graded Buffers



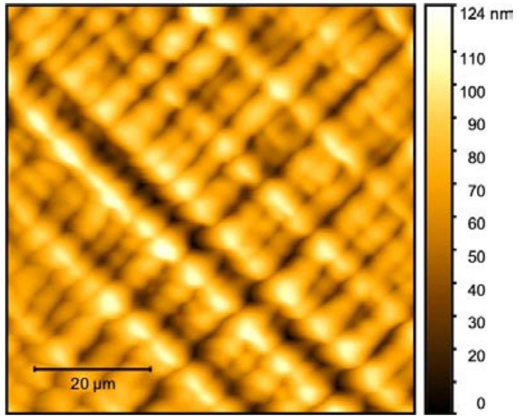


Growth on GaAs Potentially Cheaper

Phosphide Grades on InP vs. GaAs

On InP Substrate – 1.2% Lattice Mismatch

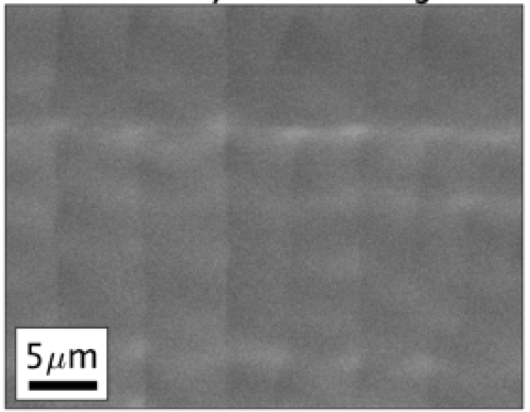
AFM Image



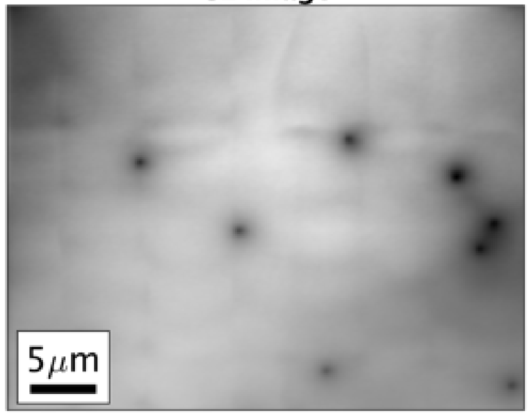
MU829

RMS = 18.5 nm

Secondary Electron Image



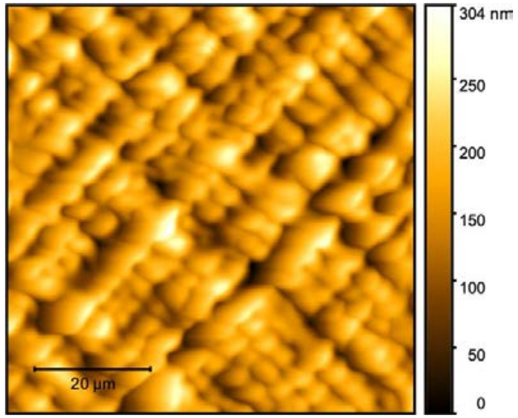
CL Image



TDD = 1.3±0.6 x 10^6 cm^{-2}

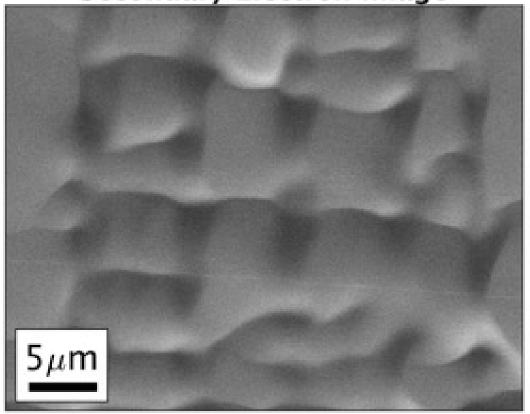
On GaAs Substrate – 5% Lattice Mismatch

AFM Image

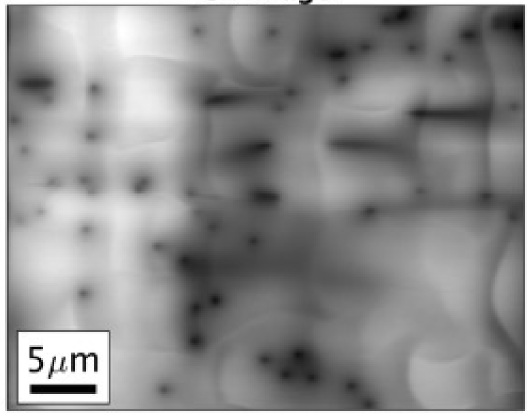


MU824

Secondary Electron Image



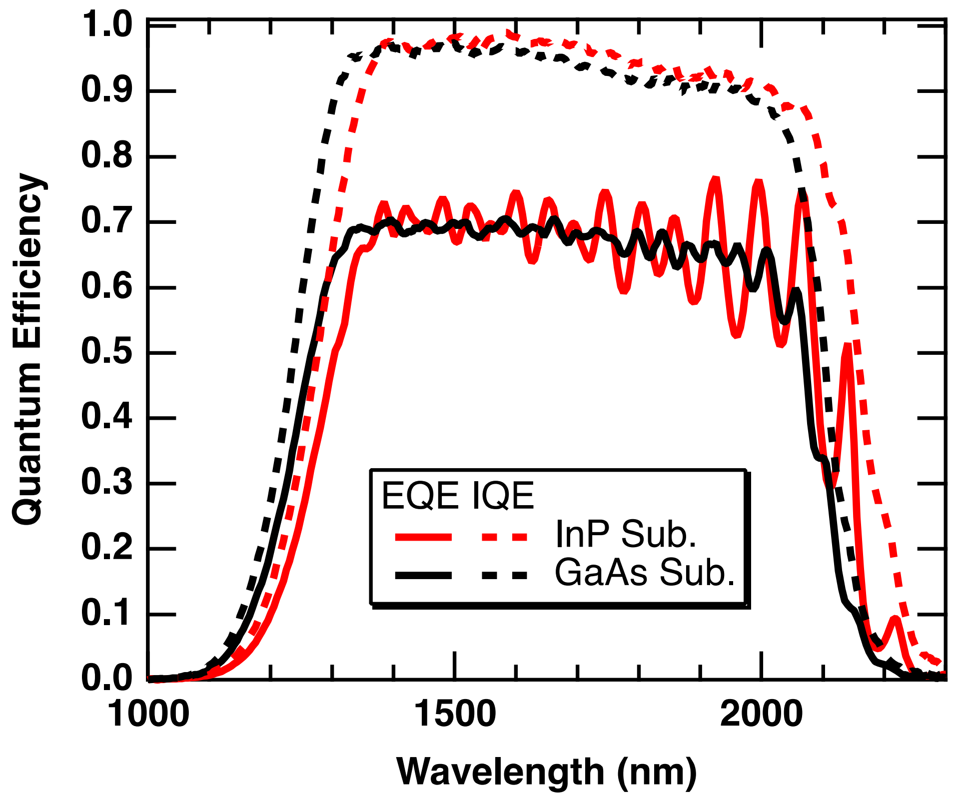
CL Image

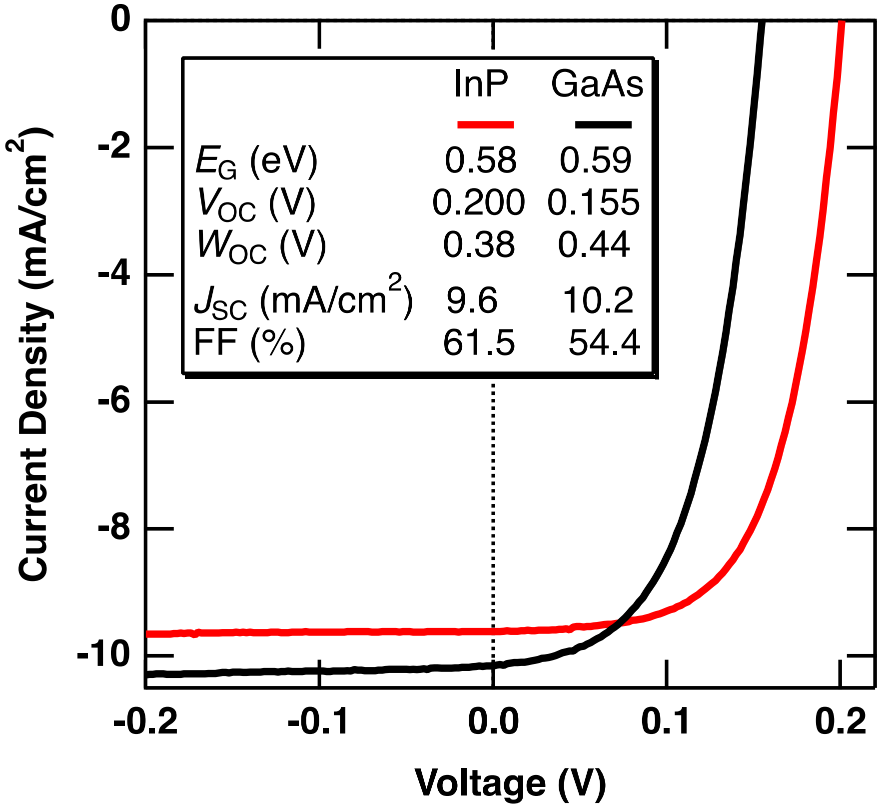


TDD = 8.9±1.7 x 10^6 cm^{-2}

Schulte *et al.,* Adv. Energy Mat., 2303367 (2024)

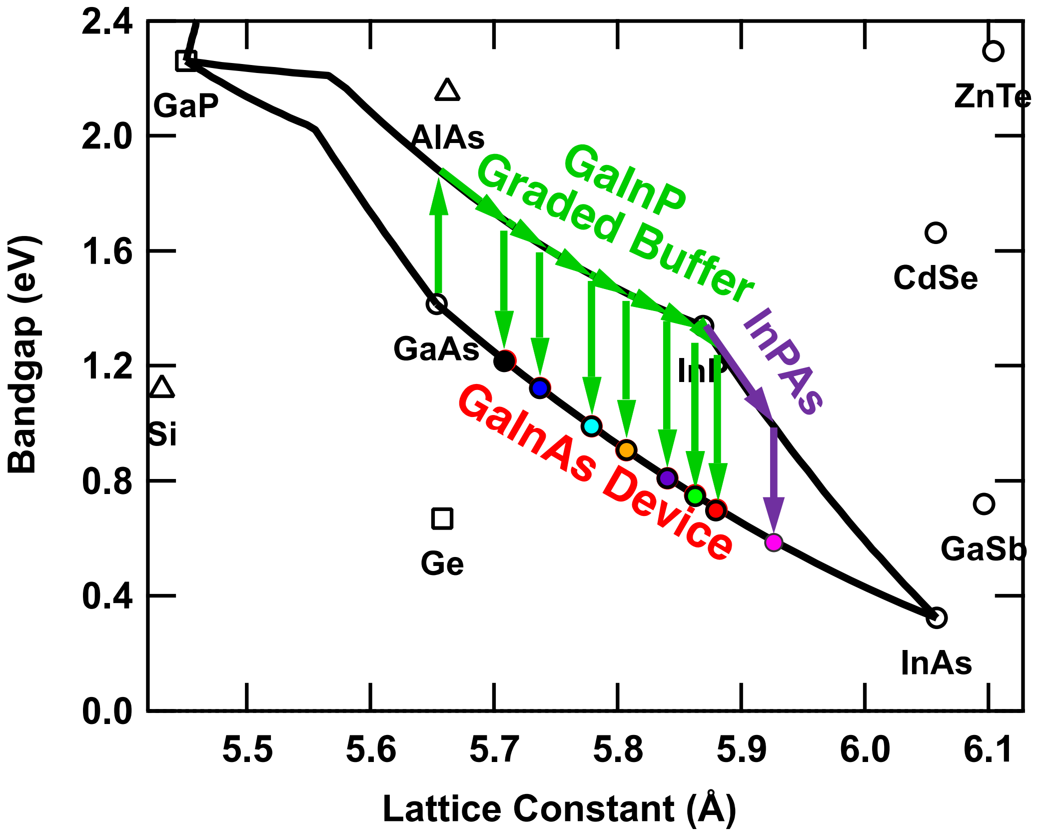
One-Sun Data



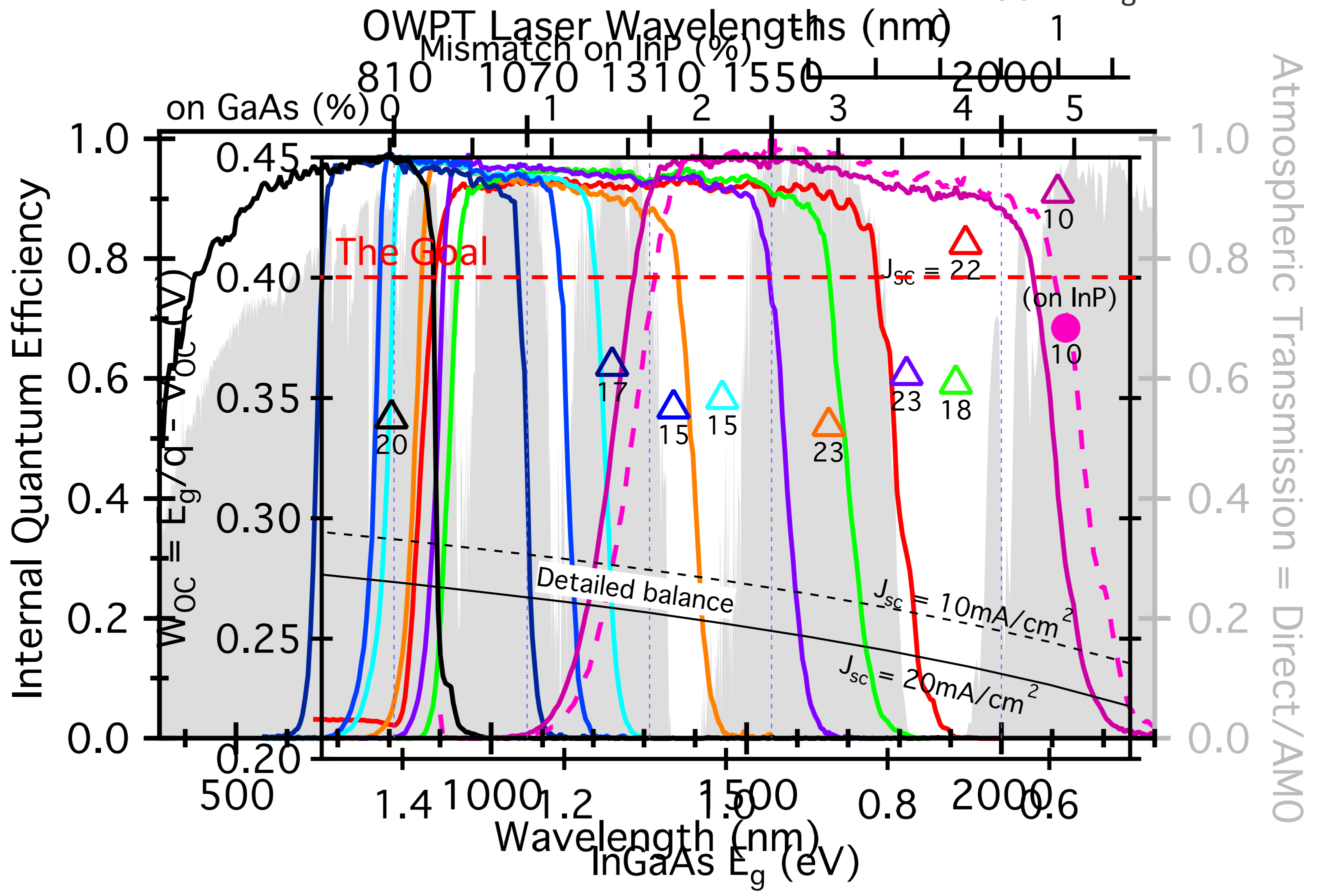


Schulte *et al.*, Adv. Energy Mat., 2303367 (2024)

Spanning a Wide Range with GaInAs

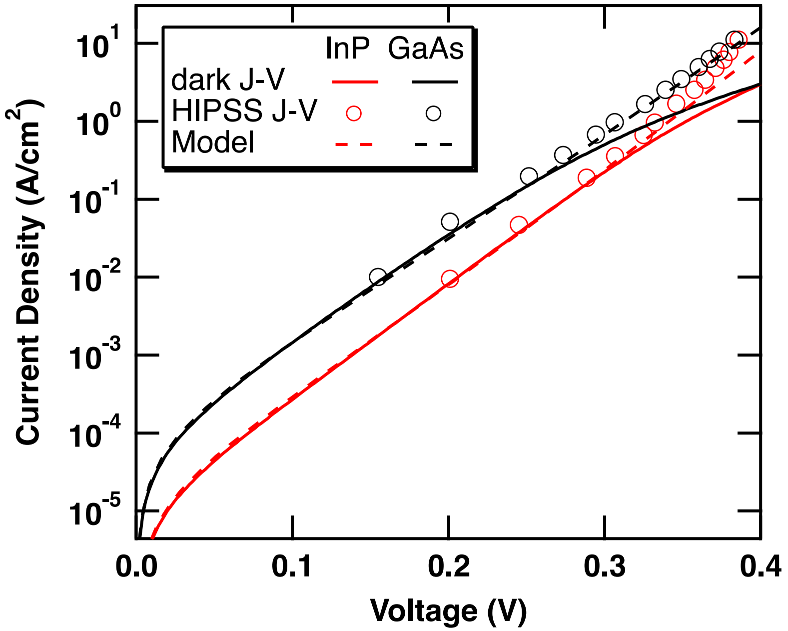


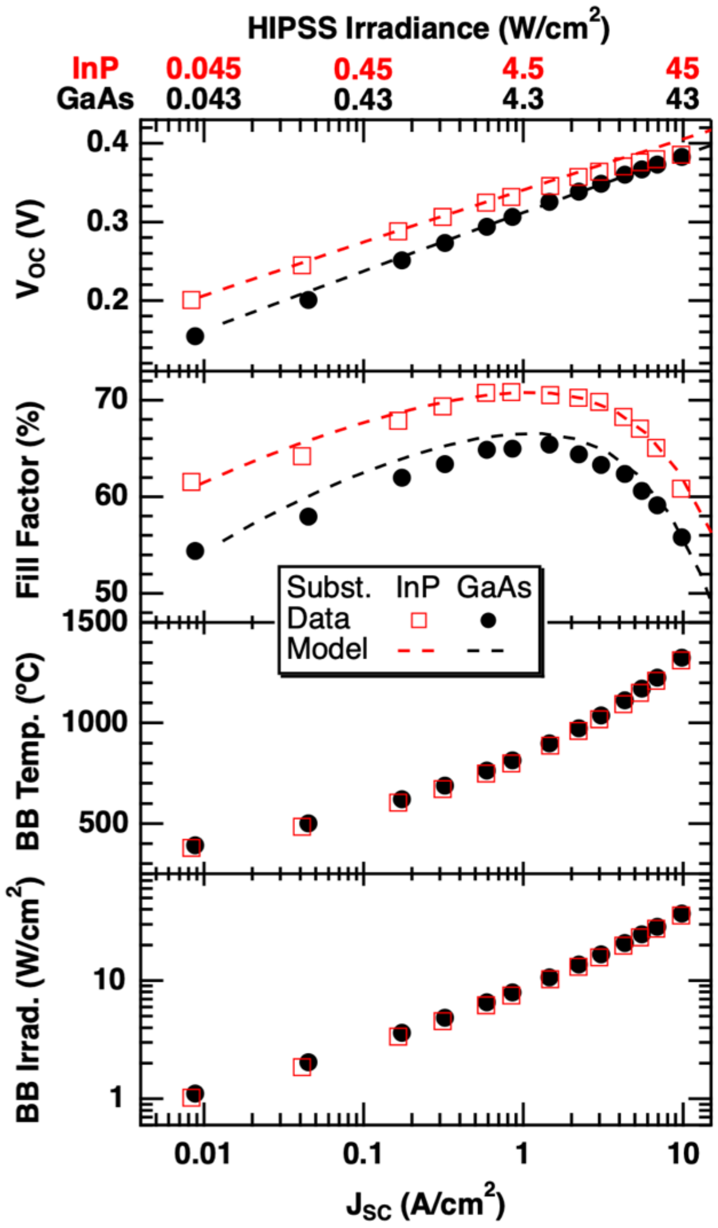
Quality: How close can we get the V_{OC} to E_g?



(For a given current density)

White Light High-Concentration Measurements



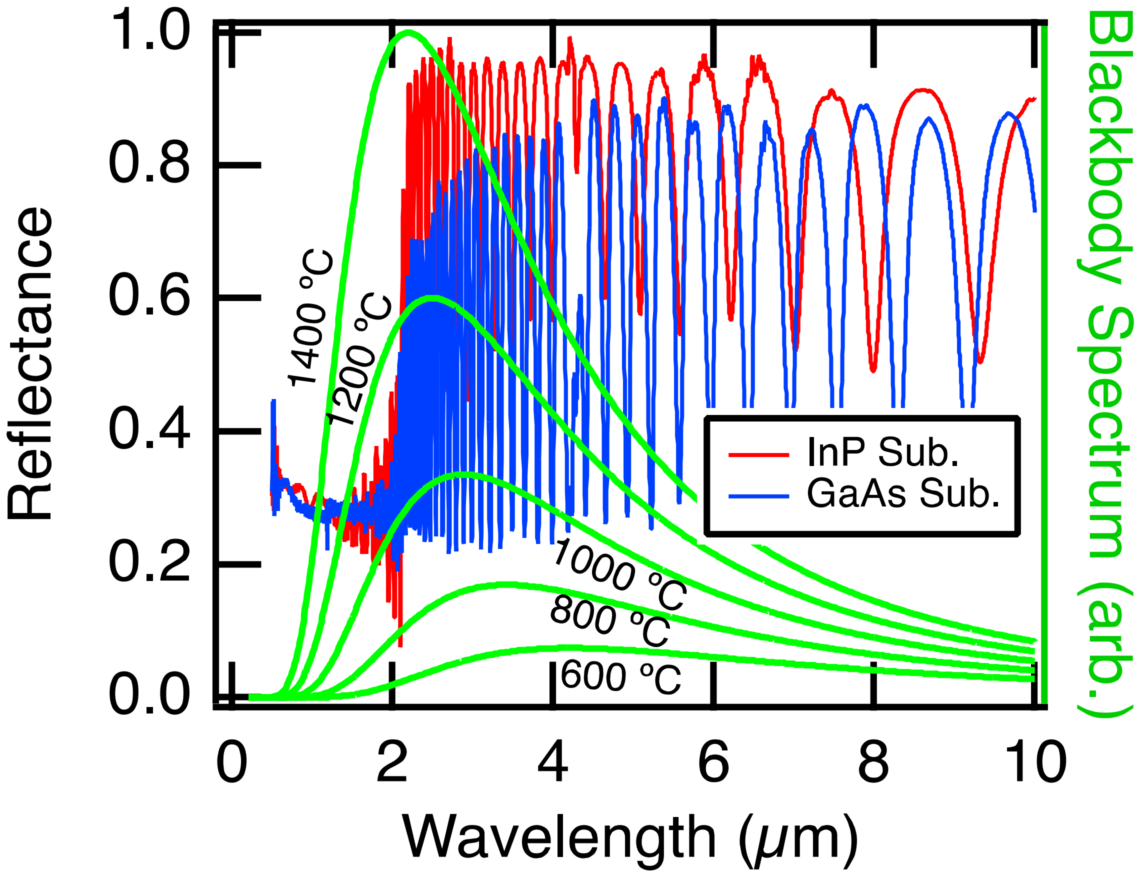


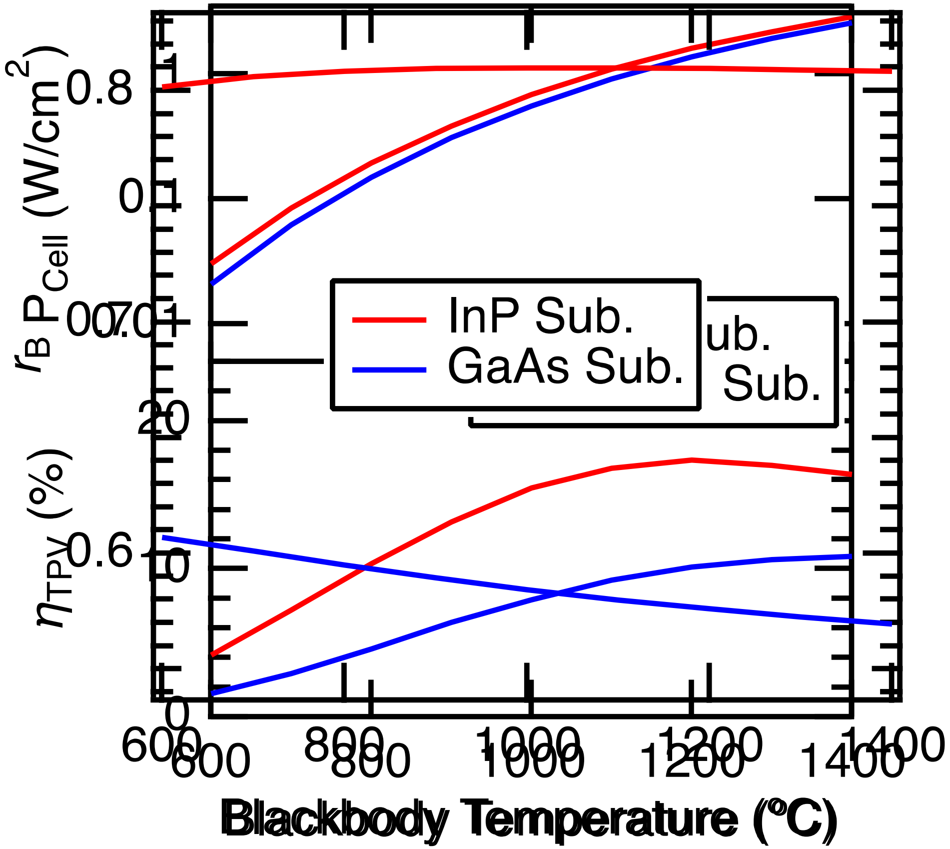
Model Fit Parameters

	InP-based	GaAs-based
J_{01} (A cm^{-2})	8.4x10^{-07}	7.3x 10^{-07}
J_{0n} (A cm^{-2})	1.1x10^{-05}	7.5x10^{-05}
n	1.3	1.3
R_S (mΩ cm^2)	6.9	8.5

Schulte *et al.*, Adv. Energy Mat., 2303367 (2024)

Reflectivity and Estimated TPV Efficiency

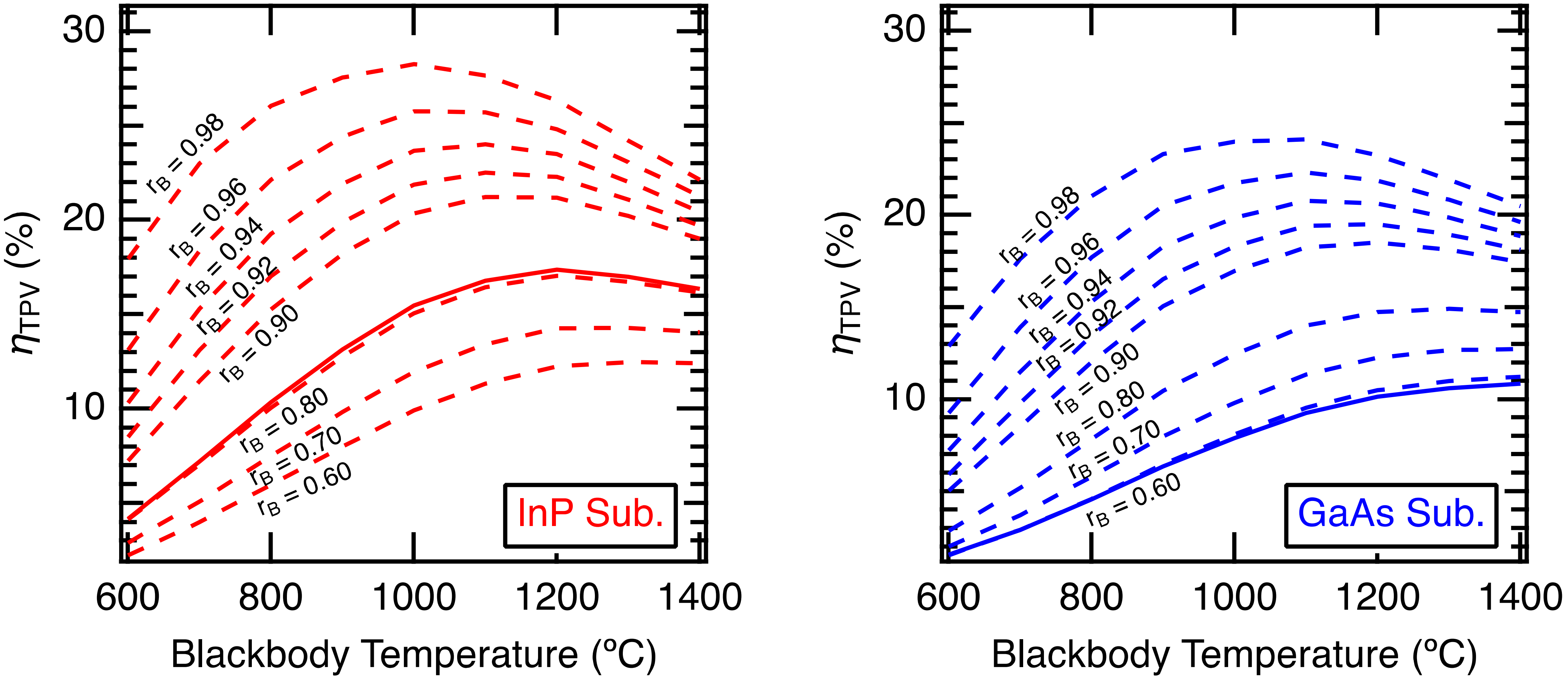




$$\text{TPV Efficiency} = \frac{\text{Power Out}}{\text{Power In} - \text{Power Reflected}}$$

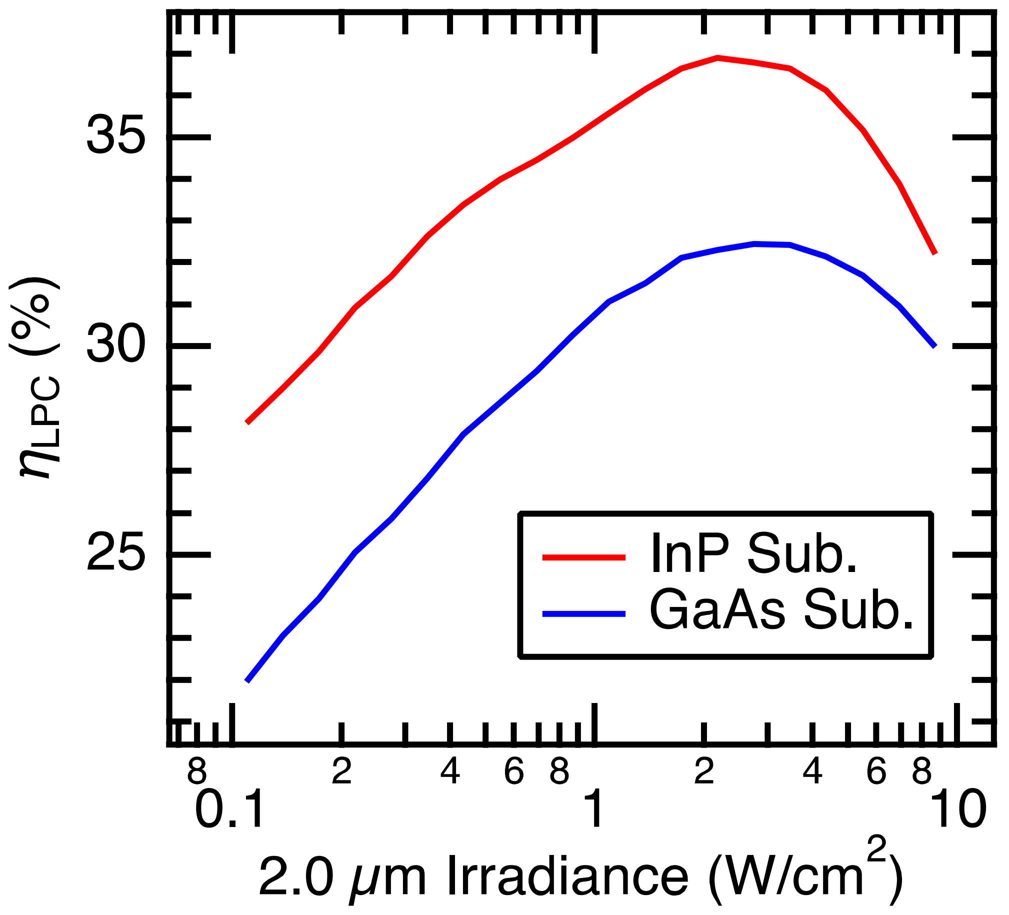
Schulte *et al.,* Adv. Energy Mat., 2303367 (2024)

Improved Sub-bandgap Reflectance Increases TPV Efficiency



Schulte *et al.,* Adv. Energy Mat., 2303367 (2024)

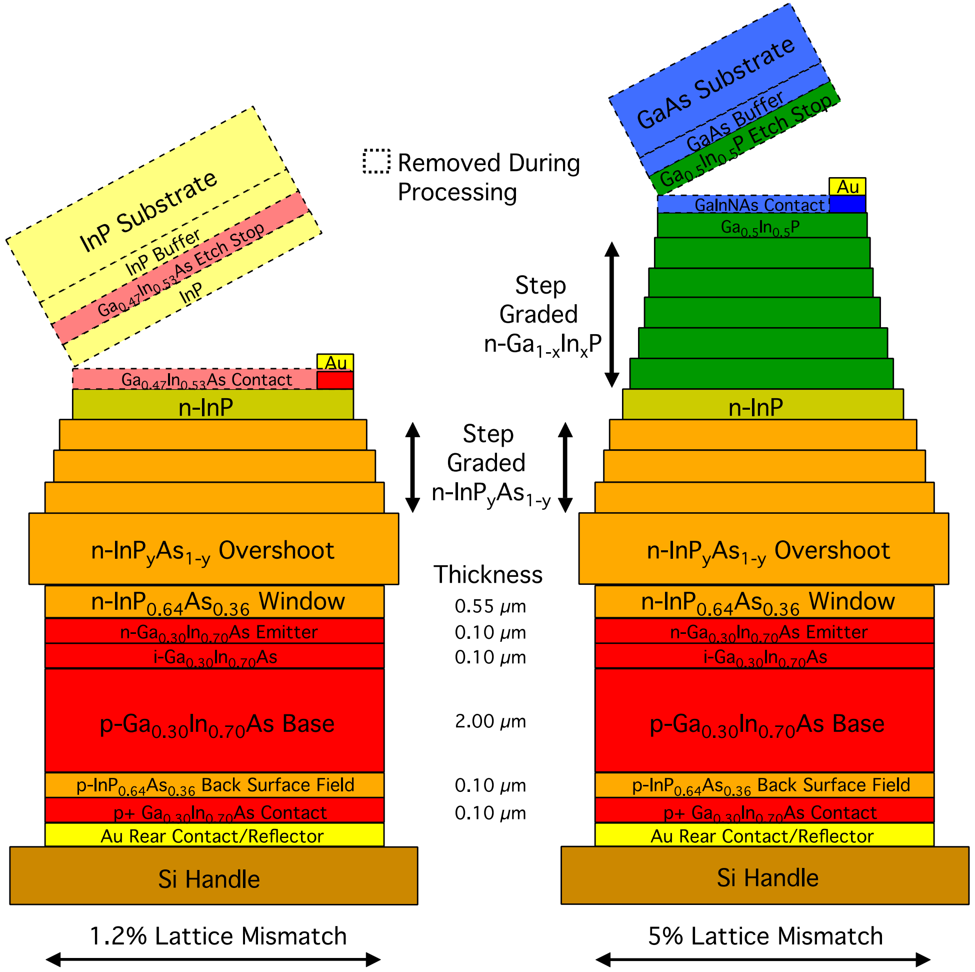
Estimated Laser Power Converter Performance



- Assumptions: no device heating, monochromatic light, 90% IQE

Conclusions

- Developed inverted metamorphic ~0.60 eV $Ga_{0.3}In_{0.7}As$ photovoltaic converters on InP ***and*** GaAs substrates.
- The device grown on GaAs exhibits a higher threading dislocation density, yet the devices yield comparable V_{OC} above 0.38 V under high irradiance.
- Estimated TPV efficiencies of 16.8 vs. 9.2% at 1100 °C; improvement of sub-bandgap key to efficiency improvement
- We estimate peak efficiencies of 36.8% and 32.5% for irradiation from an idealized 2.0 µm source.



Acknowledgements

kevin.schulte@nrel.gov

www.nrel.gov

NREL III-V Team

NREL Technicians
- Michelle Young
- Sarah Collins

This work was authored [in part] by the National Renewable Energy Laboratory (NREL), operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. This work was supported by the Laboratory Directed Research and Development (LDRD) Program at NREL. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL/PR-5900-88656