The Impact of InGaAs Absorber Thickness on Intervalley Extraction in Hot Carrier Solar Cells

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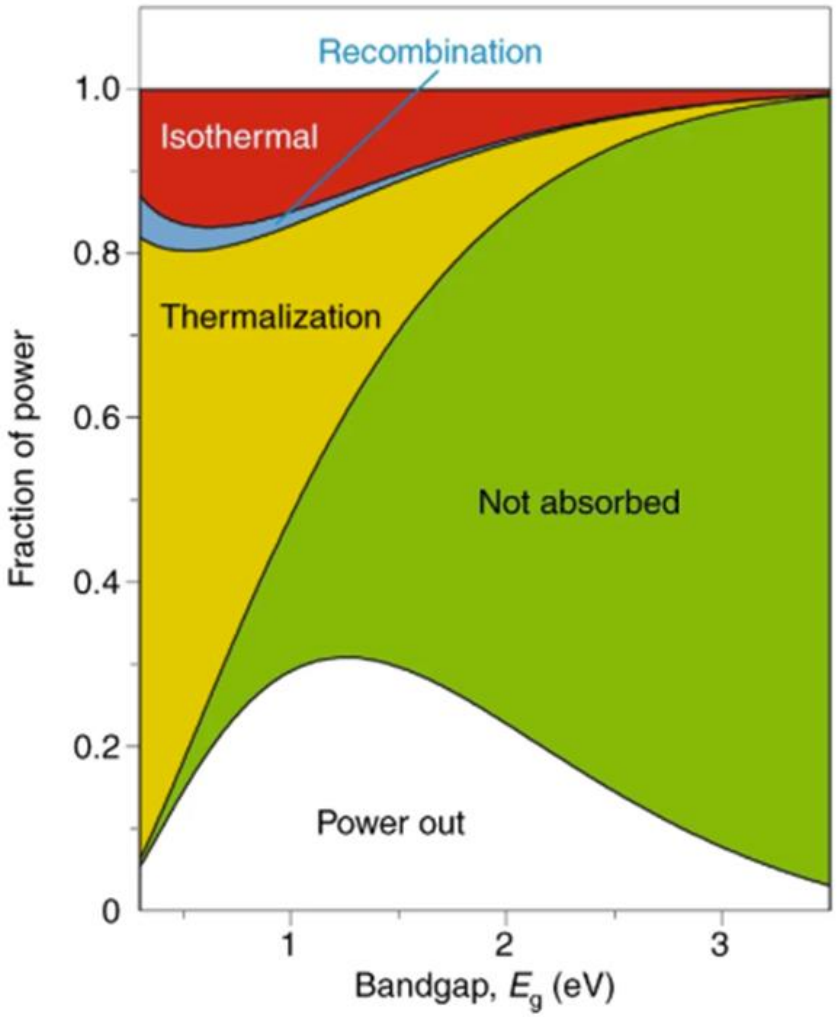
- Hot Carriers and Band Structure
- Intervalley Scattering and the Gunn Effect
- Potential Device Structures
- Band Alignments and Barriers
- Future Work

Introduction

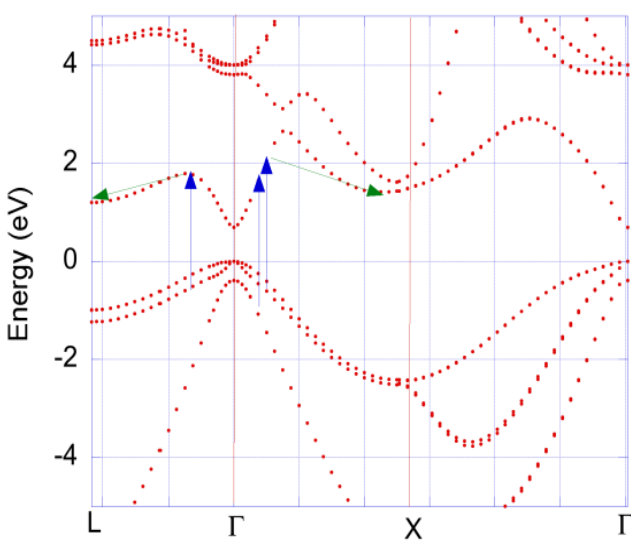


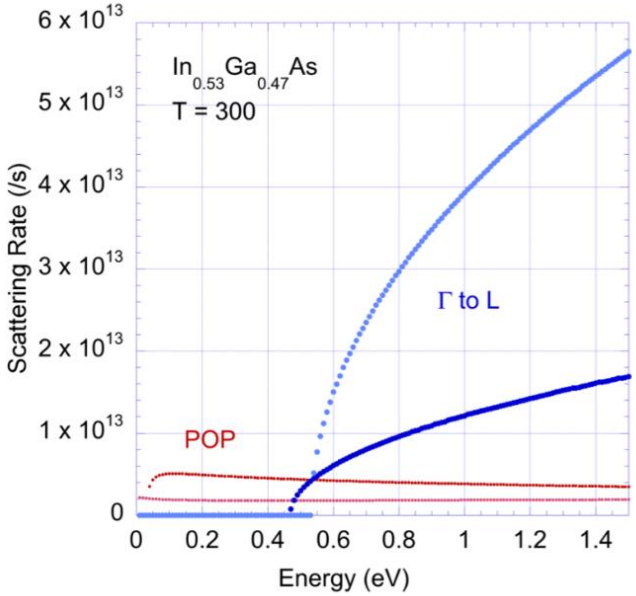
- Single gap solar cells are limited to ~30% efficiency
- Photons above the bandgap will generate “hot carriers” that swiftly thermalize
- A hot carrier solar cell addresses *thermalization loss* by extracting those high energy electrons

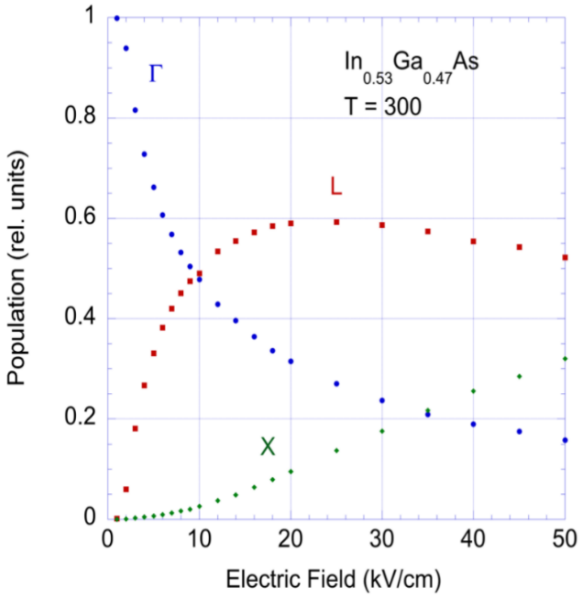
Guillemoles, J., Kirchartz, T., Cahen, D. *et al.* Guide for the perplexed to the Shockley–Queisser model for solar cells. *Nat. Photonics* **13,** 501–505 (2019). https://doi.org/10.1038/s41566-019-0479-2

Valley Photovoltaics: Intervalley Scattering

David K. Ferry, ASU. "In Search of a True Hot Carrier Solar Cell,"
D K Ferry, Semicond. Sci. Technol. Vol. **34** no. 4 (2019).



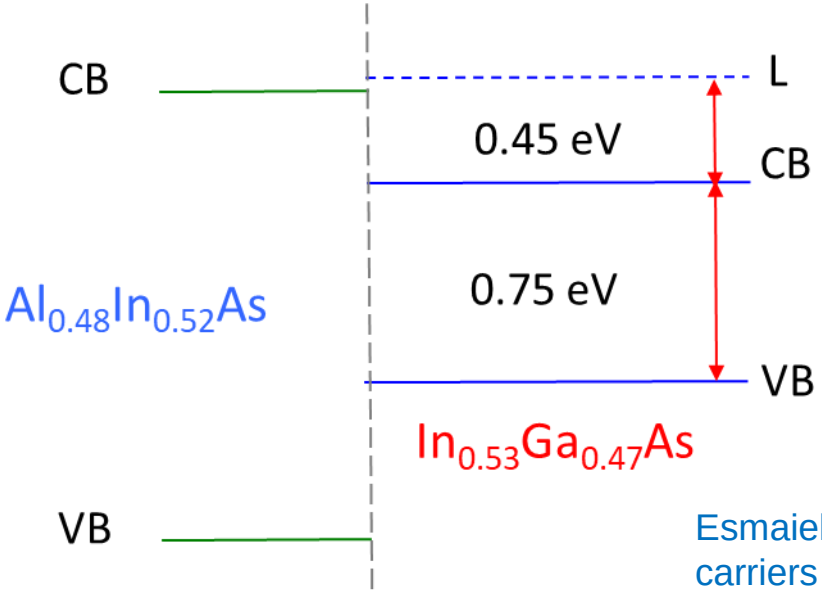




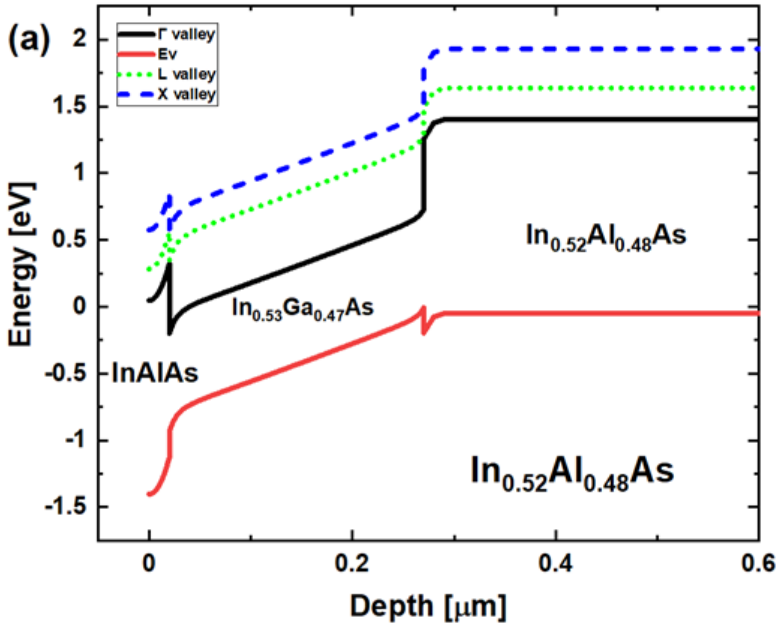
- High energy electrons: Intervalley scattering
- Low energy electrons: The Gunn Effect
- Transfer, store, and extract via upper valleys!

Device Structure

n+: $In_{0.52}Al_{0.48}As$, 20 nm, 1e18 cm-3
n : $In_{0.53}Ga_{0.47}As$, 250nm, 1e15 cm^{-3}
p+: $In_{0.52}Al_{0.48}As$, 1000nm, 1e18 cm^{-3}
p: InP substrate



- Need a resonant barrier material with InGaAs, and an absorber with both a bandgap and an L valley in the solar spectrum.

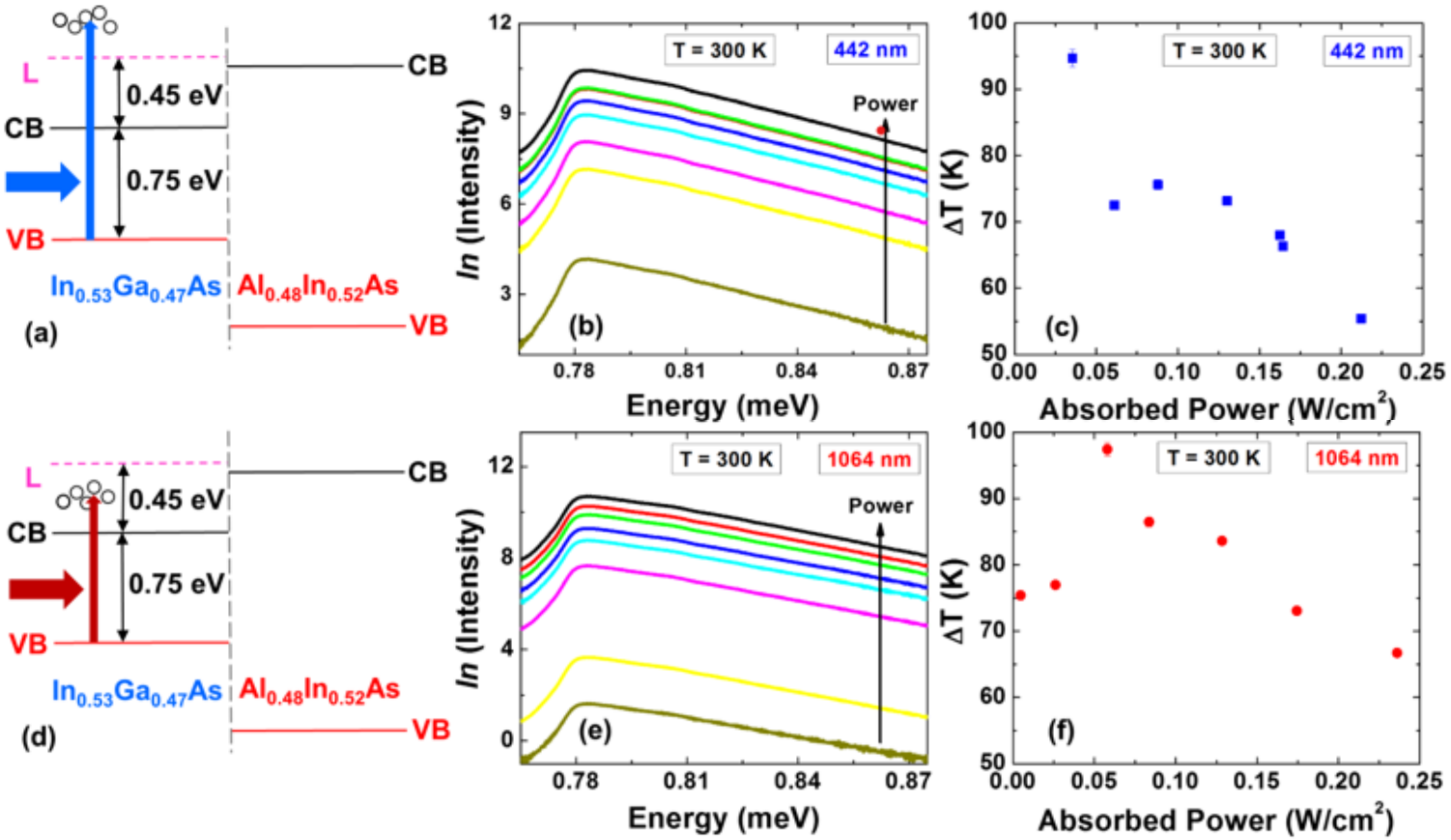


Esmaielpour et al., "Exploiting intervalley scattering to harness hot carriers in III–V solar cells," Nature Energy **5,** 336-343 (2020).

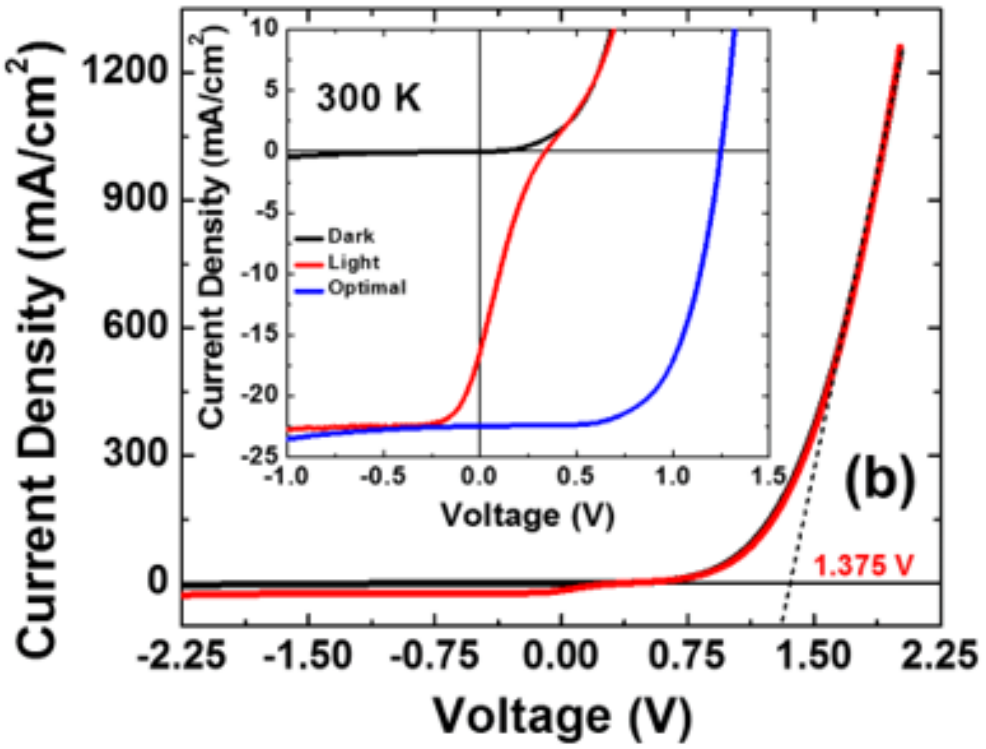
Evidence of Hot Carriers

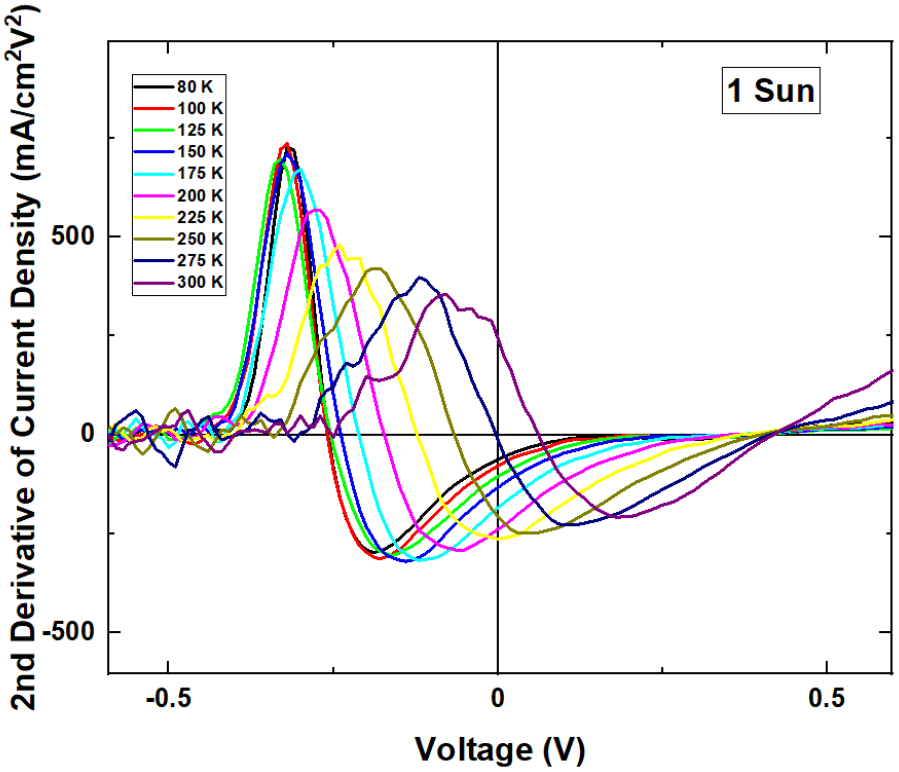
- The carrier temperature in the device can be quantified by fitting the high energy tail of the photoluminescence spectrum to the generalized Planck relation:

$$I(E) = \varepsilon(E) \cdot \exp\left[\frac{-E}{k_B T_c}\right]$$



Role of Valley Degeneracy at Absorber/Barrier Interface

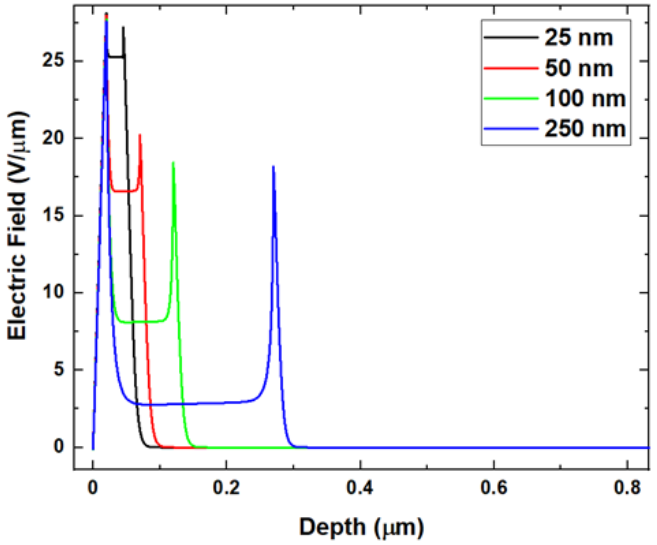


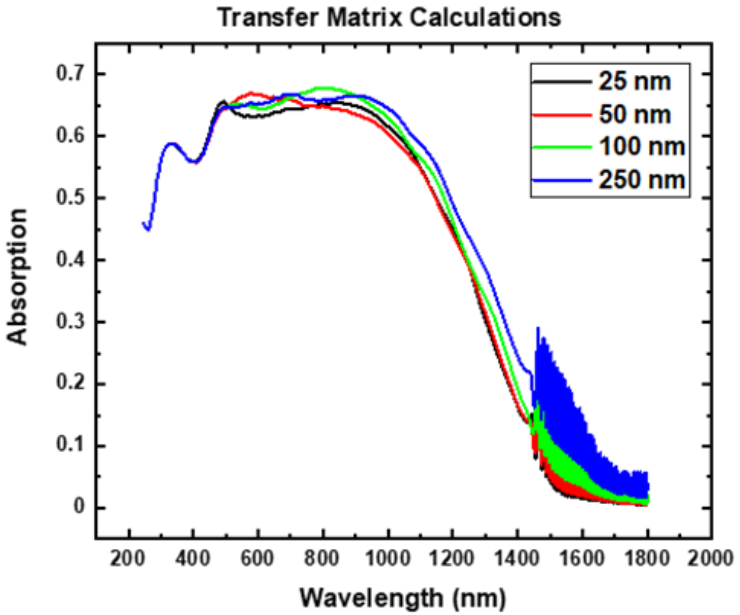


- Initial suggestion: L of the absorber to Γ of the top layer is not an efficient transition.

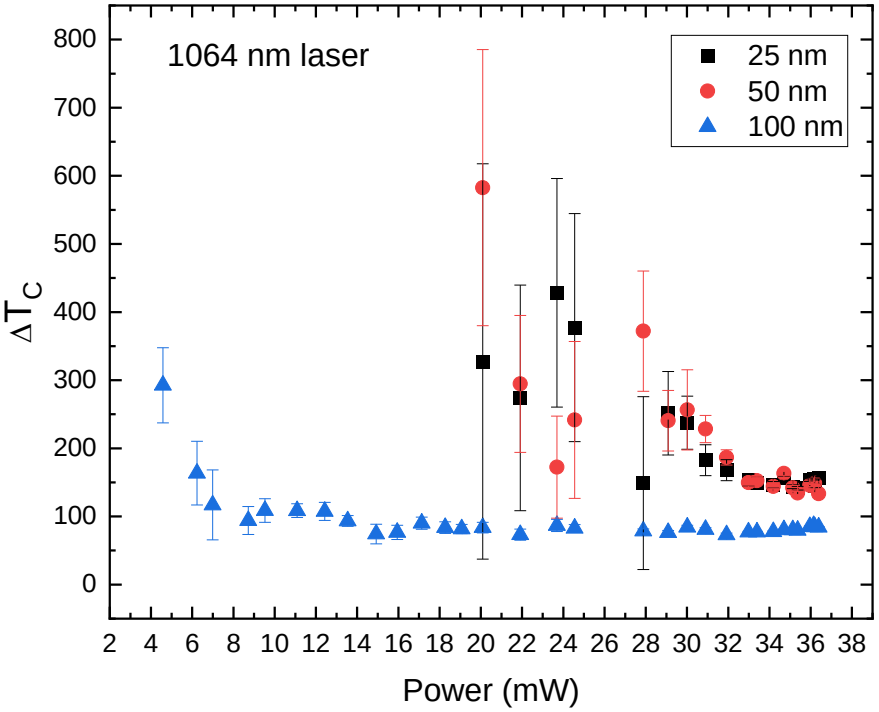
Altering the Absorber Thickness

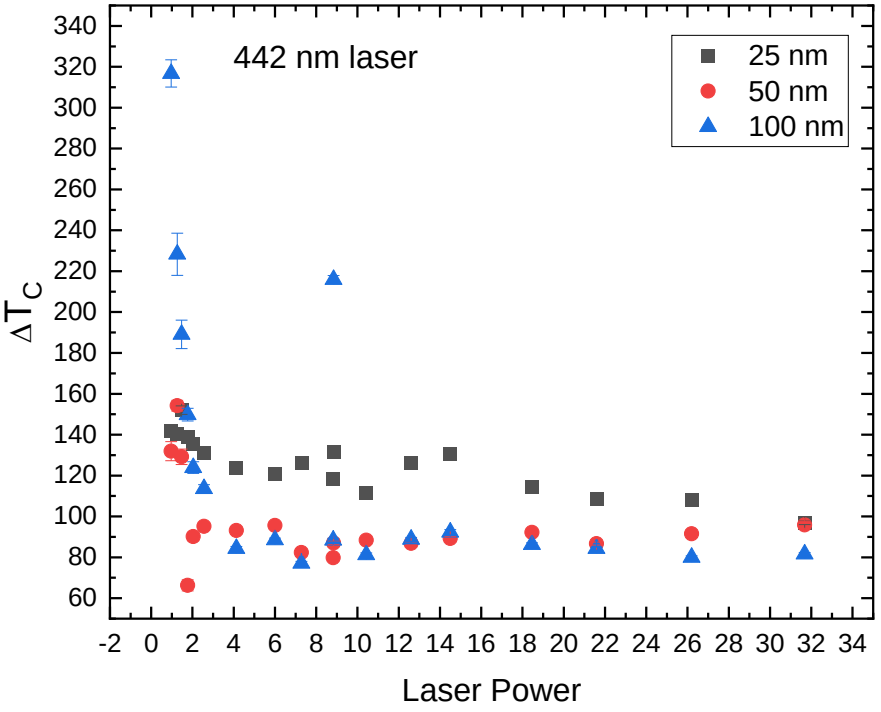
- Probe the mechanisms by altering the thickness of the InGaAs layer.
- Electric field strength inside the device increases as the thickness decreases.
- Absorptivity decreases as thickness decreases.



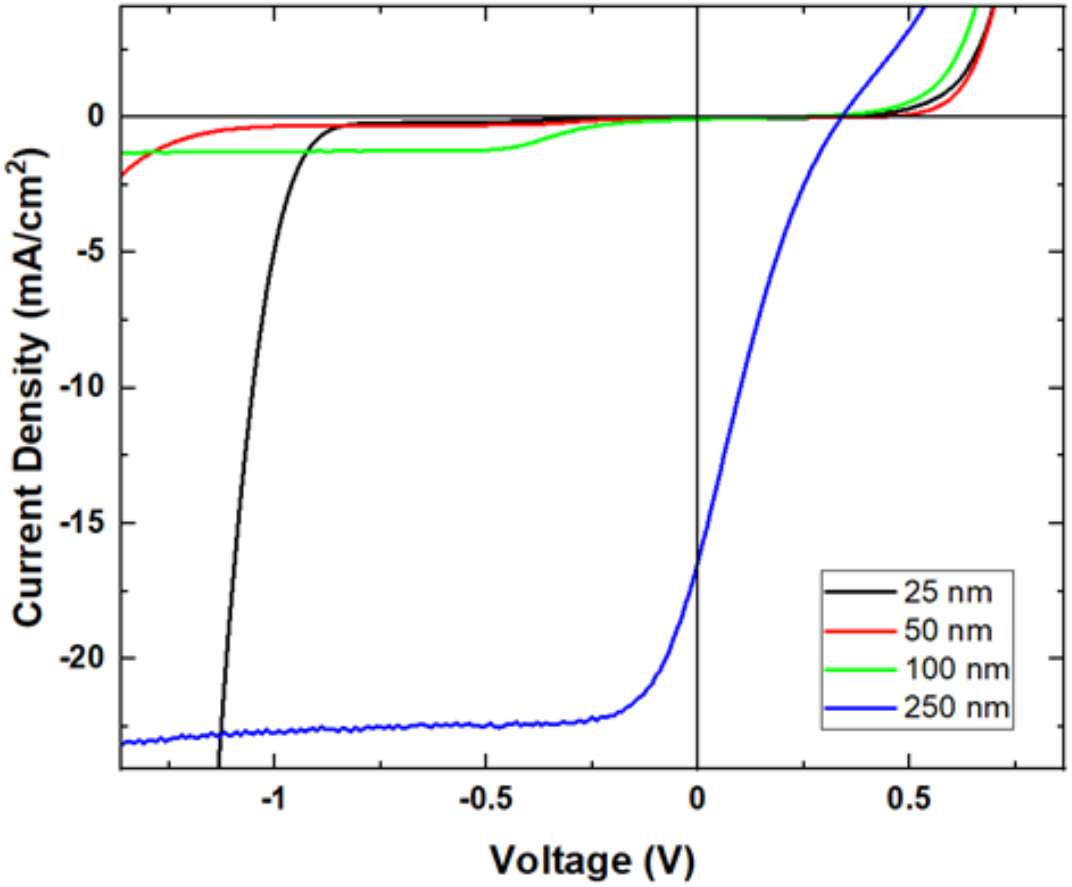


Photoluminescence

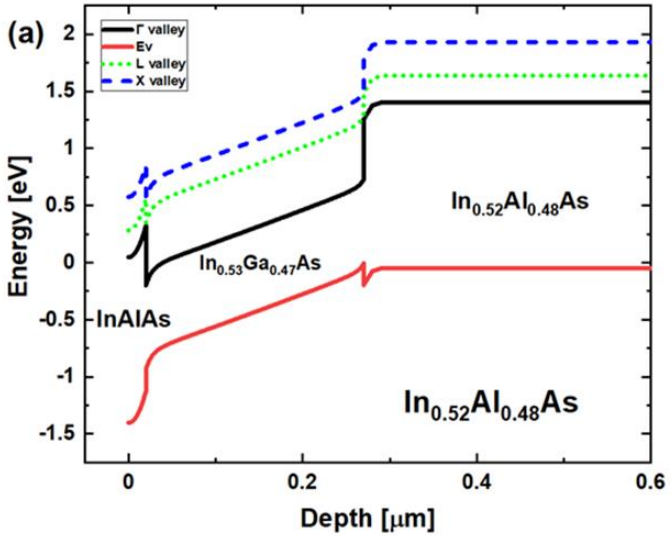


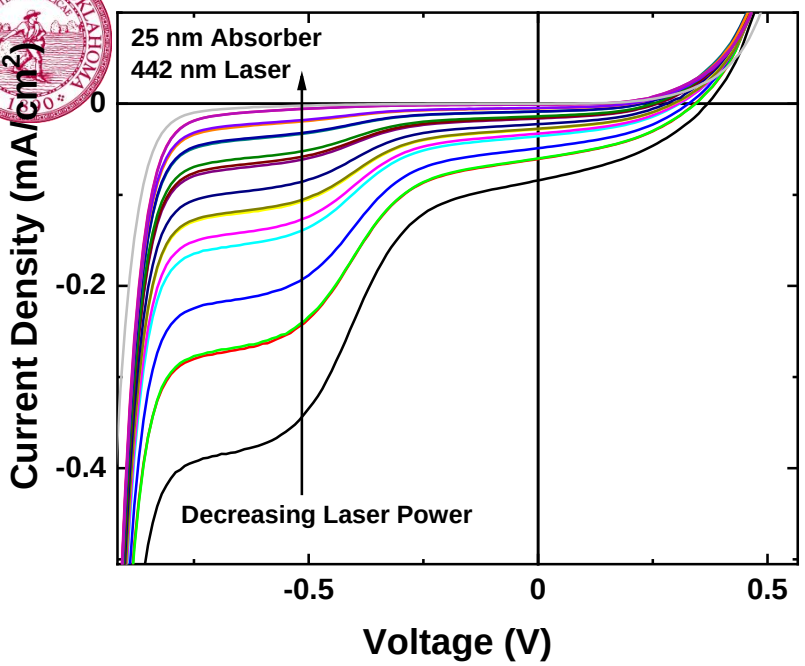


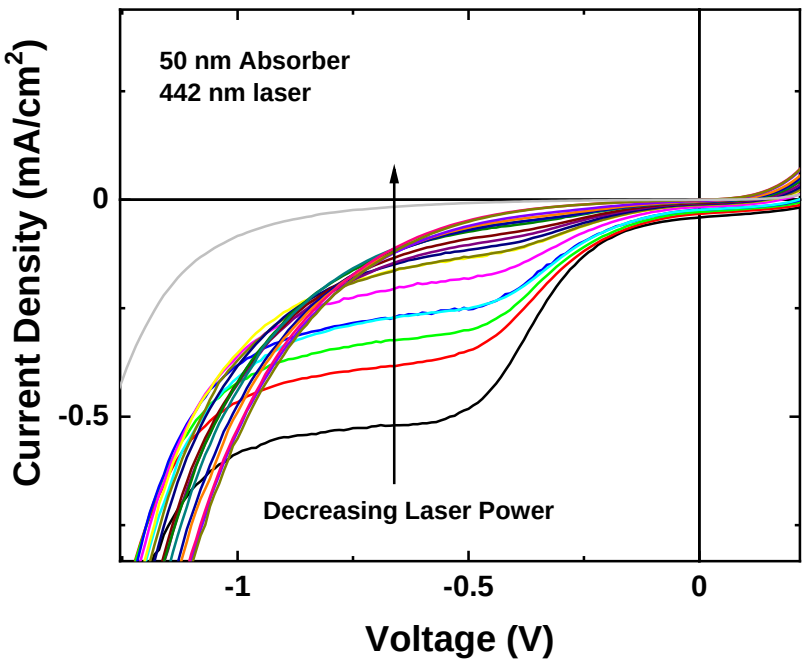
Current Density-Voltage

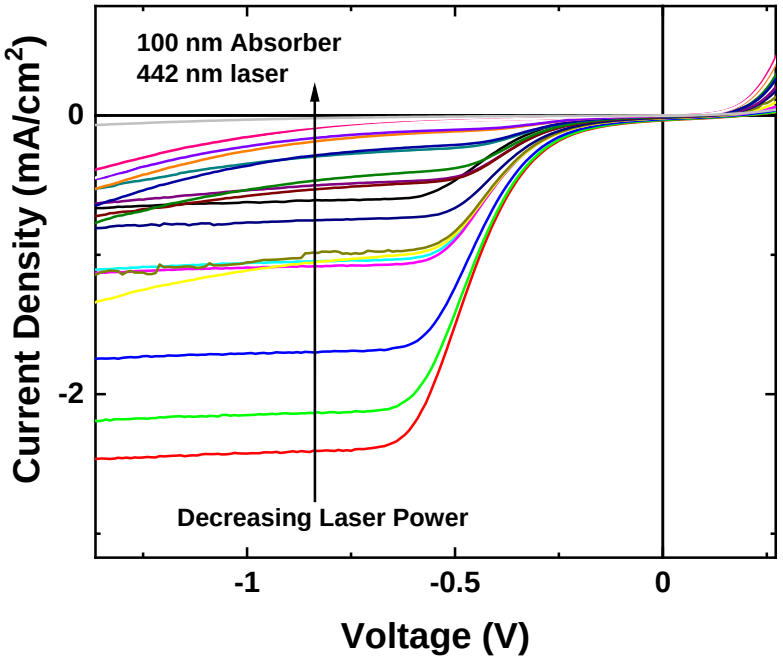


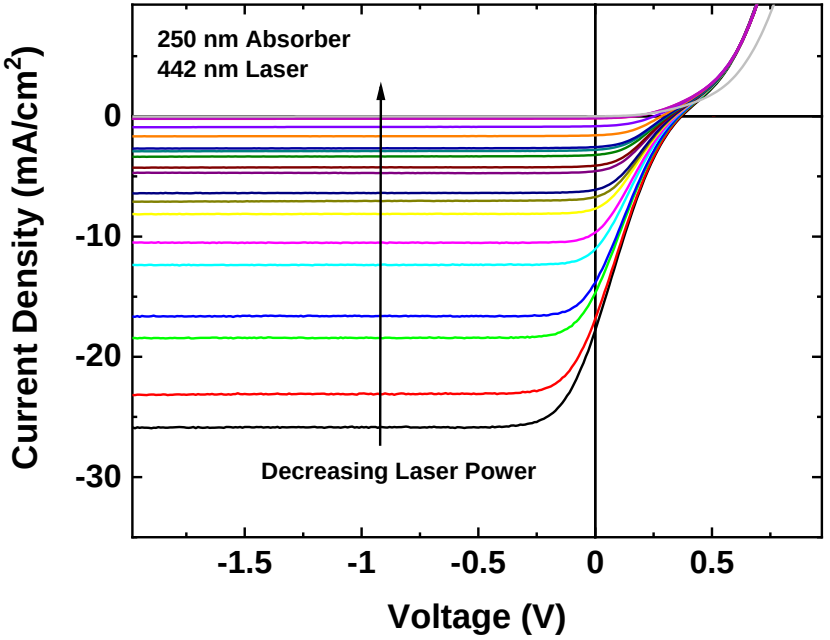
Solar simulator (1 Sun AM1.5G) measurements at room temperature.

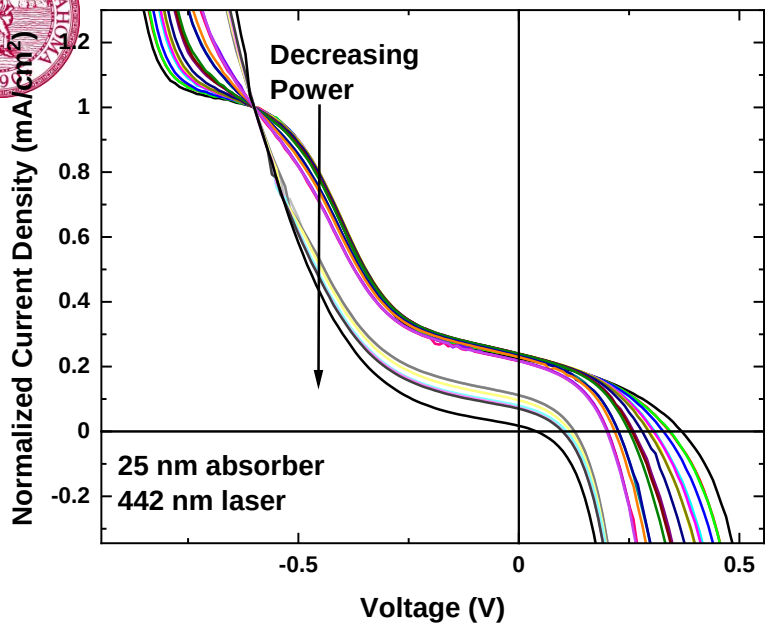


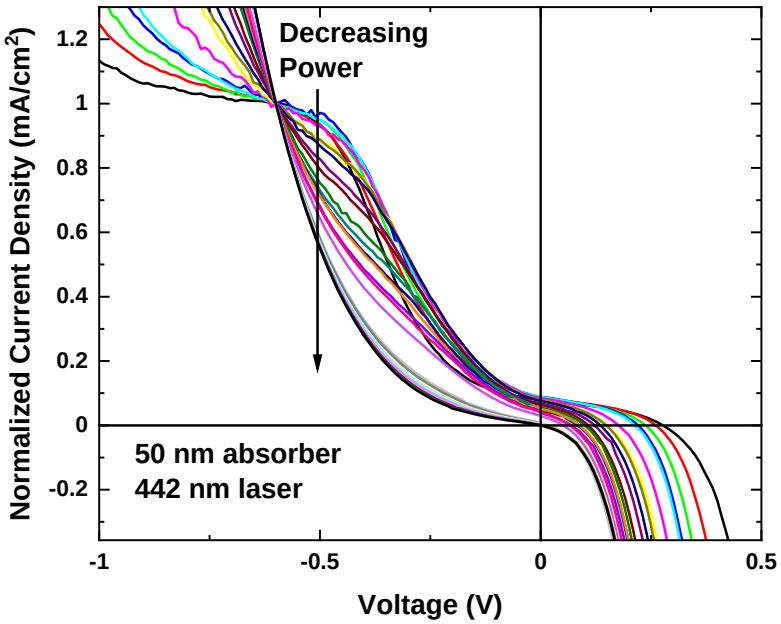

25 nm Absorber
442 nm Laser
Decreasing Laser Power
Current Density (mA/cm2)
Voltage (V)
0
-0.2
-0.4
-0.5
0
0.5

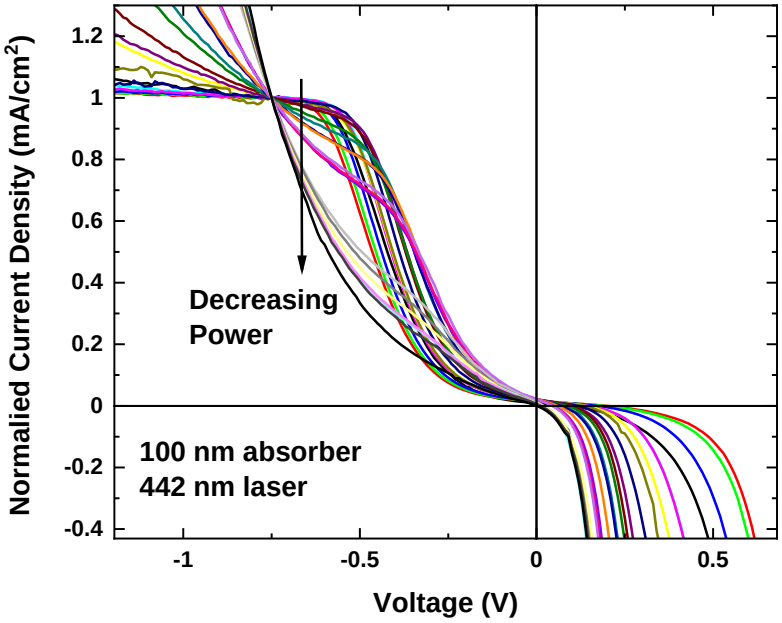

50 nm Absorber
442 nm laser
Decreasing Laser Power
Current Density (mA/cm2)
Voltage (V)
0
-0.5
-1
-0.5
0

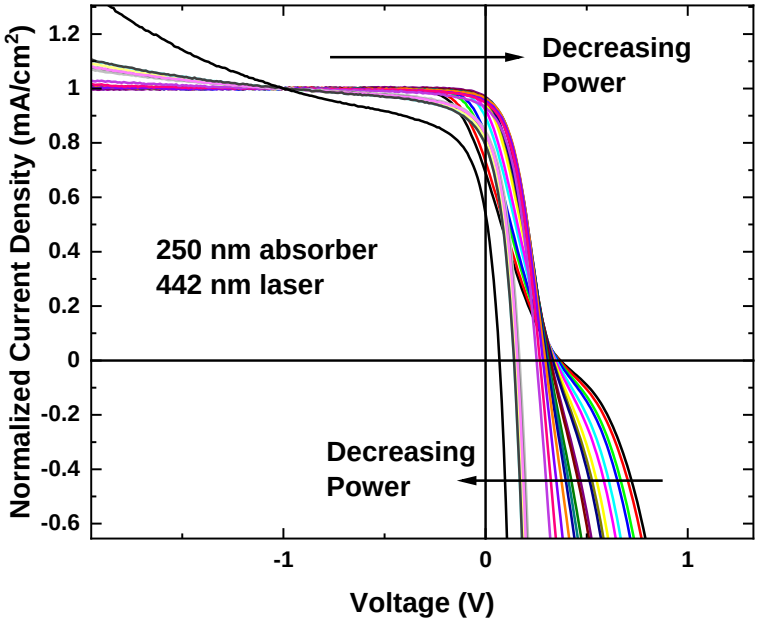

100 nm Absorber
442 nm laser
Decreasing Laser Power
Current Density (mA/cm2)
Voltage (V)
0
-2
-1
-0.5
0


250 nm Absorber
442 nm Laser
Decreasing Laser Power
Current Density (mA/cm2)
Voltage (V)
0
-10
-20
-30
-1.5
-1
-0.5
0
0.5


Decreasing
Power
25 nm absorber
442 nm laser
Normalized Current Density (mA/cm^2)
Voltage (V)


Decreasing
Power
50 nm absorber
442 nm laser
Normalized Current Density (mA/cm^2)
Voltage (V)


Decreasing
Power
100 nm absorber
442 nm laser
Normalied Current Density (mA/cm^2)
Voltage (V)


Decreasing
Power
250 nm absorber
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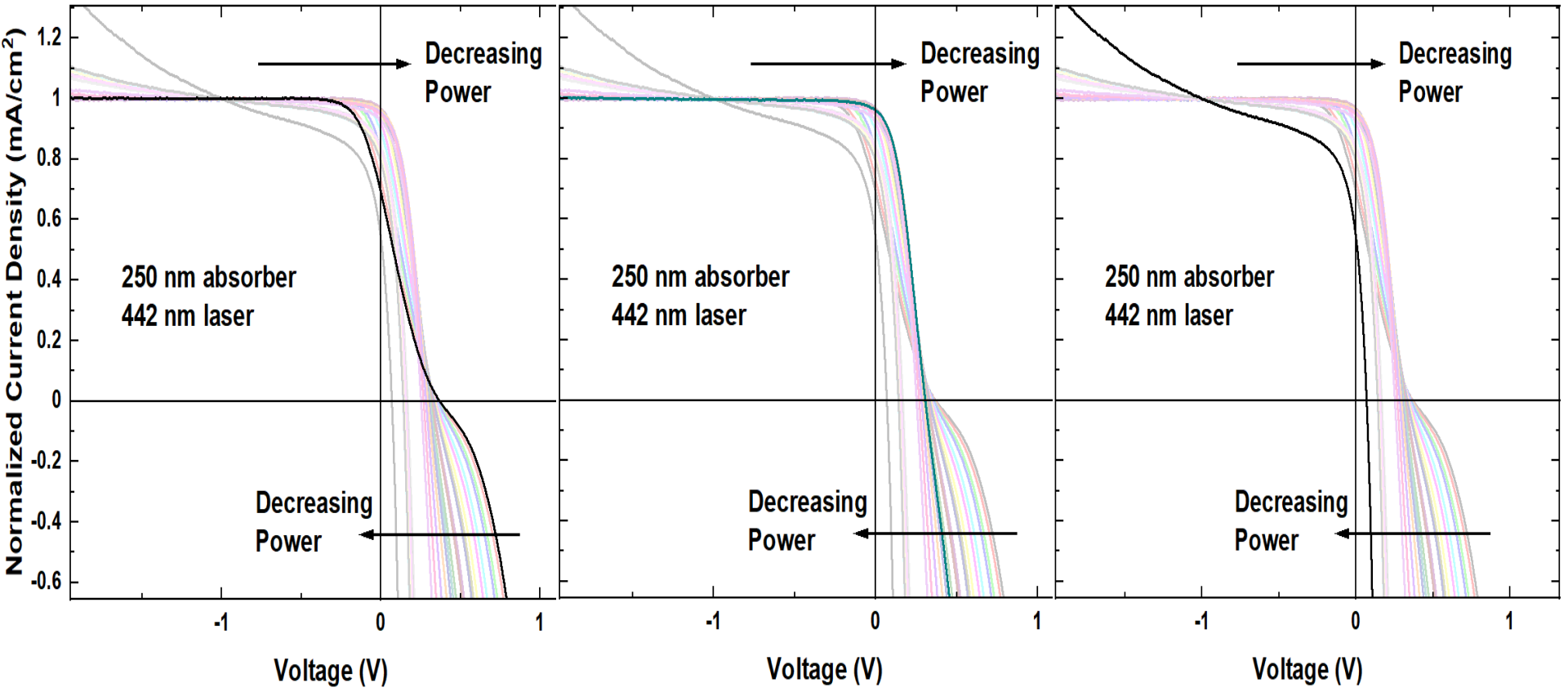
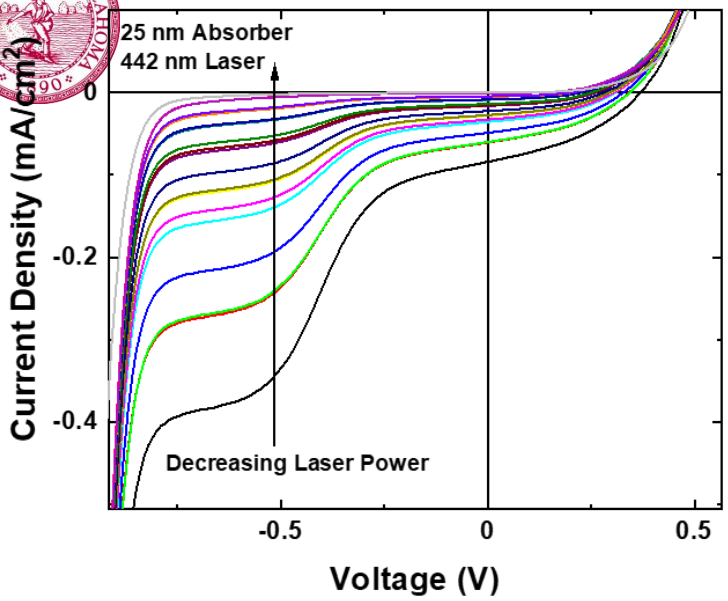
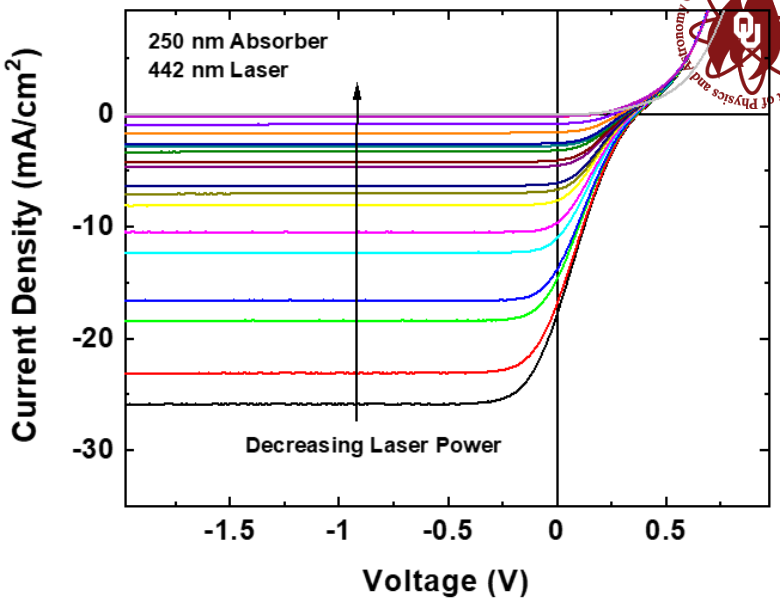
Normalized Current Density (mA/cm^2)
Voltage (V)



High Laser Power → Low Laser Power

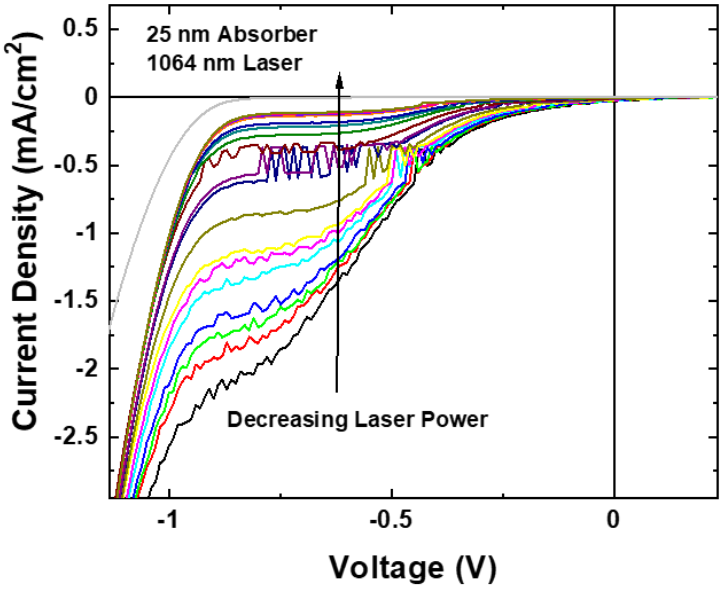




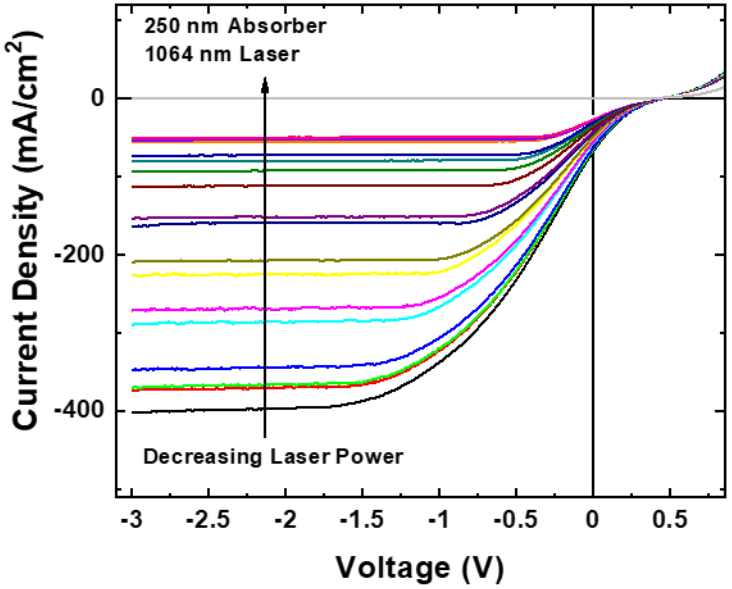
442 nm (above L)

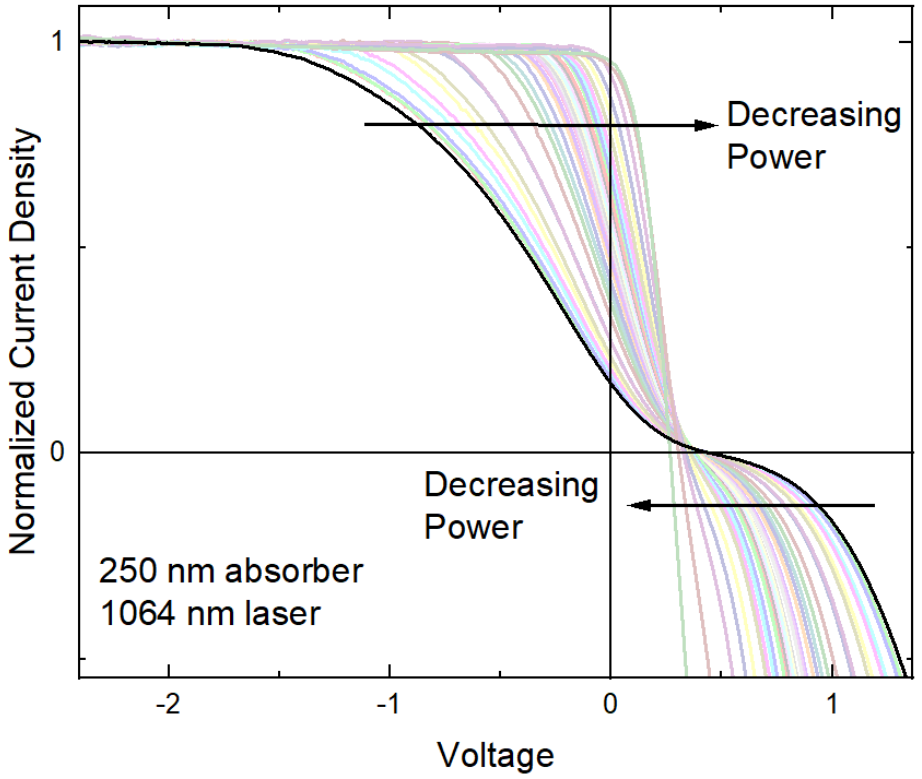
25 nm absorber

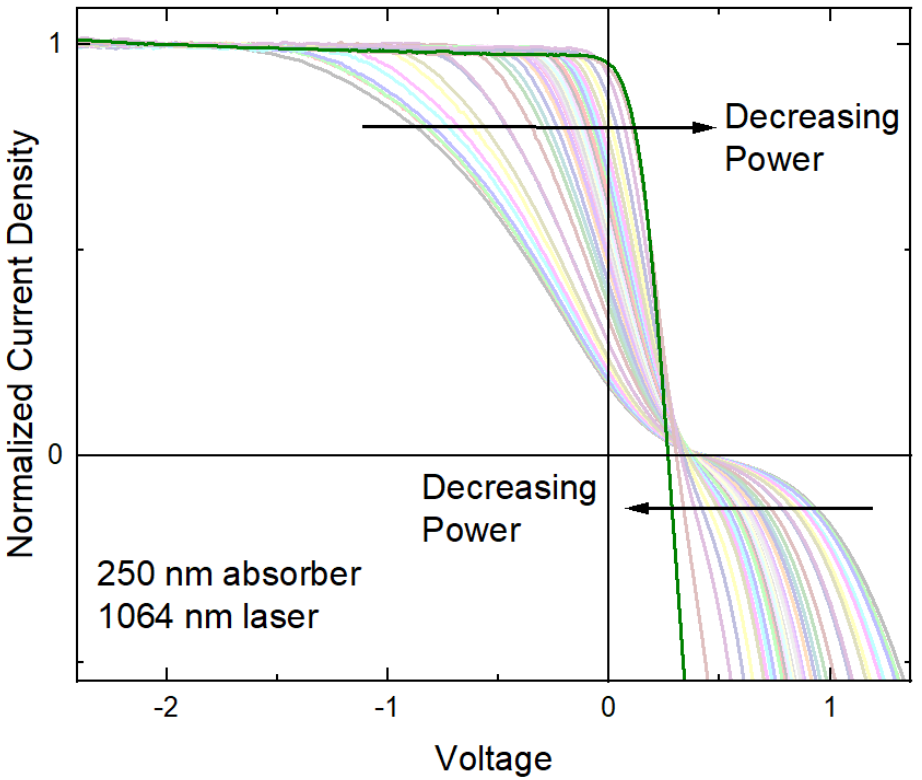
250 nm absorber



1064 nm (below L)







High Laser Power → Low Laser Power

Conclusions and Acknowledgments

- Valley photovoltaics has demonstrated maintenance of hot carrier populations under practical conditions for solar cell operation.
- InGaAs serves well as an absorber material, but modifications to the top layer and the extraction pathway are necessary to advance the design.
- Providing an internal electric field is necessary but not sufficient to produce a functioning valley photovoltaic device.

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