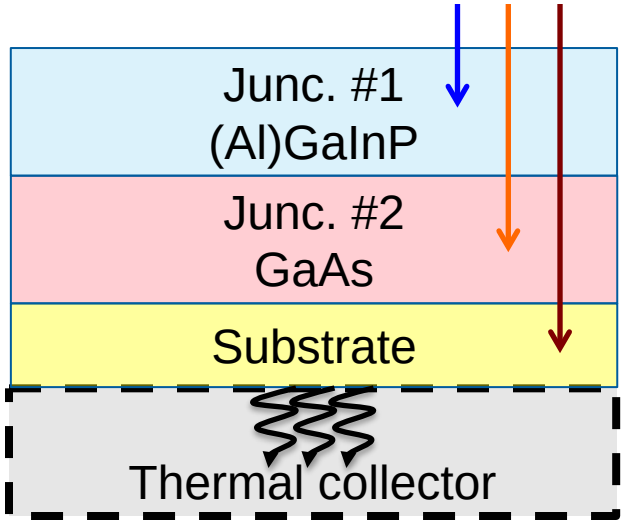
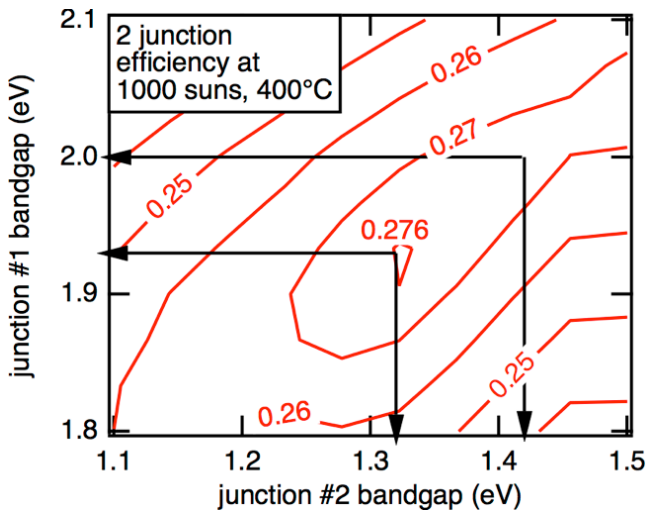
Minjoo Larry Lee, Yale University

Dual-junction solar cells for high efficiency at elevated temperature

What is the technology?

- ***A solar cell with efficiency exceeding 25% under high optical concentration at T > 400 °C***
  - *Cells designed from the ground up to be efficient at high temperature*
  - *Coatings, dopants, and contact metals with high robustness for long-time service at T>400°C*
  - *Reliability, failure modes, and high lifetime*





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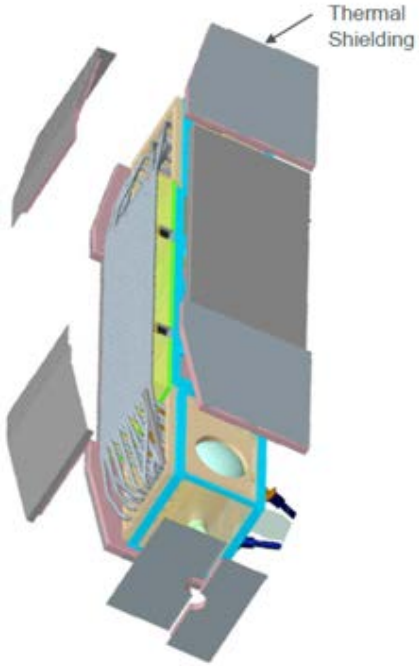
How does it improve the state-of-the-art?

- *This technology may allow **straightforward integration** of a photovoltaic 'topping cycle' with CSP*
  - *Ultra-high efficiency combined with storage and dispatchability*
  - *Allows true full-spectrum utilization*
  - *Will allow greater solar energy penetration and utilization*
- *Specific areas requiring invention*
  - *Solar cells with material combinations that are **designed** to be efficient at >400°C*
  - *Non-reactive metallizations*
  - *Tunnel junctions that can survive long times at T>400°C with minimal degradation*
  - *Anti-reflective coatings that are robust and perform well at high-T*
  - *Strategies to eliminate group-V desorption*
  - *Testing capabilities to determine efficiency at high T and reliability*



- On heat shields of CSP towers [1]: 100X – 1,000X 1-sun, T > 100 °C

[1] Image courtesy DoE and Pratt & Whitney

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Status and achievements of the project to date

- *Task 1- Modeling*
  - *Models show good agreement with experimental results*
- *Task 2- Thermally robust cell components*
  - *Demonstrated anti-reflection coatings with low solar-weighted reflectance at >400 °C and minimal change after 24h anneal*
  - *Identified several contact metal stacks with minimal roughening and low contact resistance after 24h anneal*
- *Task 3- Tunnel junctions*
  - *Modeled then demonstrated tunnel junctions with high performance at >400 °C*
  - *Demonstrated excellent tunneling after 200h anneal*
- *Task 4- Grow and fabricate 1J and 2J cells with high efficiency at >400 °C*
  - *Demonstrated 2J AlGaInP/GaAs cells with Voc > 2.4V at 1-sun, 25°C*
- *Task 5- Accelerated lifetime testing*
  - *QTP written*
- *Task 6- T2M*
  - *Developed relationship with SunCore America and CSP expert Dr. Clifford Ho, Sandia*

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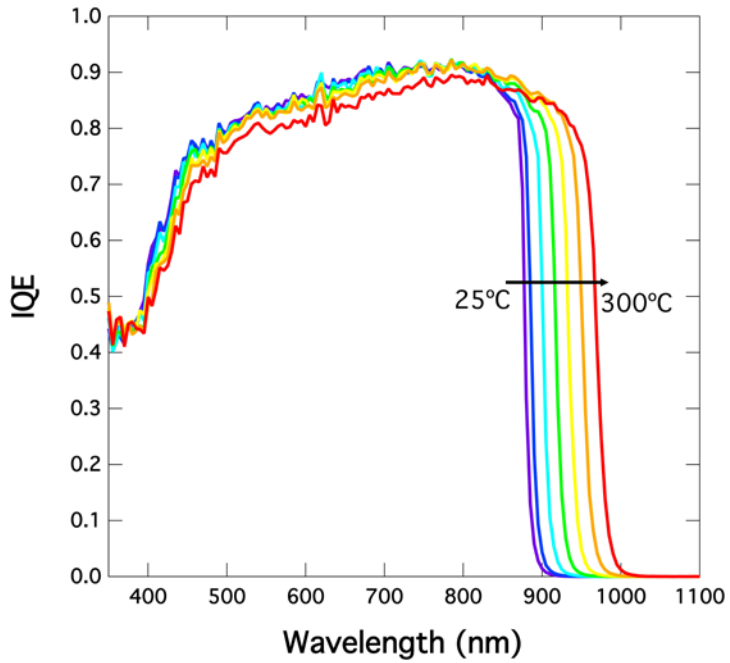
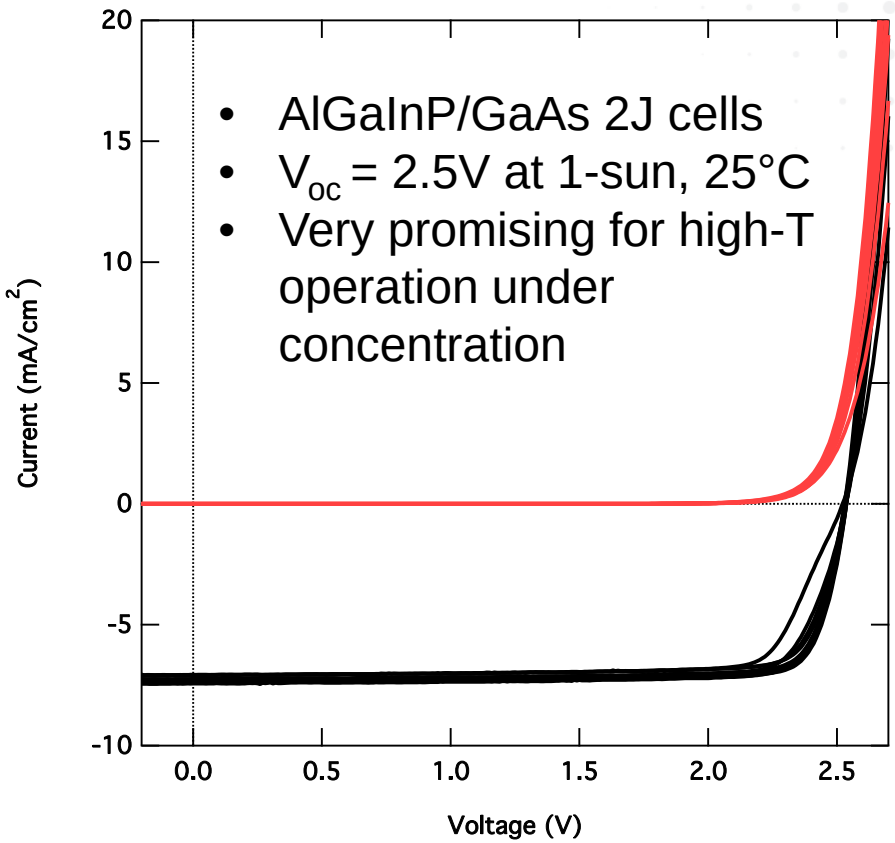
Challenges that the team has encountered

- *Thermometry of cells under steady-state concentrated illumination*
  - *Transmission or luminescence spectroscopy*
  - *Finite-element modeling of temperature profile*
- *On-sun testing of cells under high concentration at 400 °C*
- *Integrating thermally robust metal/semiconductor contacts with thick grid metal needed for CPV*

- Progress on GaAs and AlGaInP junctions



- Minimal reduction in IQE at high temperatures
- Clear shift in bandgap at high temperatures



- AlGaInP/GaAs 2J cells
- V_{oc} = 2.5V at 1-sun, 25°C
- Very promising for high-T operation under concentration