Record Efficiency InGaAs Thermophotovoltaic Cells For Energy Storage Applications

Myles Steiner, Eric Tervo, Ryan France, Cecilia Luciano, Dustin Nizamian, Benjamin Johnson, Alexandra Young, Leah Kuritzky, Emmett Perl, Moritz Limpinsel, Brendan Kayes, Tarun Narayan, Madhan Arulanandam, Richard King, Andrew Ponec, David Bierman, Justin Briggs

CPV-18 / TPV-13

April 26, 2022

Photo by Dennis Schroeder, NREL 55200

Thermal energy storage of excess grid electricity

when demand and price are *low*:

electricity in

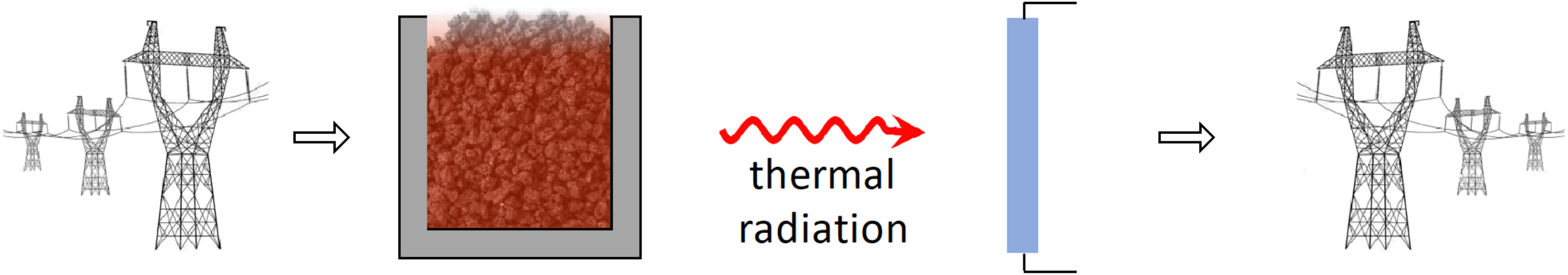
Long-duration

thermal storage

thermophotovoltaics

when demand and price are *high*:

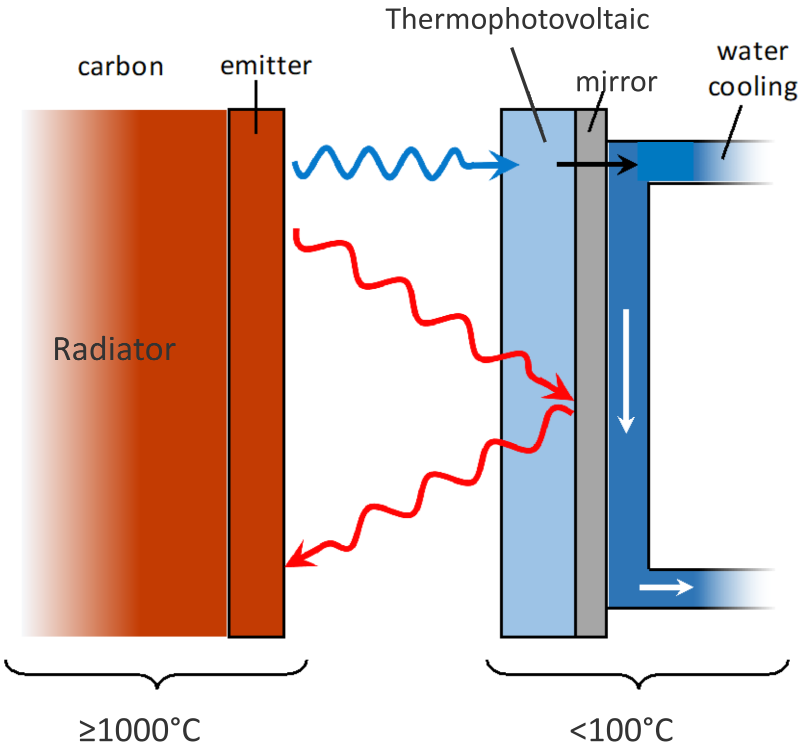
electricity out



≥ 1000°C
Low loss if well-insulated

< 100 °C
High efficiency with good recycling

Thermal energy storage of excess grid electricity



High semiconductor material quality

Optimized diode device architecture

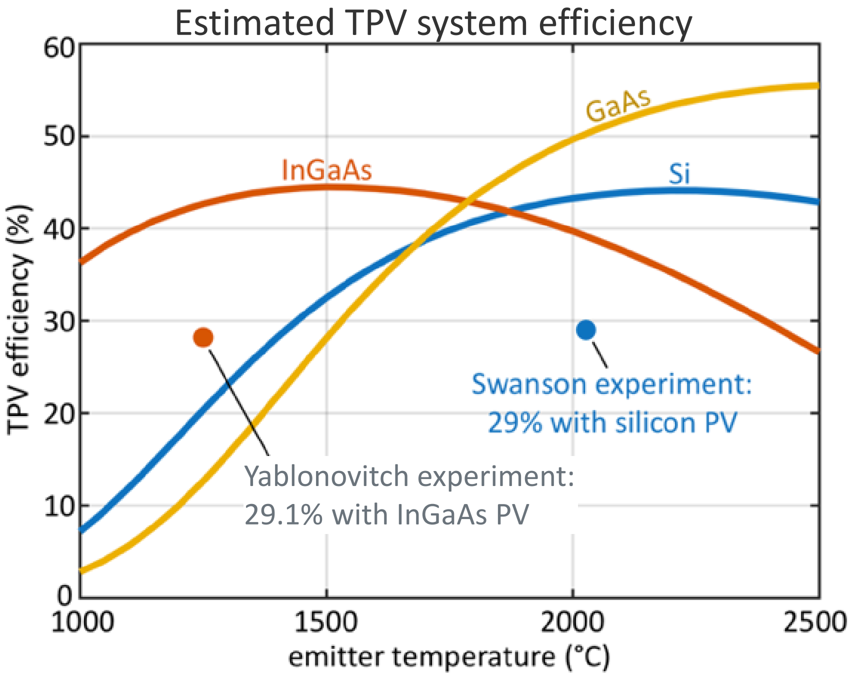
$$\text{TPV Efficiency} = \frac{\text{Power Output}}{\text{Power Incident} - \text{Power Reflected}}$$

Emitter temperature

High reflectance of the back mirror

Low parasitic absorption in the semiconductor

Thermophotovoltaic efficiency



Higher incident power density

More materials and system complexity

High semiconductor material quality

Optimized diode device architecture

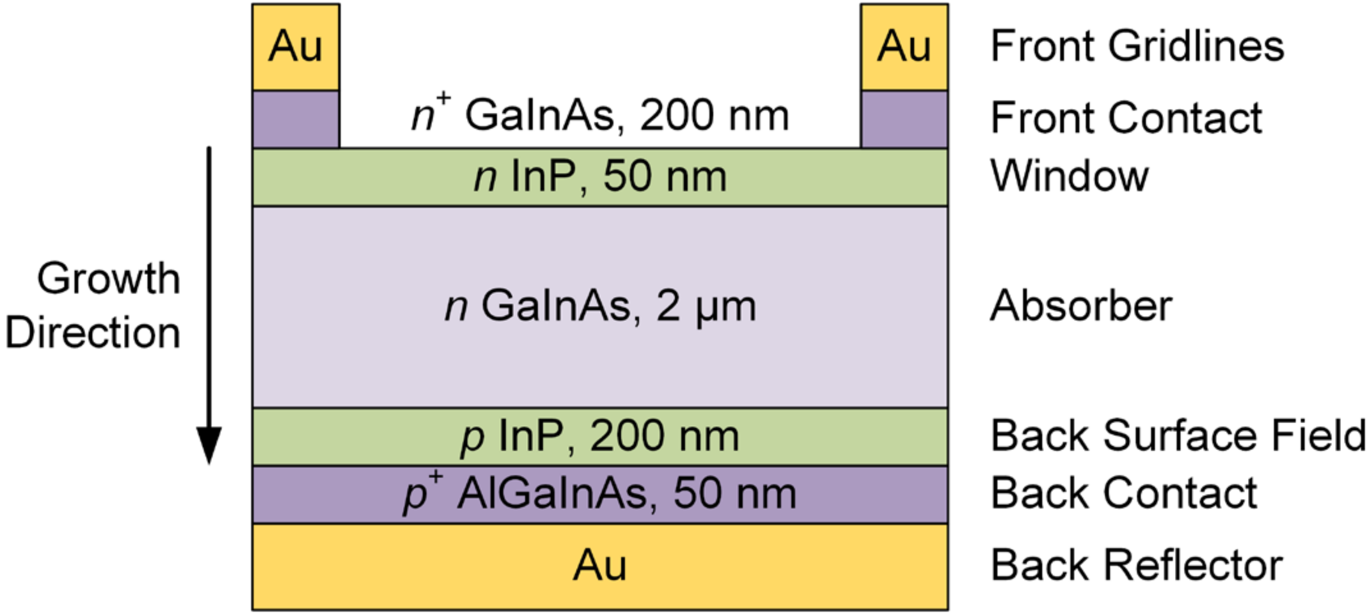
$$\text{TPV Efficiency} = \frac{\text{Power Output}}{\text{Power Incident} - \text{Power Reflected}}$$

Emitter temperature

High reflectance of the back mirror

Low parasitic absorption in the semiconductor

Rear heterojunction architecture with a thick n-type absorber



Grids 10 µm x ~6 µm tall, spaced ~50-200 µm apart

R_{sheet} ~ 30-60 Ω/sqr

All dimensions are nominal.

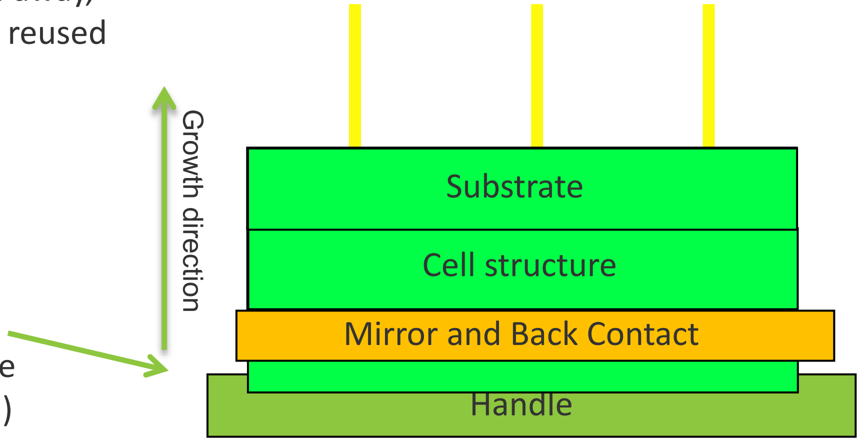
Inverted TPV devices

Inverted growth gives easy access to the device backside for applying advanced contacts
→ Enables a range of device designs

InP substrate can be etched away, or potentially removed and reused

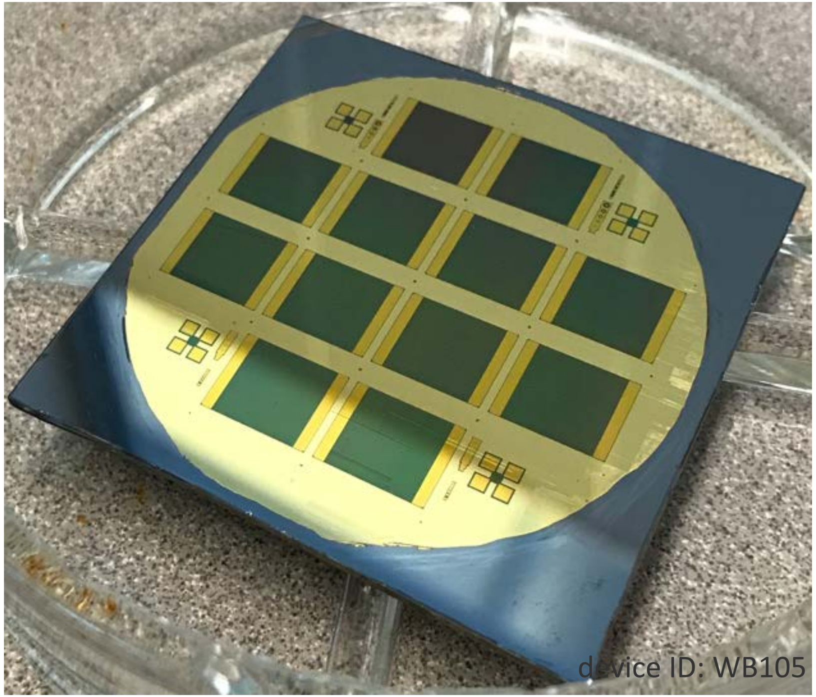
Handle can be:

- silicon or glass
- something flexible
- another solar cell (if the back contact is gridded)

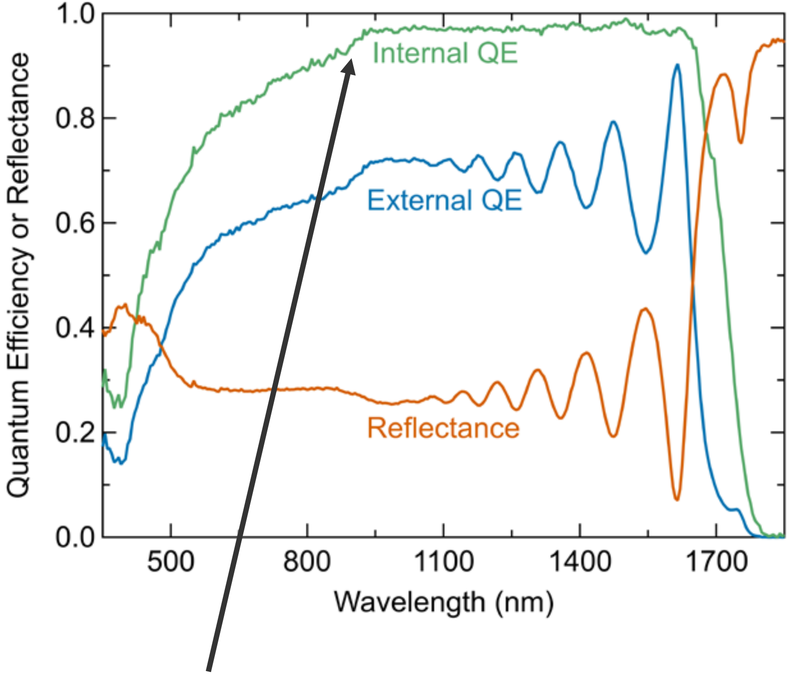


Large area TPV cells

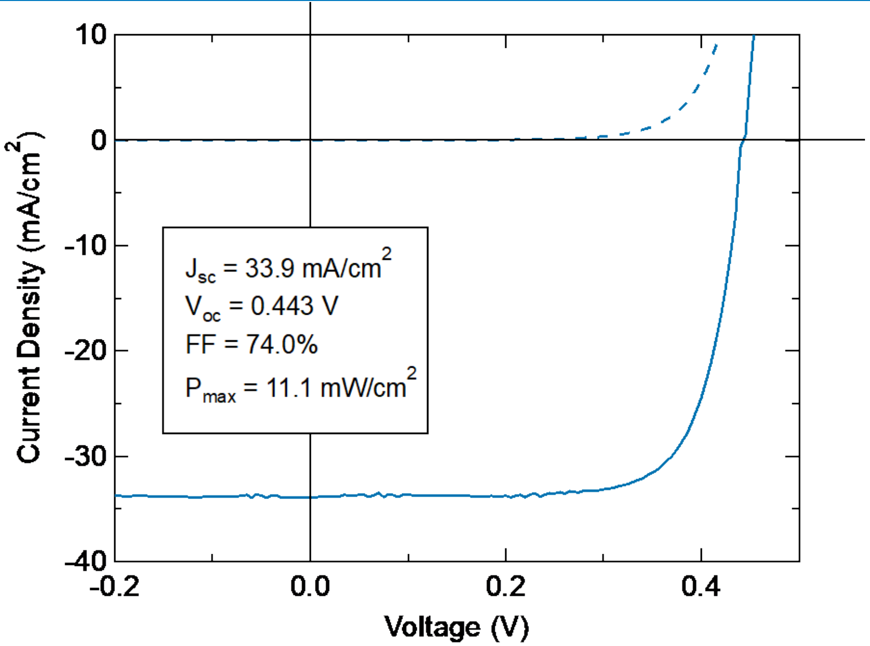
- Growth and fabrication on a 2” reactor at NREL yields 12 TPV cells
- Each cell has an illuminated area of 0.64 cm^2
- Individual cells can be cleaved or diced from the wafer after fabrication
- Back metal thickness is ~2.5 μm and front grids are > 5 μm tall, for decreased series resistance



“One-sun” characteristics



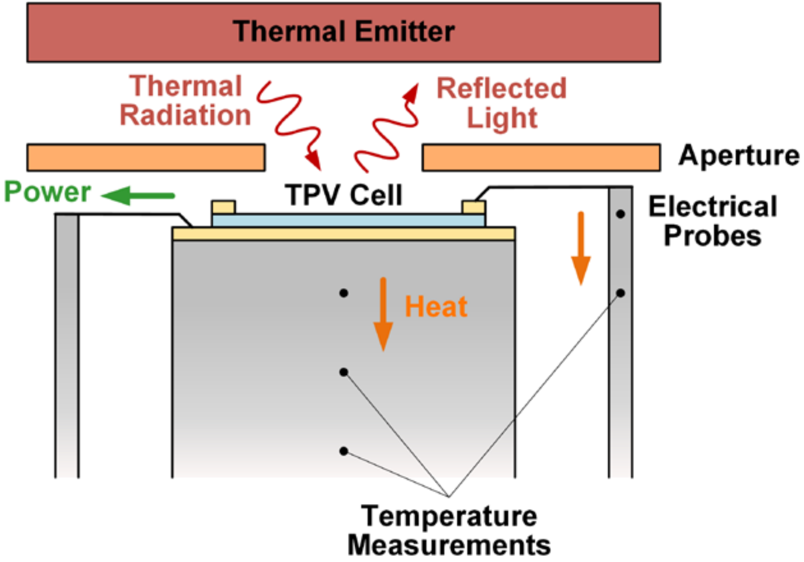
Excellent collection efficiency



Woc = Eg/q – Voc = 0.304 V
(at 1000 W/m^2)

We estimate the internal luminescent efficiency to be ≥ 98%

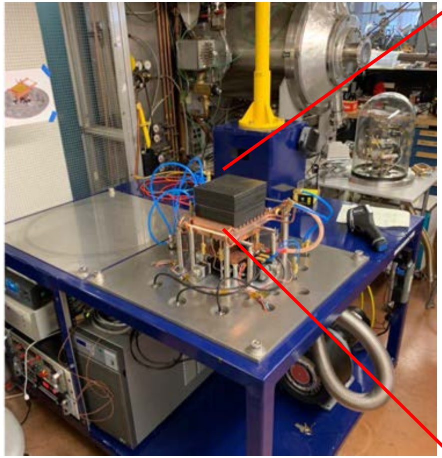
TPV measurements at Antora Energy

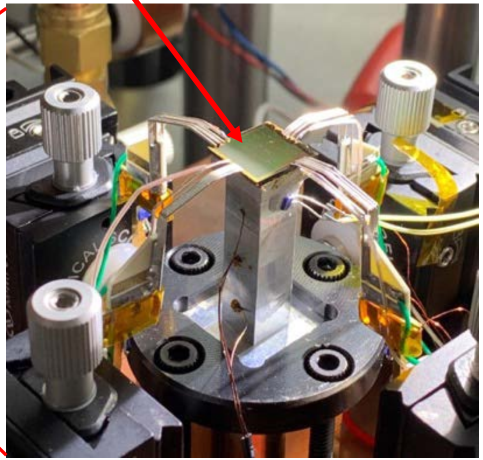


$$\text{TPV Efficiency} = \frac{\text{Power Out}}{\text{Power Out + Heat Absorbed}}$$

TPV “V2” test bed

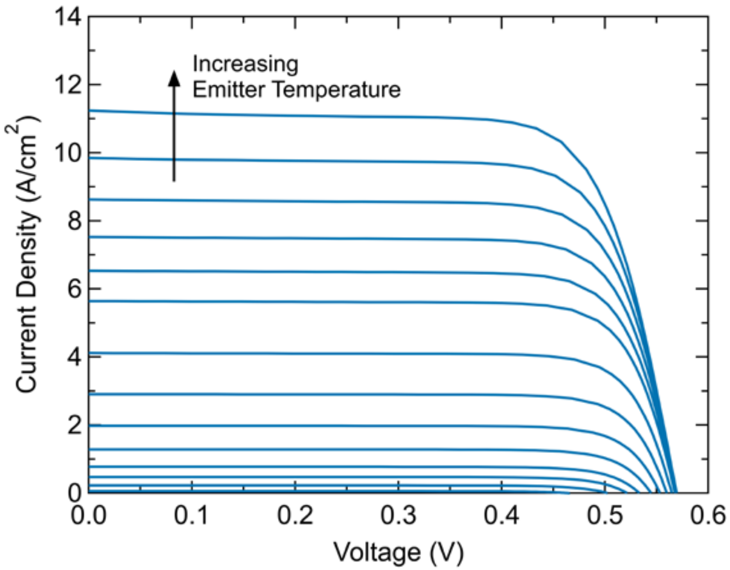
InGaAs cell

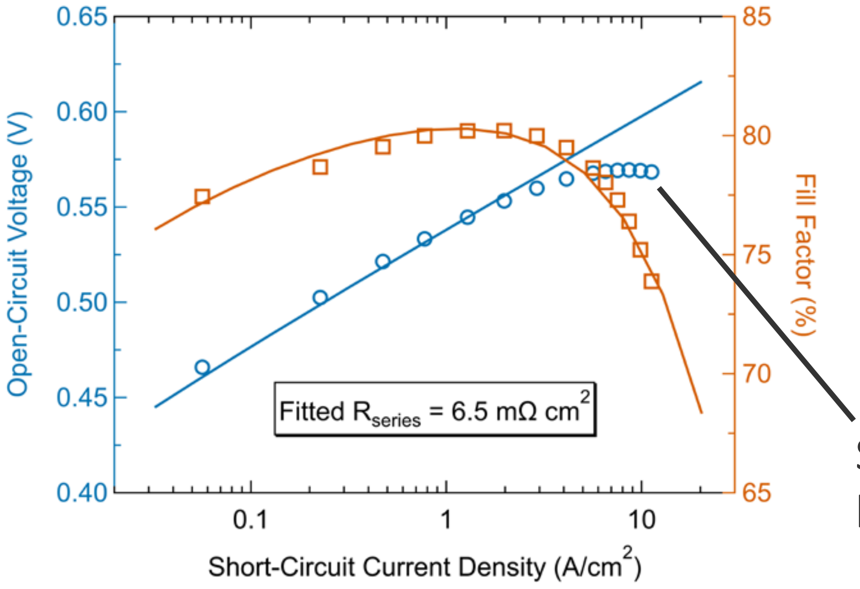




Contact the cell on all four sides, to control series resistance.

High intensity performance metrics





Some sample heating

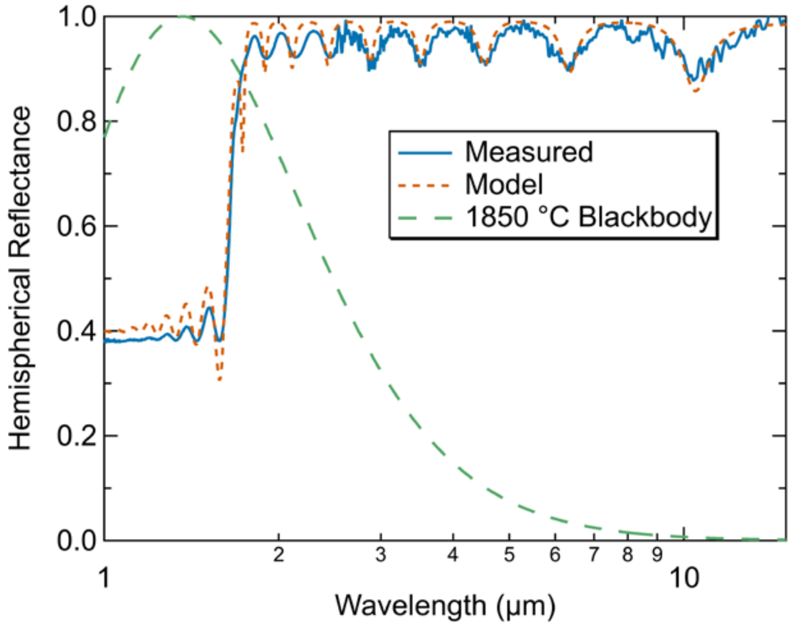
Equivalent of ~330 suns relative to 1000 W/m^2

Modeled after J. Geisz *et al.*, Journal of Photovoltaics, **5**, 1827 (2015).

Manuscript in preparation

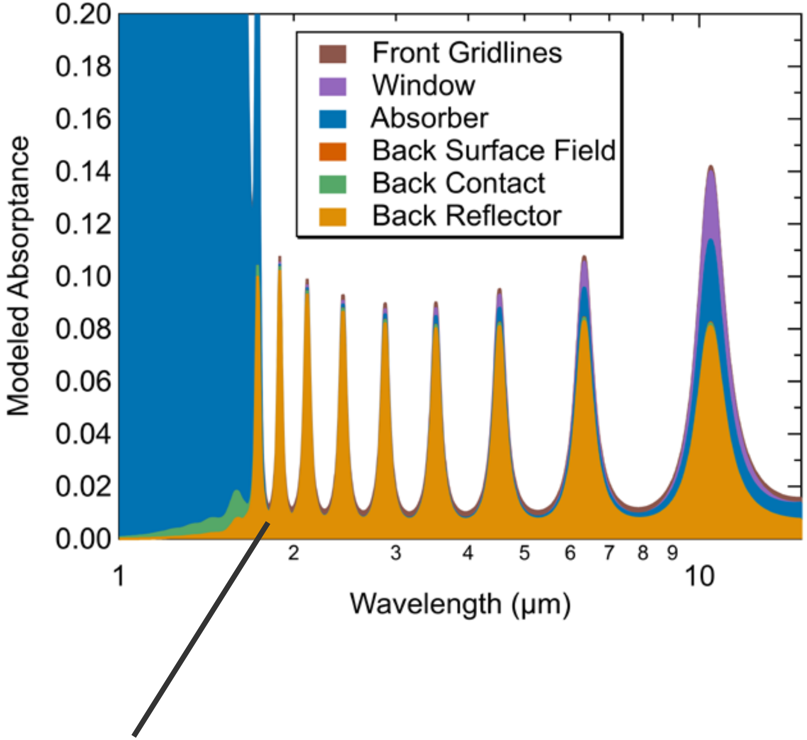
Absorption losses

FTIR measurement and model



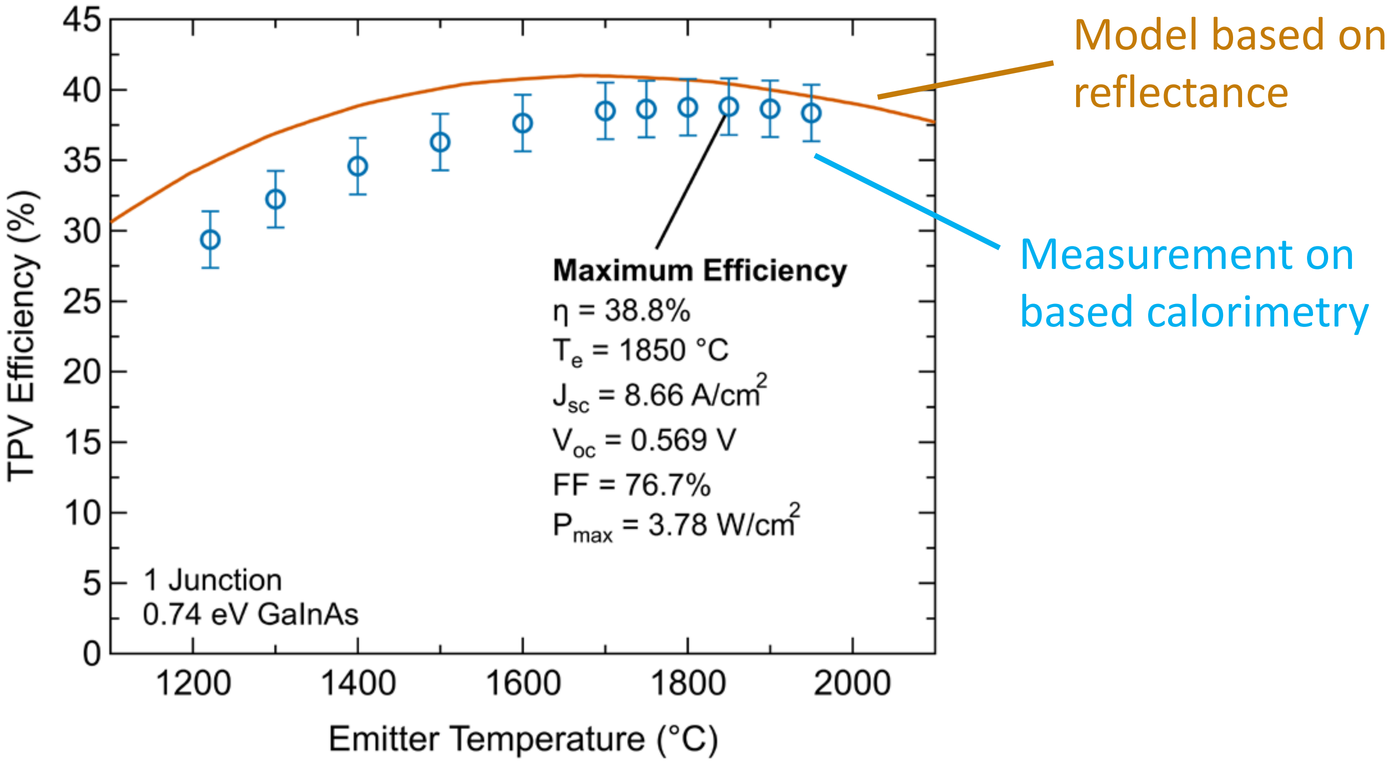
1850°C weighted reflectance = 94.7%

Optical model including Drude FCA

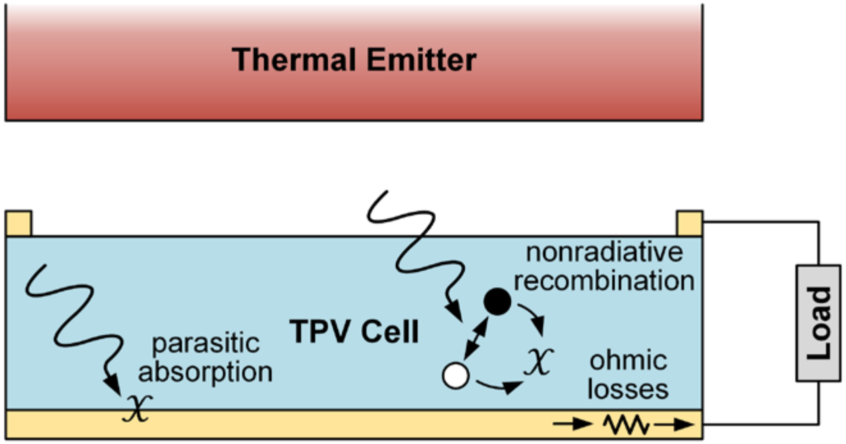


Gold back reflector dominates the parasitic absorption

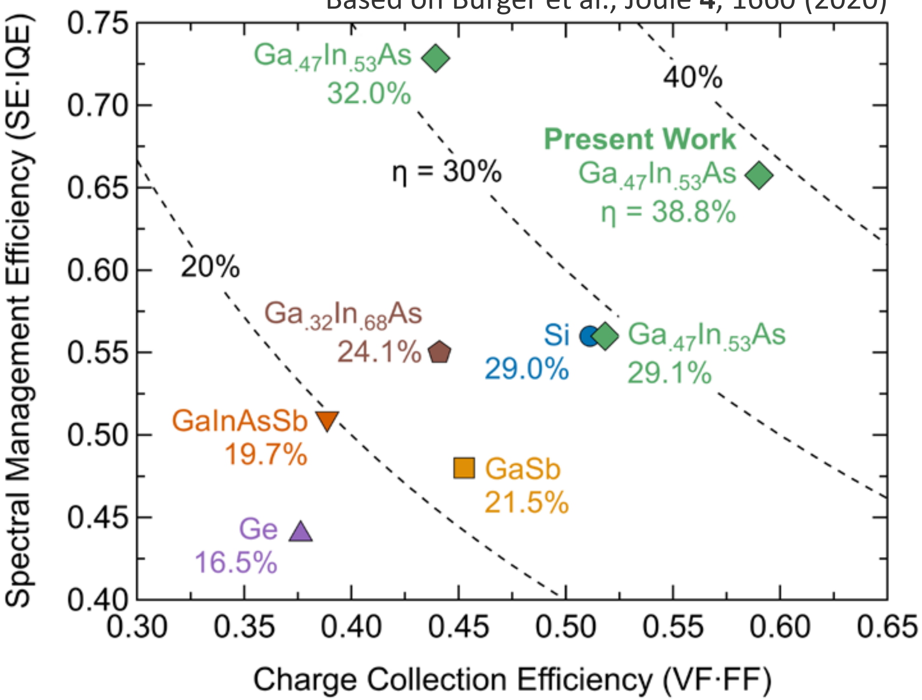
TPV efficiency



Considering the different losses…



Based on Burger et al., Joule **4**, 1660 (2020)

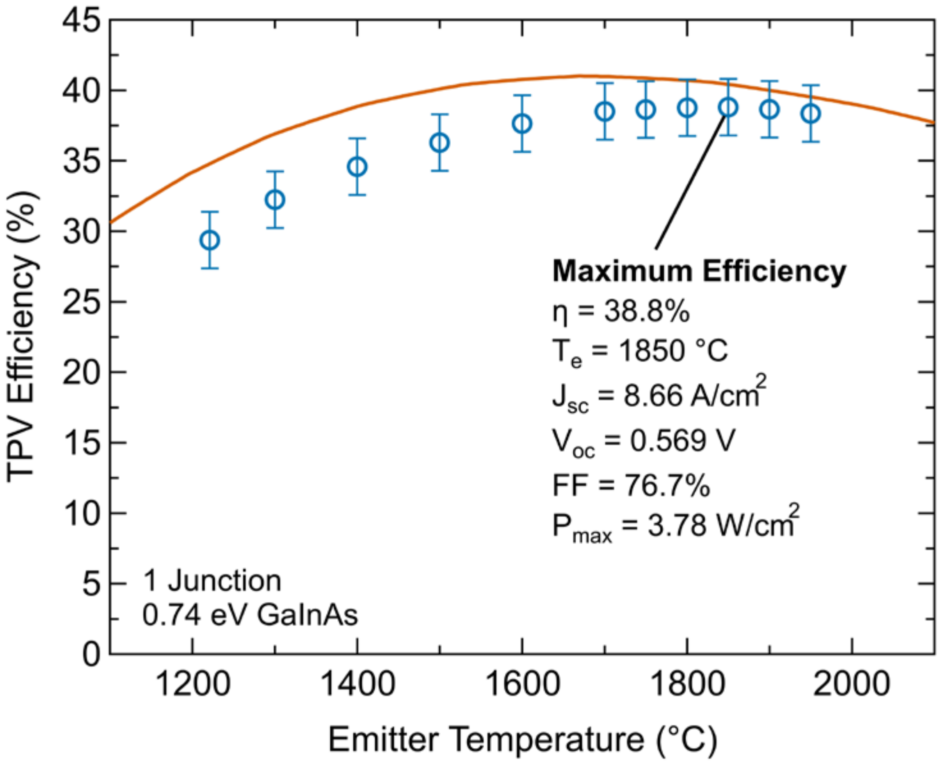


$$\eta_{TPV} = SE \times IQE \times VF \times FF$$

Charge collection = Voltage Factor x Fill Factor

Spectral management = Spectral Efficiency x Internal Quantum Efficiency

TPV efficiency



Pathways for improvement:

- Better reflector on the back
  - Silver mirror
  - Patterned dielectric mirror
- Lower bandgap absorber
- Tandem cell to lower current and reduce thermalization losses
  - GaInAsP/InGaAs

Thank you

www.nrel.gov

myles.steiner@nrel.gov

NREL/PR-5900-82094

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Advanced Research Projects Agency – Energy, and by Shell Gamechanger. 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 Transforming ENERGY