Excitation energy dependence of the photovoltaic behavior of InAs/GaAsSb quantum dot solar cells

A.J. Roeth, Y. Cheng, A. Meleco, V. R. Whiteside, M. C. Debnath, M. B. Santos, and I. R. Sellers

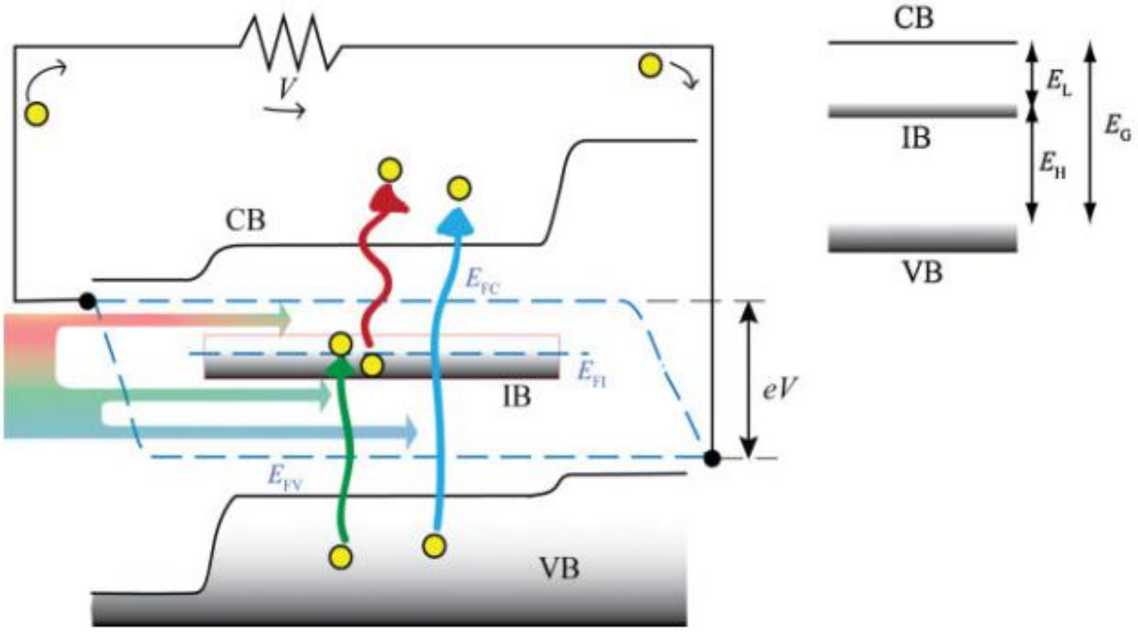
Homer L. Dodge Department of Physics & Astronomy University of Oklahoma, Norman, Oklahoma

- Intermediate band solar cells and our material system
- Experimental data and analysis
  - Previous results
  - 975 nm laser
  - 632 nm laser
- Summary and future goals

Intermediate Band Solar Cells

- Intermediate band solar cells absorb below band gap photons
- Retain open circuit voltage while increasing short circuit current
- Intermediate band can be created using quantum dots
- InAs/GaAs quantum dots most studied
- InAs/GaAsSb quantum dots: higher quantum dot density, quasi-type-II band alignment, divide solar spectrum effectively

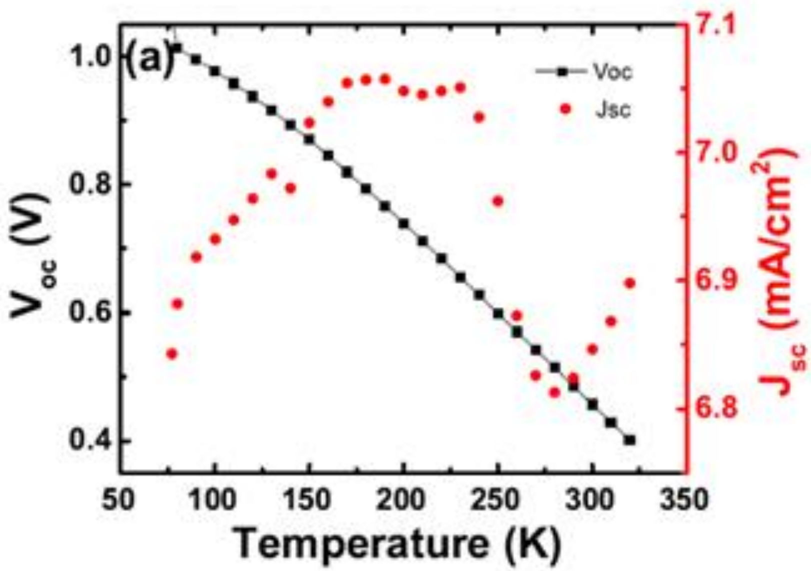
Intermediate Band Solar Cell Band Diagram



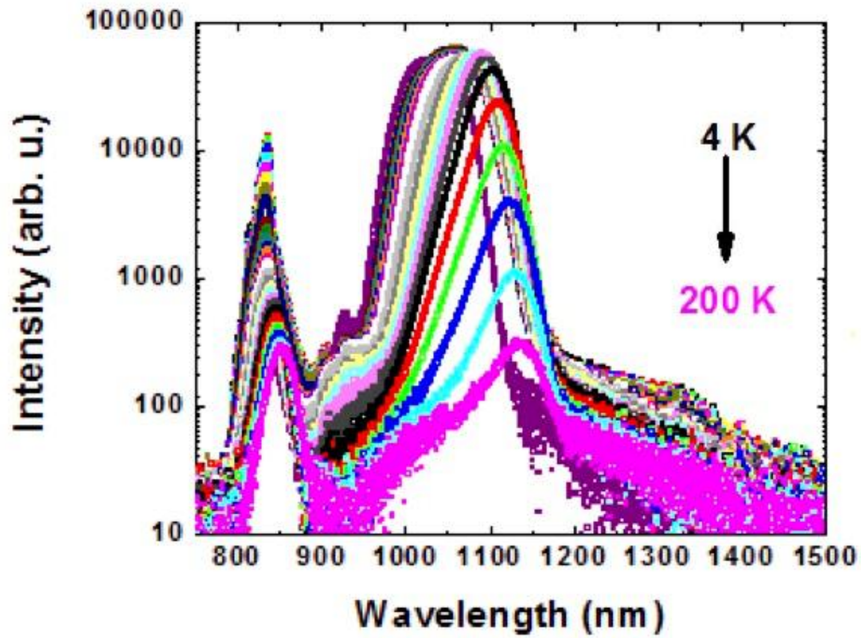
Luque, A. and Martí, A. (2010), The Intermediate Band Solar Cell: Progress Toward the Realization of an Attractive Concept. Adv. Mater., 22: 160–174.

Experiment

- Previous data - Large drop in open circuit voltage indicates defects
- Short circuit current expected to increase with temperature – unexpected behavior at 150K and above, corresponds with temperature dependent photoluminescence
- Location of defects unknown – hypothesized to be outside of quantum dots



Cheng, Y. et al. "Investigation Of Inas/Gaas1–Xsbx Quantum Dots For Applications In Intermediate Band Solar Cells". Solar Energy Materials and Solar Cells 147 (2016): 94-100. Web. 5 Apr. 2016.

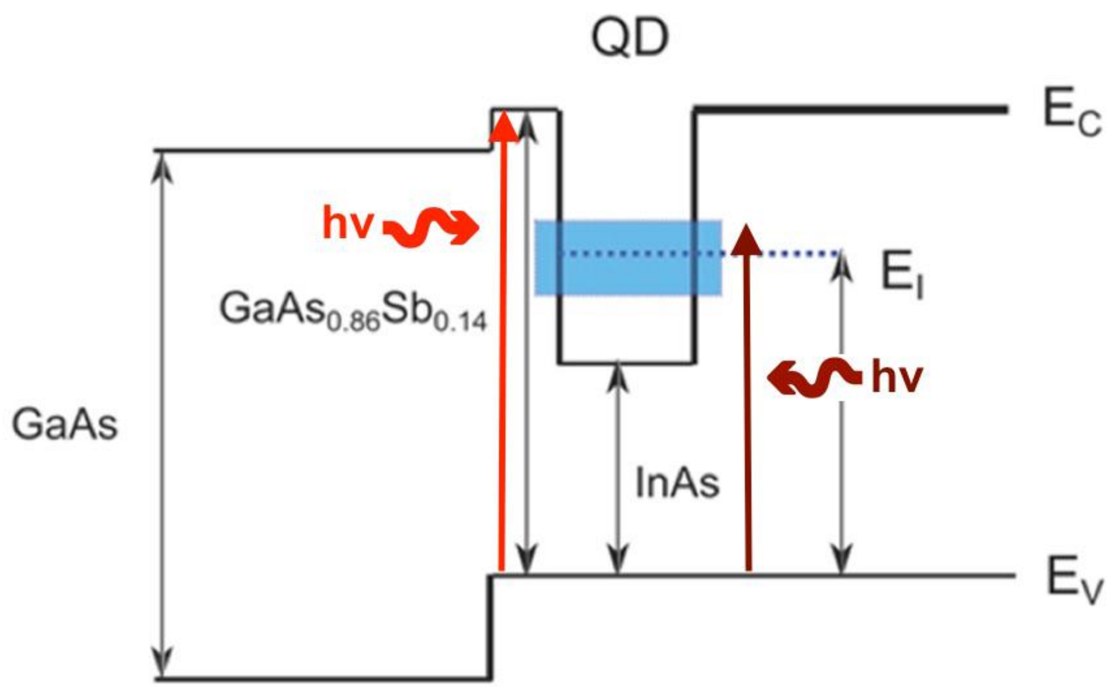


Meleco, A (2016). "Indium Arsenide/Gallium Arsenide Antimonide Quantum Dots and Their Applications in Intermediate Band Solar Cells (Master's Thesis)."

Experiment

- Lasers of different energies to probe particular areas of band structure
- Infrared 975nm laser is below bandgap
- Red 632nm laser is above bandgap

Band Diagram of InAs/GaAsSb Structure

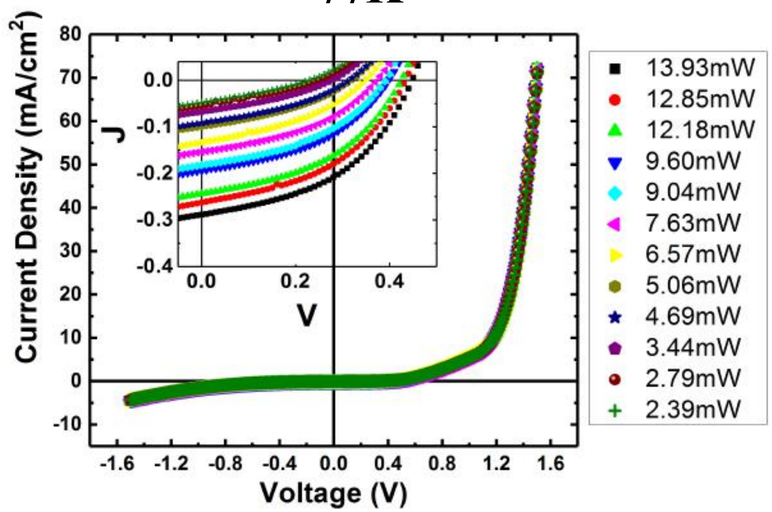


Cheng, Y. et al. "Investigation Of Inas/Gaas1−Xsbx Quantum Dots For Applications In Intermediate Band Solar Cells". Solar Energy Materials and Solar Cells 147 (2016): 94-100. Web. 5 Apr. 2016.

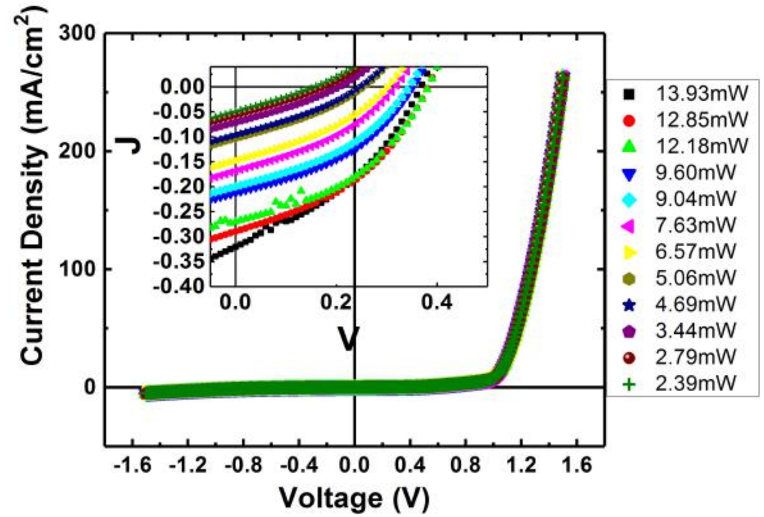
Experimental Data and Analysis: 975nm excitation

- Temperature dependent current density vs. voltage for 975nm infrared laser (below bandgap photons)

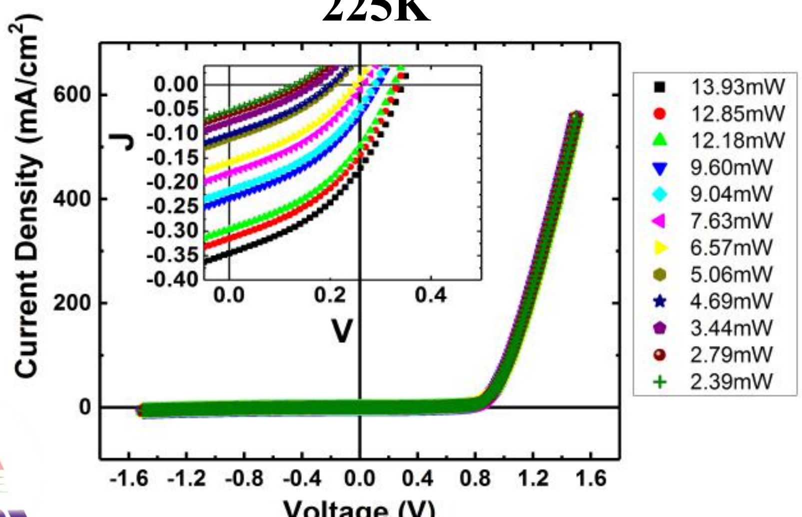
77K



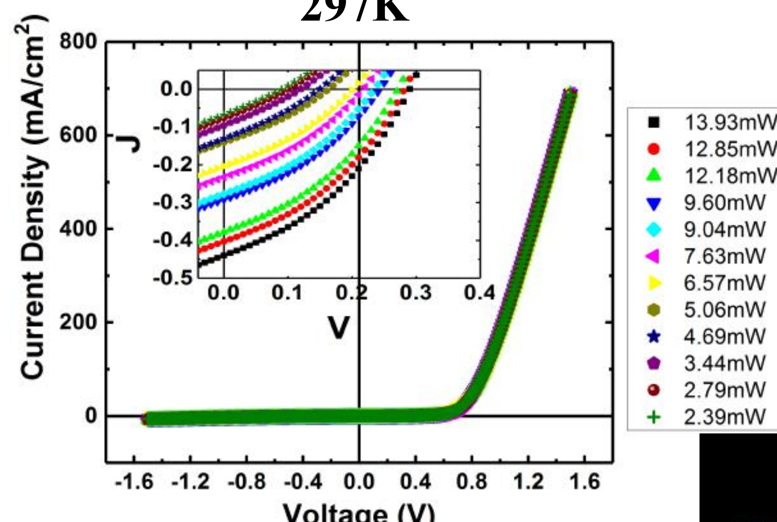
150K



225K

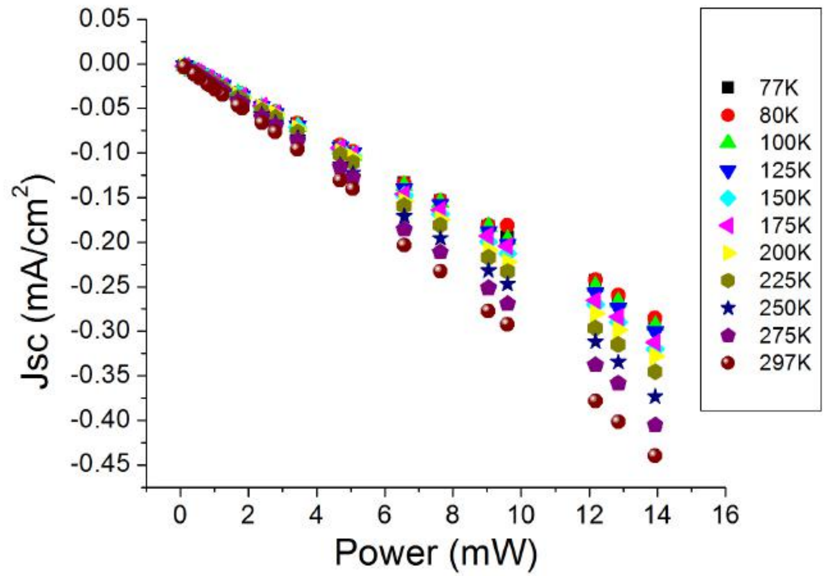


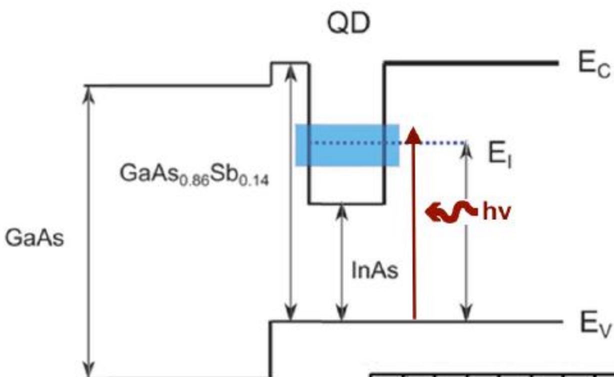
297K

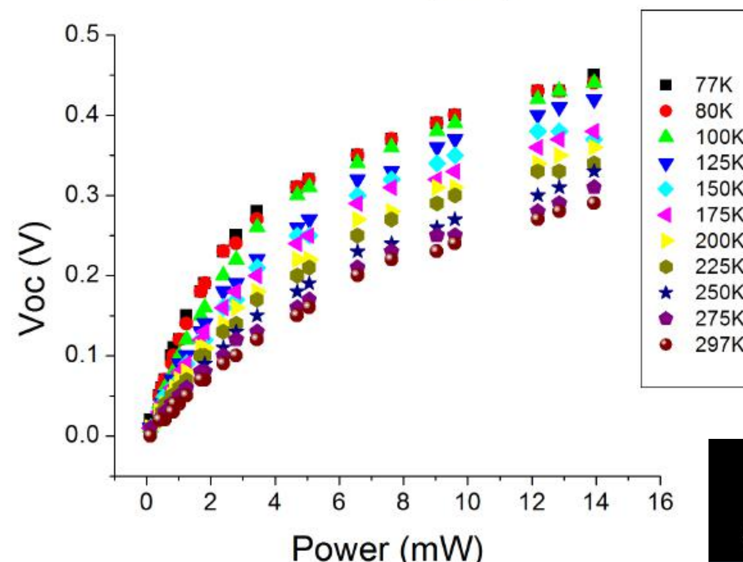


Experimental Data and Analysis: 975nm excitation

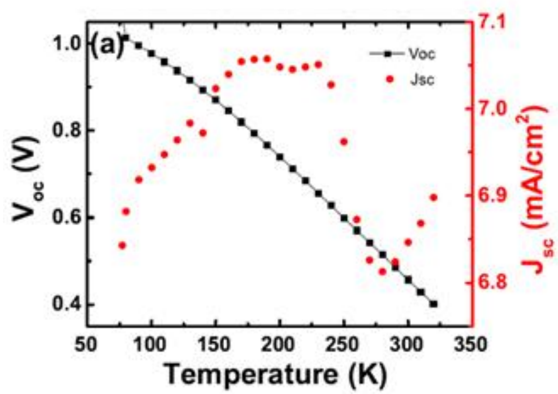
- Temperature and power dependent short circuit current and open circuit voltage for 975nm laser
- Short circuit current – increases with power and temperature
- Open circuit voltage – increases with power, decreases with temperature
- Different from whole sample results





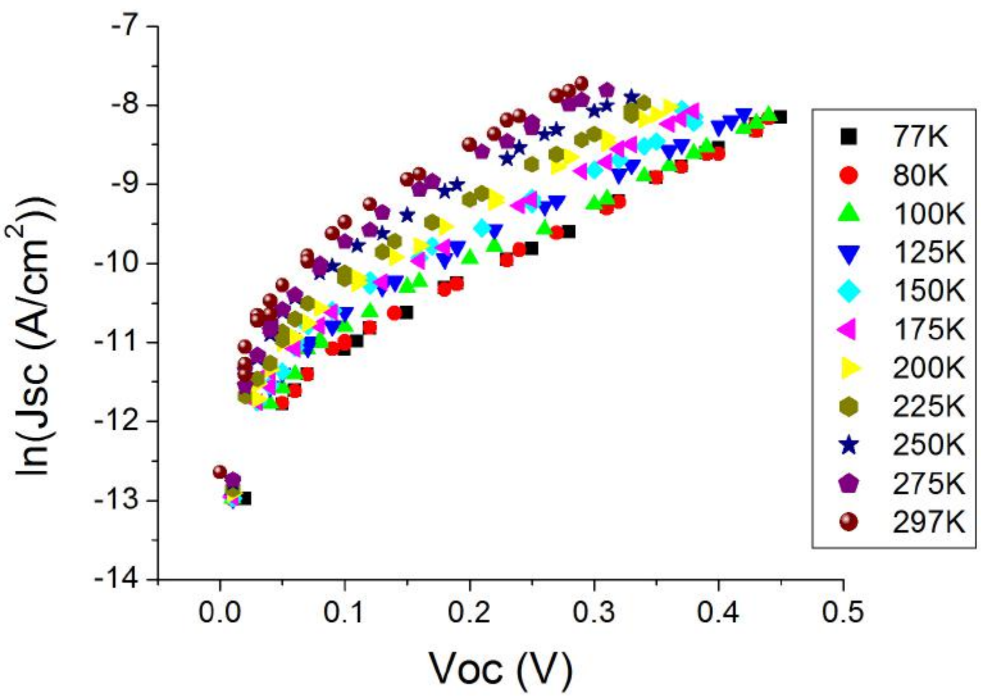


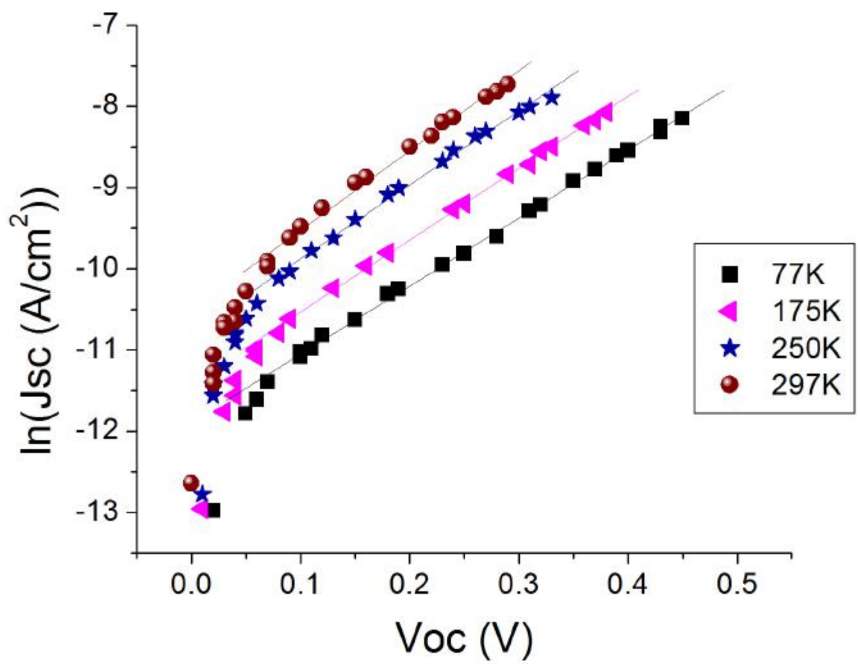
Cheng, Y. et al. "Investigation Of Inas/ Gaas1−Xsbx Quantum Dots For Applications In Intermediate Band Solar Cells". Solar Energy Materials and Solar Cells 147 (2016): 94-100. Web. 5 Apr. 2016.



Experimental Data and Analysis: Temperature Dependent Ideality Factor

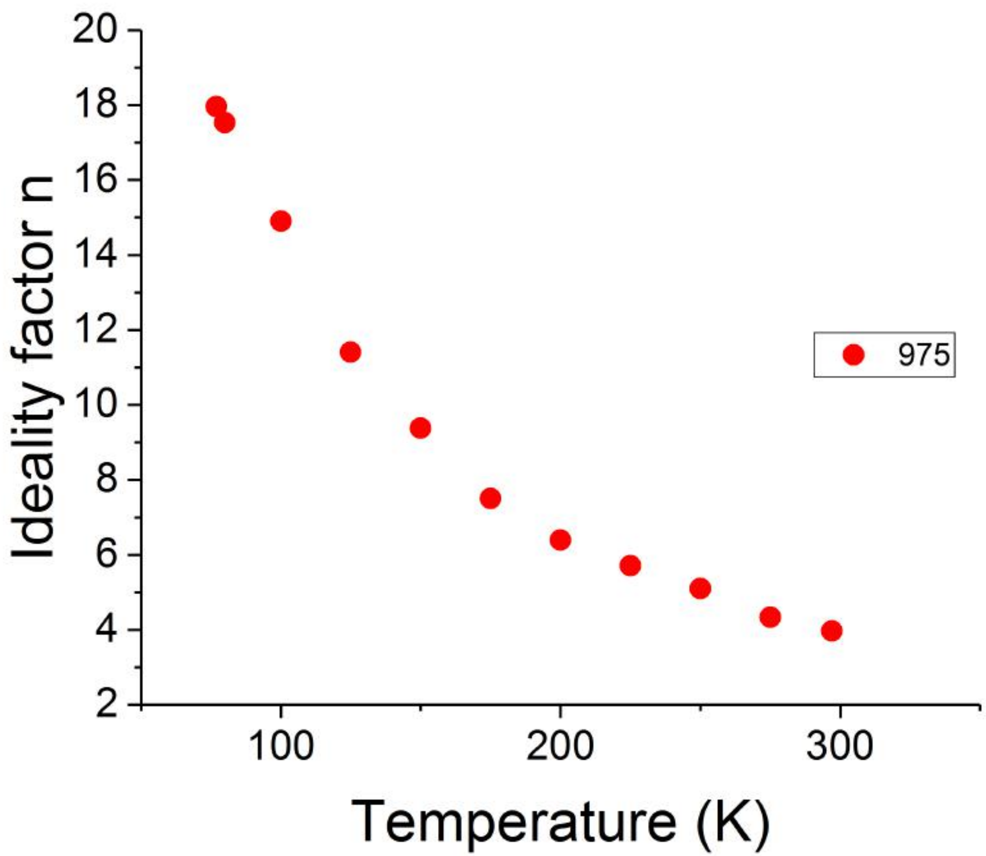
- 975nm excitation
- Dark current: $J_{dark} = J_0 (e^{qV/kT}-1)$
- Total current: $J = Jsc - J_0 (e^{qV/kT}-1)$
- $Jsc = J_0 e^{Voc/nkT}$
- Equation of fit: $\ln(Jsc) = (1/nkT) Voc + \ln(J_0)$





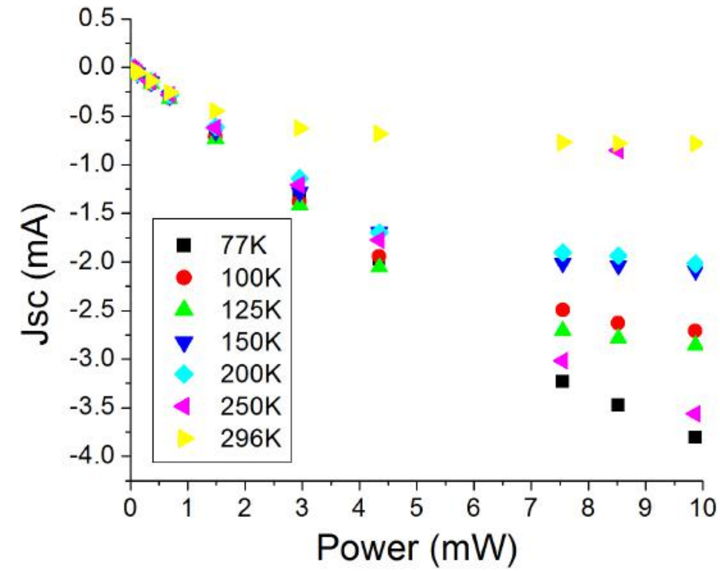
Experimental Data and Analysis: Temperature Dependent Ideality Factor

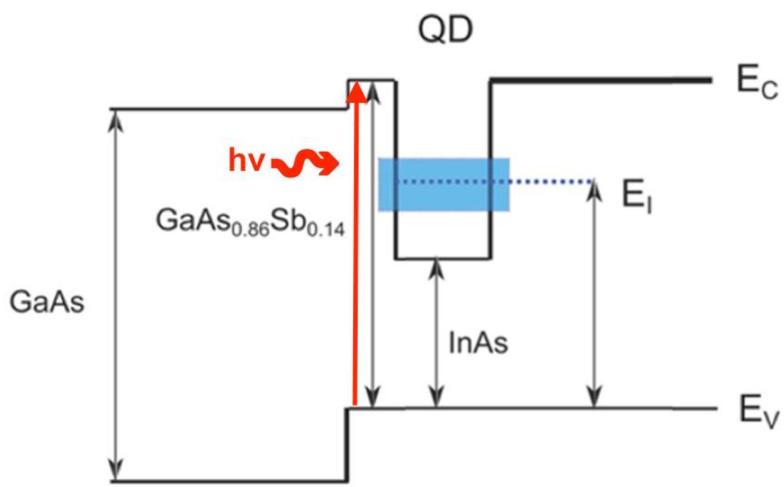
- Ideality factor n vs. temperature for 975nm excitation
- n=1 – diffuse current (ideal), n=2 – generation recombination current (expected for this sample)
- High n at low temperatures – competing quantum dots
- n approaches 2 with higher temperature but doesn't reach it

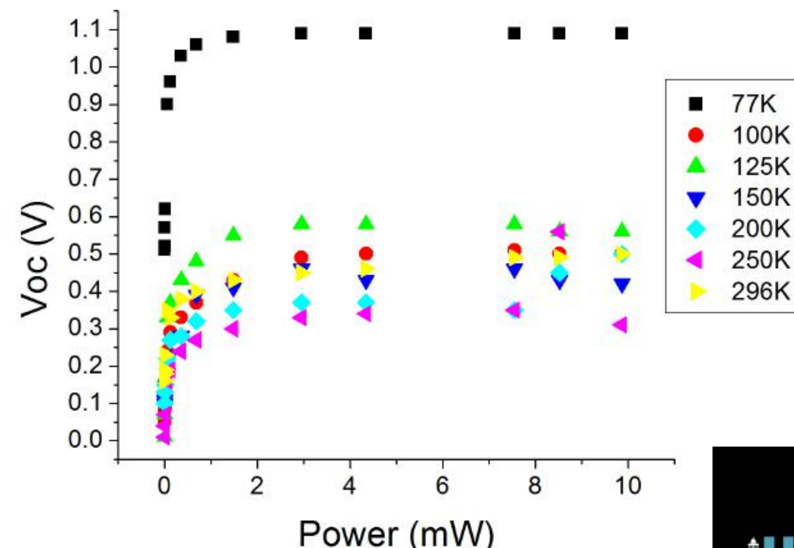


Experimental Data and Analysis: 632nm excitation

- Temperature dependent short circuit current and open circuit voltage vs. laser power for 632nm red laser
- Problems: sensitive to initial conditions/previous measurements led to lack of reproducibility
- Did not encounter this with the 975 – suggests traps outside dots





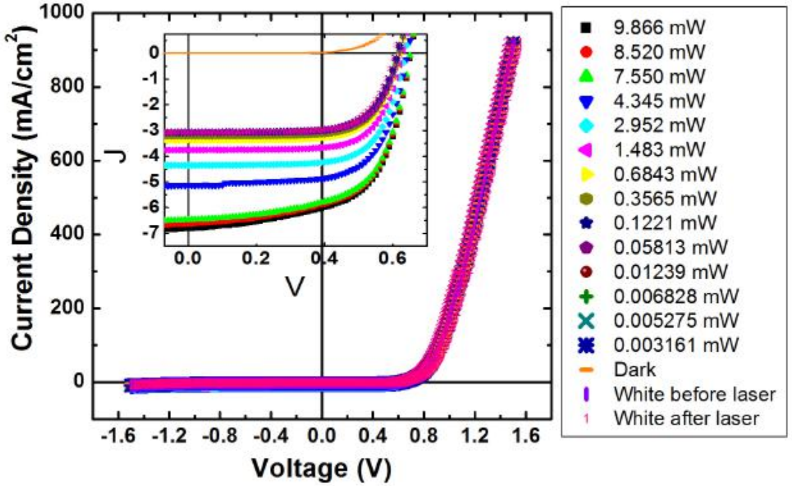


Cheng, Y. et al. "Investigation Of Inas/Gaas1−Xsbx Quantum Dots For Applications In Intermediate Band Solar Cells". Solar Energy Materials and Solar Cells 147 (2016): 94-100. Web. 5 Apr. 2016.

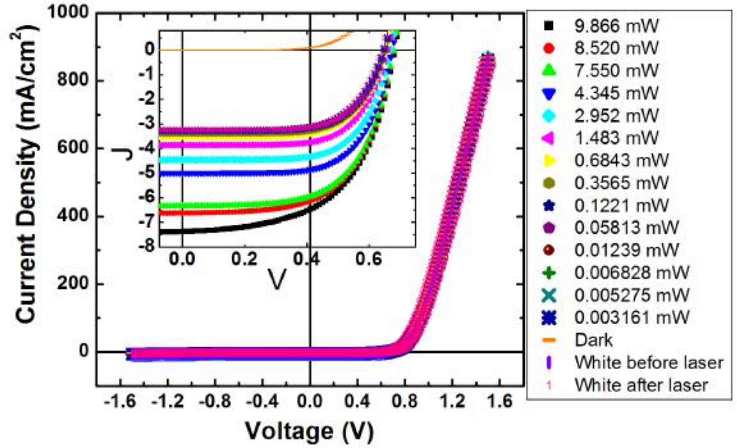
Experimental Data and Analysis: 632nm with white light

- Temperature dependent current density vs. voltage for 632nm red laser (above bandgap photons) plus white light

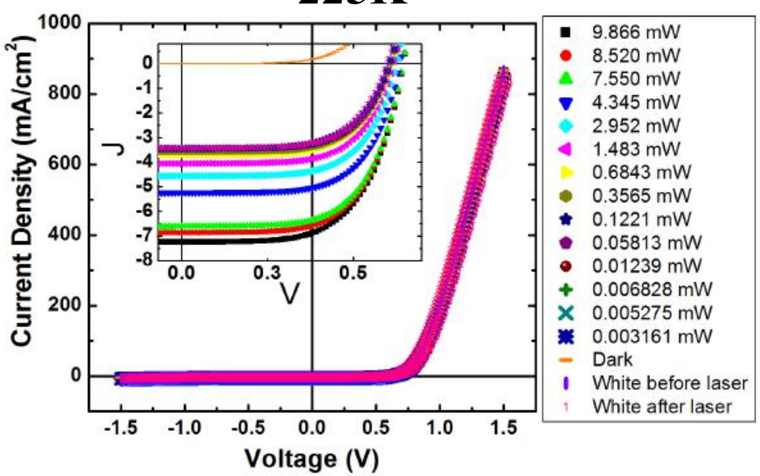
77K



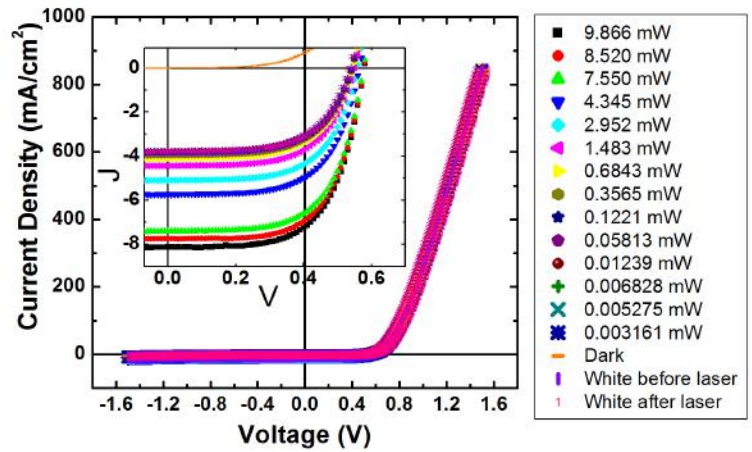
150K



225K

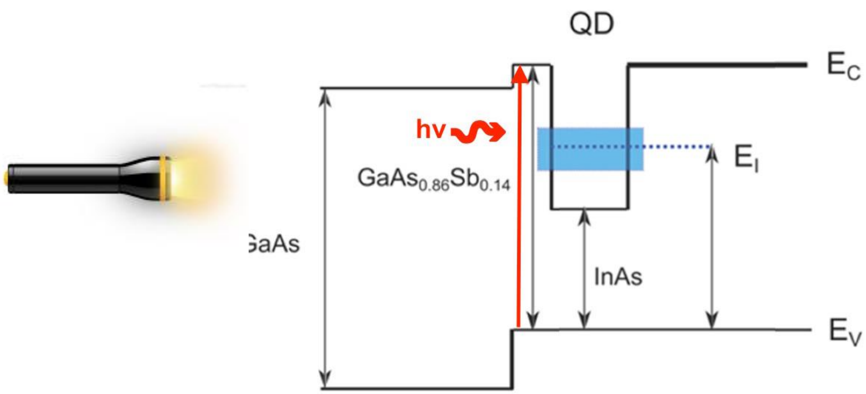


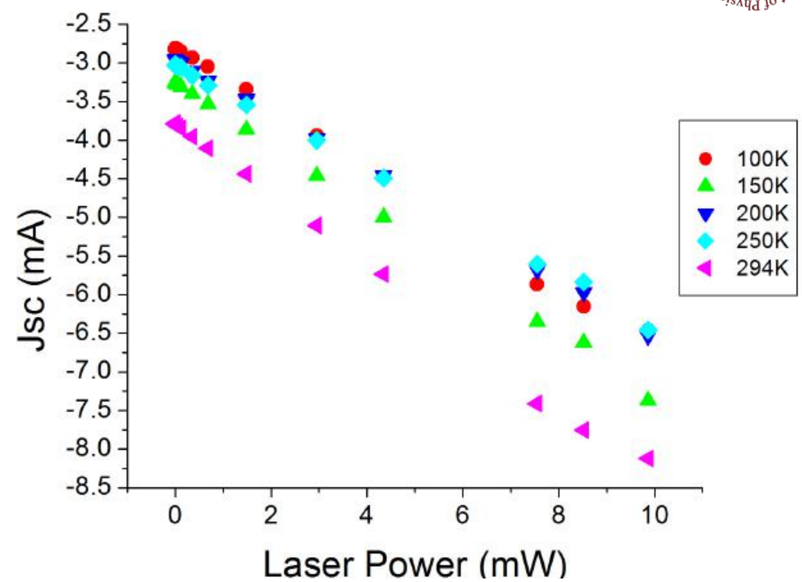
297K

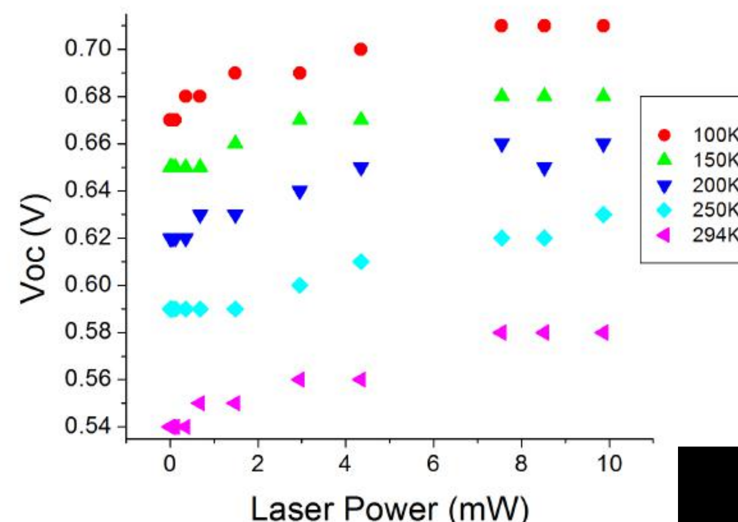


Experimental Data and Analysis: 632nm with white light

- Temperature and power dependent short circuit current and open circuit voltage for 632nm laser with white light
- White light appears to passivate defects to allow study of laser's effect
- Short circuit current – increases with power, no trend with temperature
- Open circuit voltage – increases with power, decreases with temperature
- Defects outside quantum dots



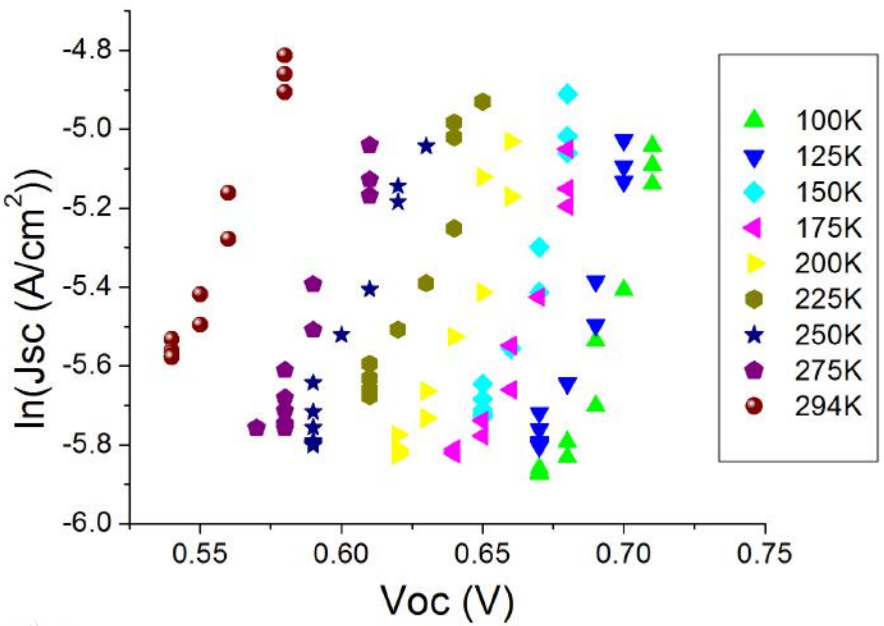


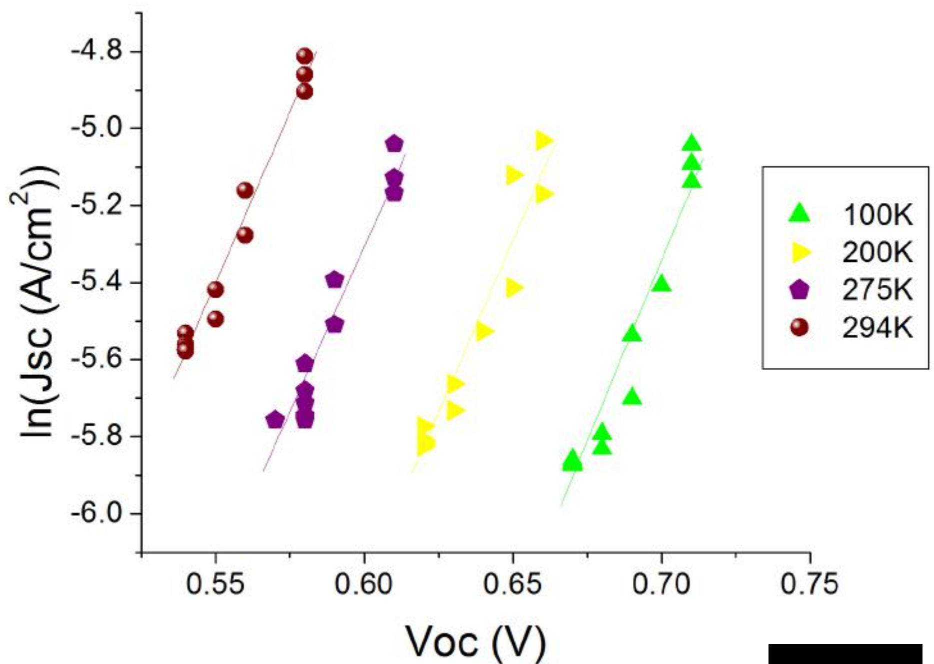


Cheng, Y. et al. "Investigation Of Inas/Gaas1−Xsbx Quantum Dots For Applications In Intermediate Band Solar Cells". Solar Energy Materials and Solar Cells 147 (2016): 94-100. Web. 5 Apr. 2016.

Experimental Data and Analysis: Temperature Dependent Ideality Factor

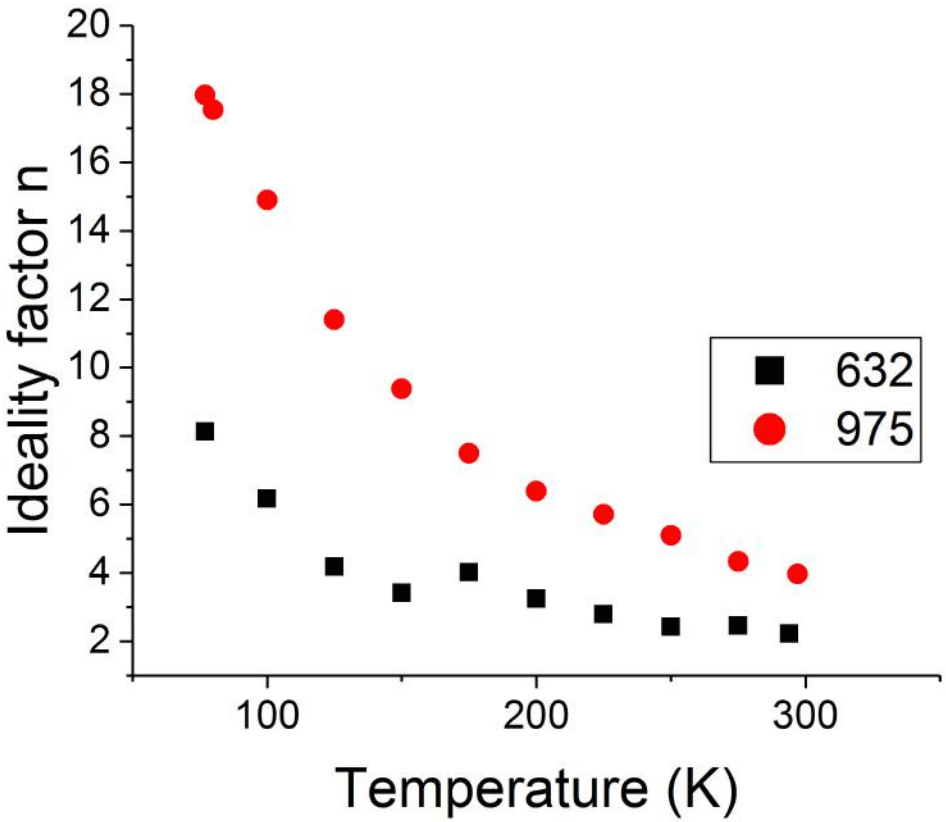
- 632nm excitation
- Dark current: $J_{dark} = J_0 (e^{qV/kT}-1)$
- Total current: $J = Jsc - J_0 (e^{qV/kT}-1)$
- $Jsc = J_0 e^{Voc/nkT}$
- Equation of fit: $\ln(Jsc) = (1/nkT) Voc + \ln(J_0)$





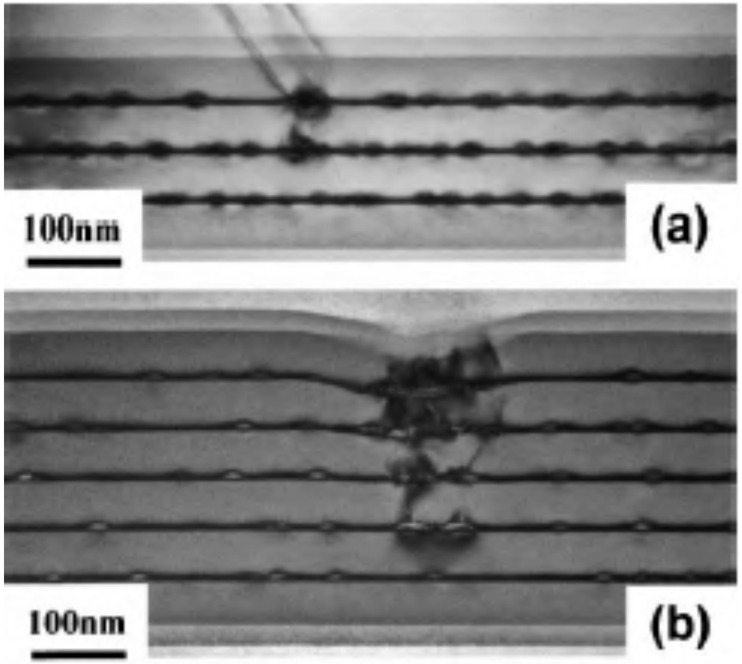
Experimental Data and Analysis: Temperature Dependent Ideality Factor

- Ideality factor n vs. temperature for both lasers
- n=1 – diffuse current (ideal), n=2 – generation recombination current (expected for this sample)
- High n at low temperatures – competing quantum dots
- n approaches 2 with higher temperature but doesn't reach it



Summary and future work

- Summary
  - Major limiting factor of this InAs/GaAsSb solar cell – probably defects outside quantum dots
  - Investigated by exciting sample below and above band gap
  - White light to passivate defects and improve reproducibility
- Future work
  - Tunneling electron microscope for imaging
  - Concentration measurements



Liu, H. et al. "Improved Performance of 1.3μm Multilayer InAs Quantum-Dot Lasers Using A High-Growth Temperature GaAs Spacer Layer". Applied Physics Letters 85 (2004). Web. 12 Mar. 2017.