Selective Defects Passivation of GaInNAs Solar Cells by Hydrogenation

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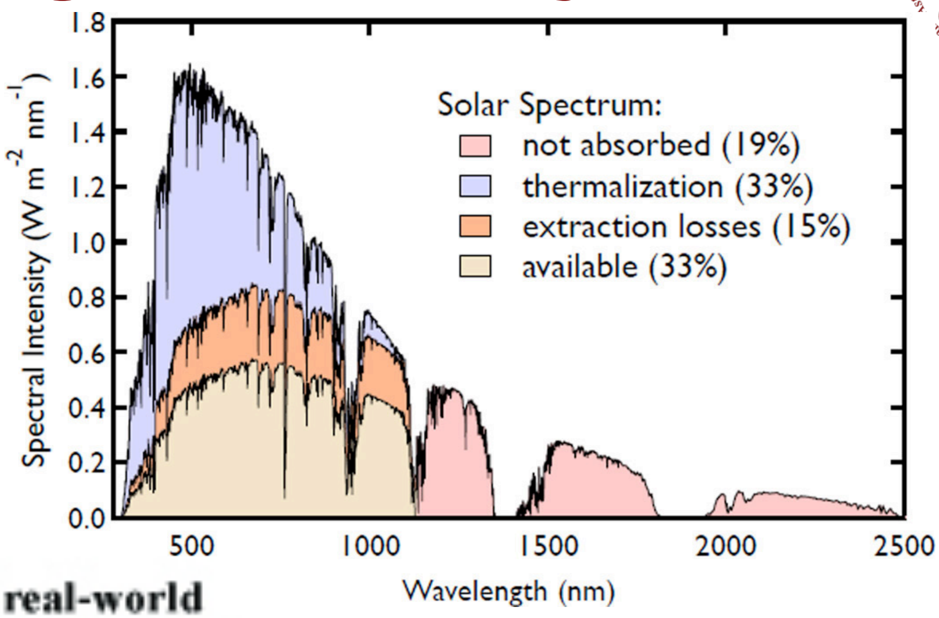
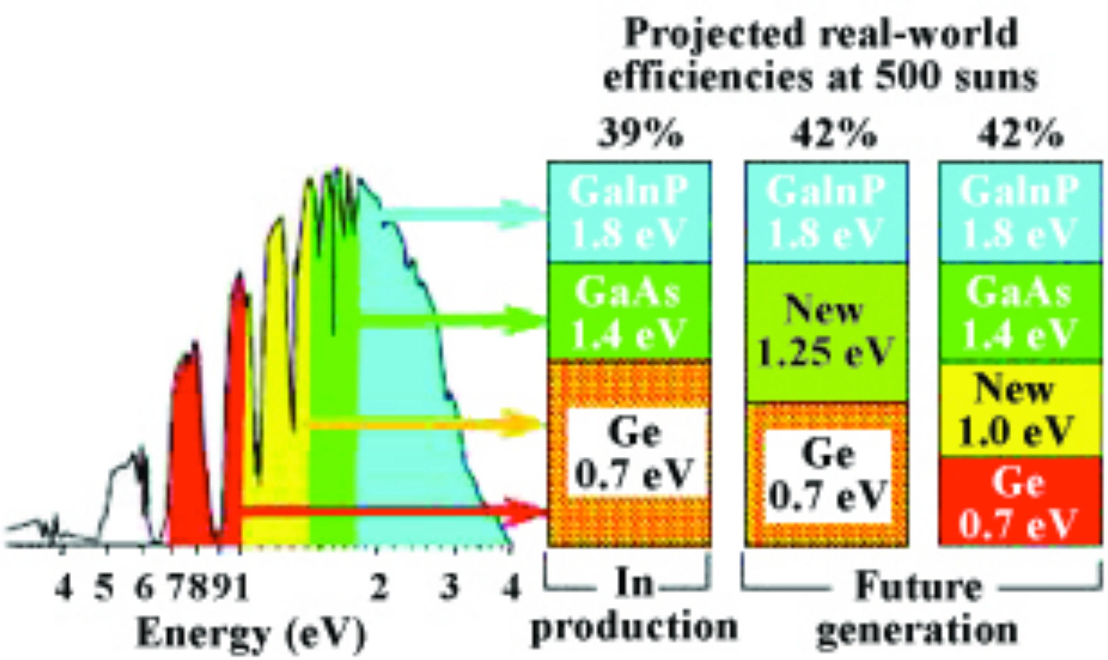
OUTLINE:

- Introduction: Single vs. Multi-junction Solar Cells
- Extra Junction – Dilute Nitride Material
- How to improve the material quality
- Dilute Nitride Solar Cells Experiments Results

Introduction: Single vs. Multi-junction



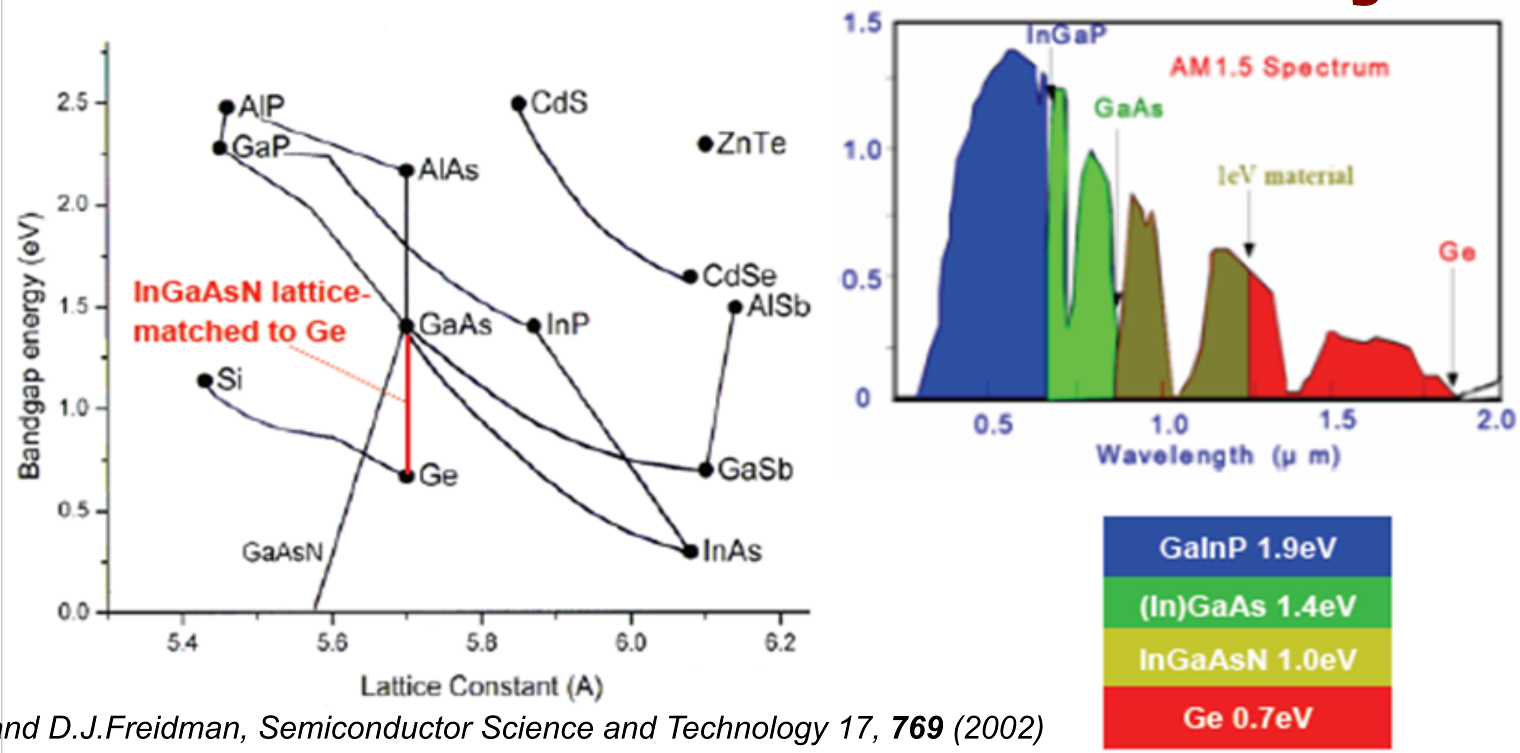
Single:
- Can absorb partial of Solar Spectra



Multi-junction:
- Each layer absorb different Solar spectrum
- Need to be
  - Lattice Matched
  - Current Matched

*J.F. Geisz and D.J.Freidman, Semiconductor Science and Technology 17, **769** (2002)*

Extra Junction:
Dilute Nitride Material as 4th Layer



*J.F. Geisz and D.J.Freidman, Semiconductor Science and Technology 17, **769** (2002)*

Design by Kurtz: GaInNAs *<u>lattice matched</u>* to GaAs/Ge
=> potential for > 42 % efficiency SC

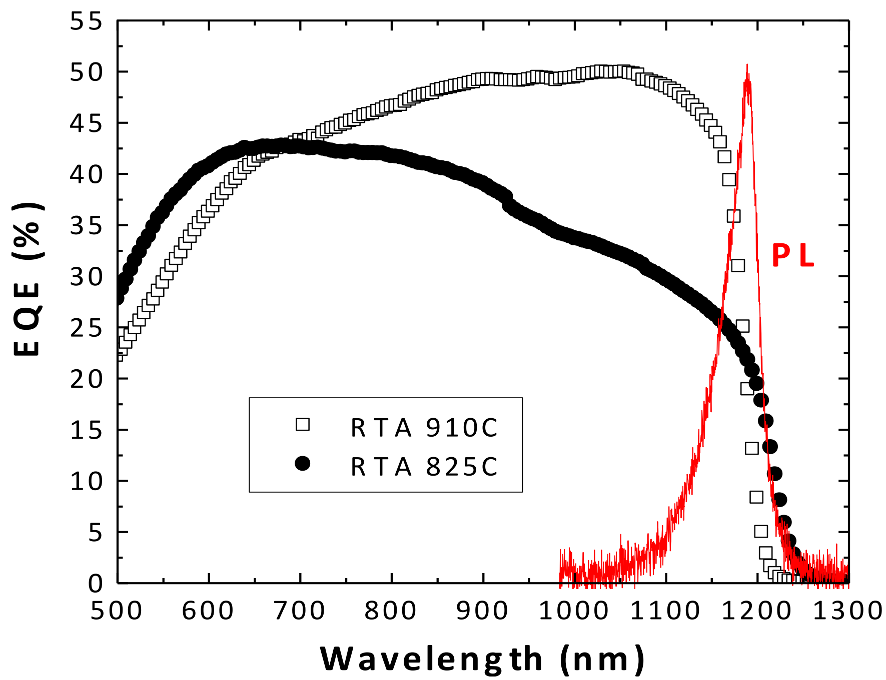
<u>Problems:</u>

- **Low Nitrogen Solubility**
- **Phase Segregation**
  =>Short Diffusion Length

How to solve
the quality problems?

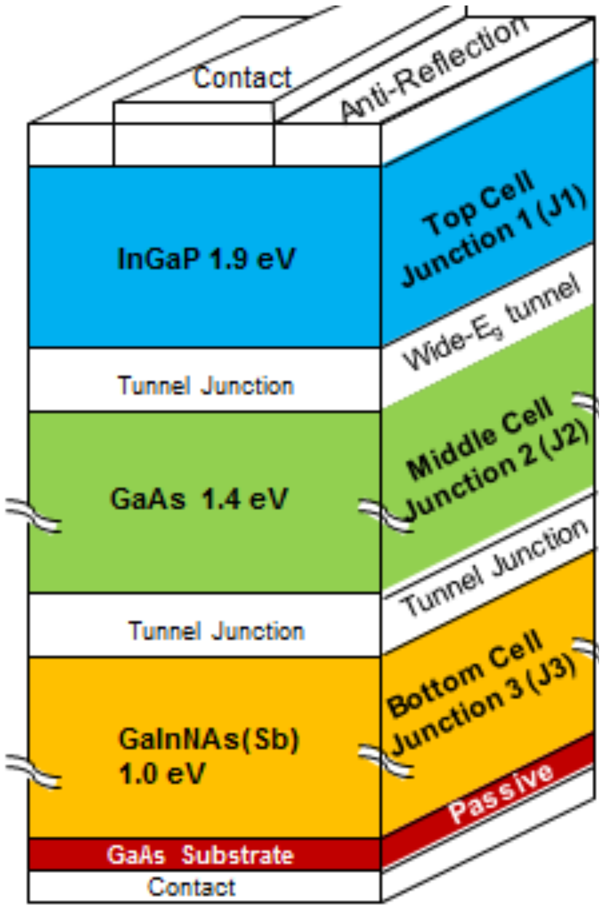
1. Rapid Thermal Anneling

- **Post-growth RTA helps improving the material quality.**



Sellers et al. Appl. Phys. Lett. ***99****, 151111 (2011)*

GaInNAs in Solar Cells



Proceedings of SPIE, ***8108***, *810804 (2011)*

- **Solar Junction achieved 43.5% Efficient CPV using Dilute Nitride ☺**

43.5% Efficient Lattice Matched Solar Cells

Michael Wiemer, Vijit Sabnis, Homan Yuen
Solar Junction, 401 Charcot Avenue, San Jose, CA, USA, 95131;

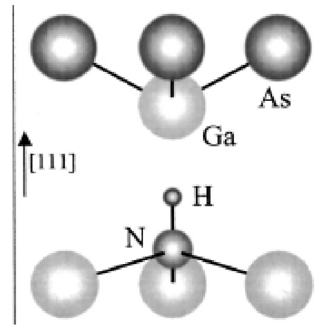
ABSTRACT

The most common triple-junction solar cell design which has been commercially available to date utilizes a germanium bottom cell with an (In)GaAs and InGaP middle and top cell respectively. This type of device has a well-known efficiency limitation somewhere around 40% at 500 suns. Higher efficiencies can be obtained by changing the effective bandgaps of the three junctions, but the choice of materials and approaches to do so is very limited. We at Solar Junction have adopted the dilute nitride material system to obtain these new bandgaps, and break through the 40% efficiency barrier. The unique advantage of the dilute nitrides is that the bandgap and lattice constant can be tuned independently, allowing bulk material lattice matched to Germanium or GaAs over a wide range of bandgaps. The dilute nitride technology in our first commercial product has enabled us to maximize the efficiency of a triple junction solar cell by using the optimal set of bandgaps (including one around 1eV). Commercial Solar Junction concentrator cells with efficiencies of 43.5% have been independently verified by NREL and Fraunhofer. These higher efficiencies are generally the result of higher output voltage, not higher current, which keeps system-level resistive wiring losses in check.

Keywords: CPV, Multi-junction, Solar Cell, Solar Junction, 43.5%, Lattice Match, Concentrator

What else to improve the quality?

2. Hydrogenation



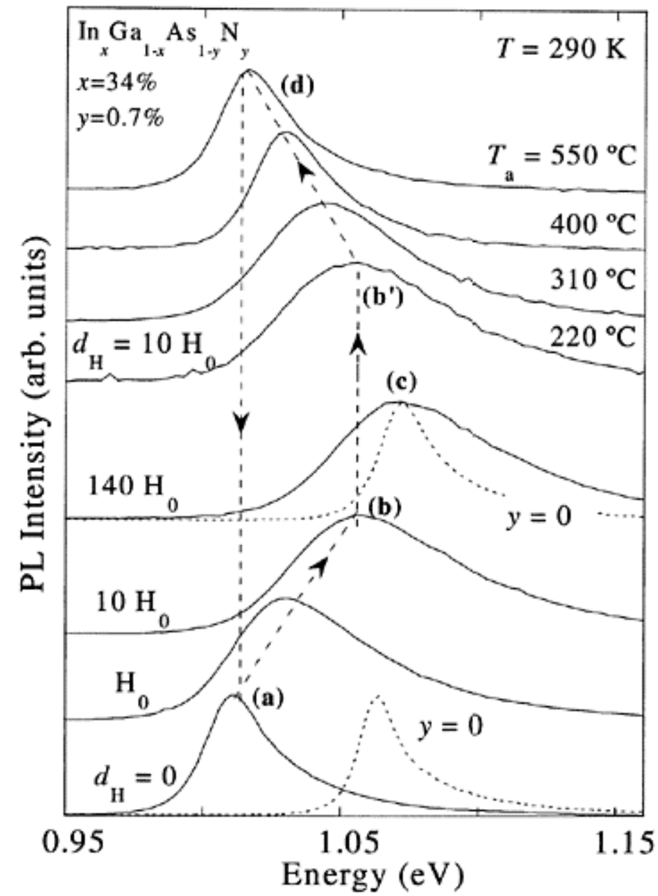
Bissiri *et al*. Phys. Rev. B. **65**, 235210 (2002)

Hydrogenation has been studied extensively in the dilute nitrides

"Physics and Applications of Dilute Nitrides," Vol 21, Chapter 6, "Role of Hydrogen in Dilute Nitrides," Polimeni & Capizzi, published by Taylor & Francis Group

- **Passivation of Defects by Hydrogenation**

- **N-H bond removes effect of nitrogen in alloy**
- **The Hydrogenation effect is reversible: RTA break the bond**
- **Disassociation temperature different for various centers**

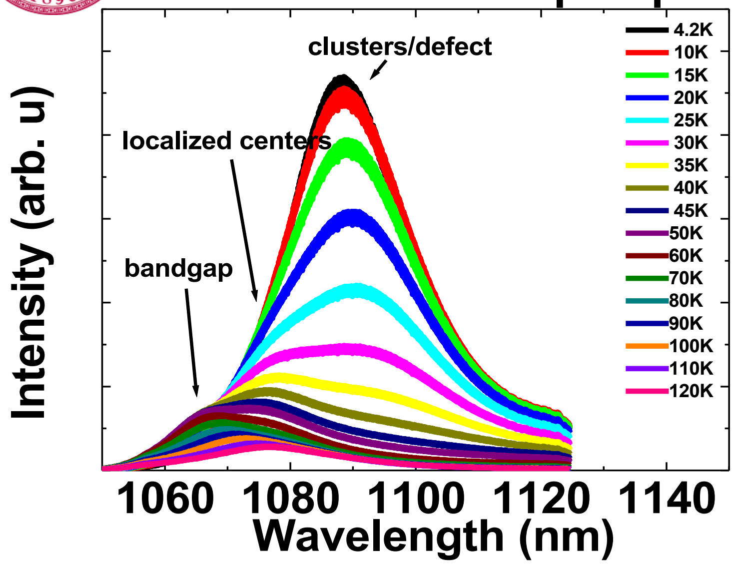


A. Polimeni *and M. Capizzi*. "Role of Hydrogenation in Dilute Nitrides". Physics and Application of Dilute Nitrides **169,** (2004)

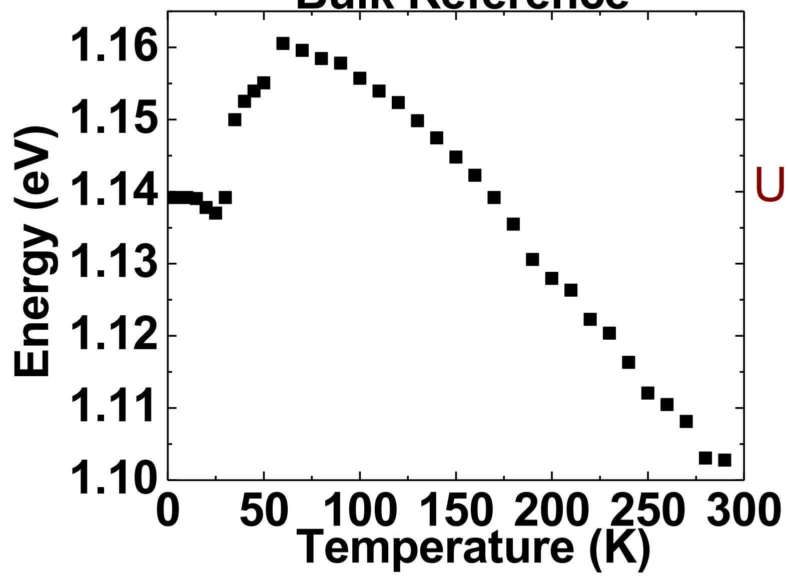
Selective Defects Passivation in Solar Cell Materials

Selective Passivation

Bulk Reference Temp.Dep.



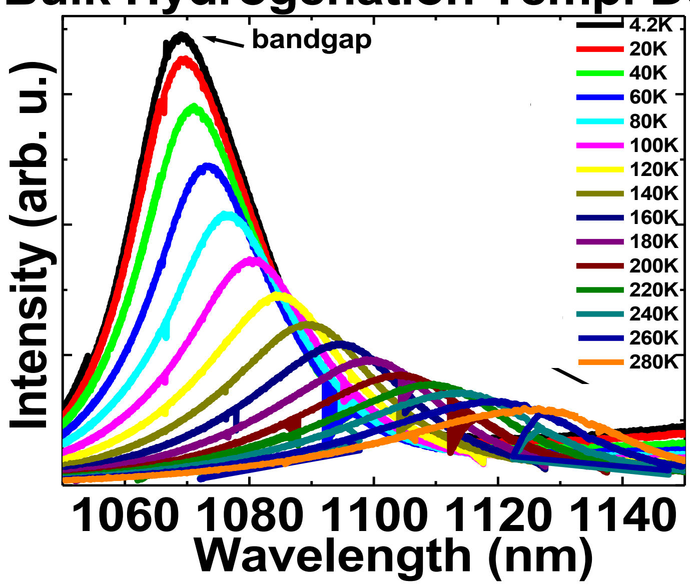
Bulk Reference



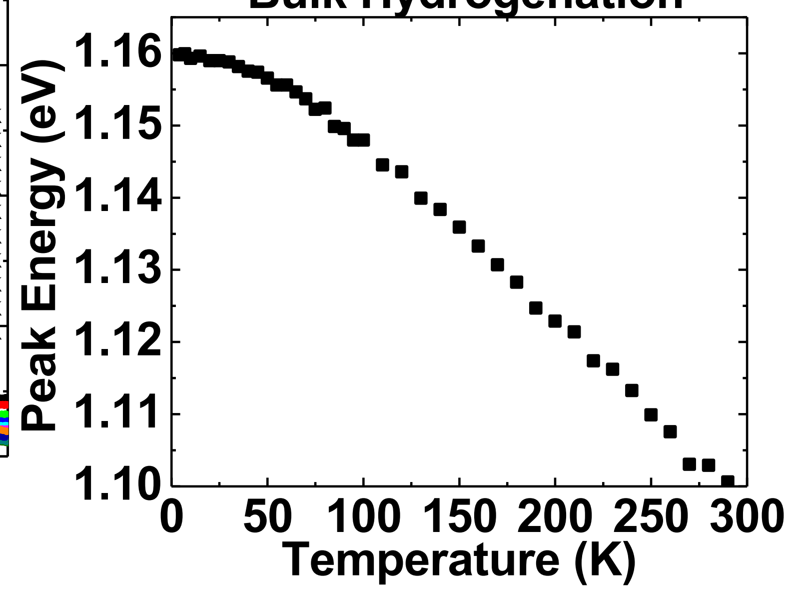
Un-hydrogenated (Top)

Hydrogenated (Bottom)

Bulk Hydrogenation Temp. Dep.



Bulk Hydrogenation

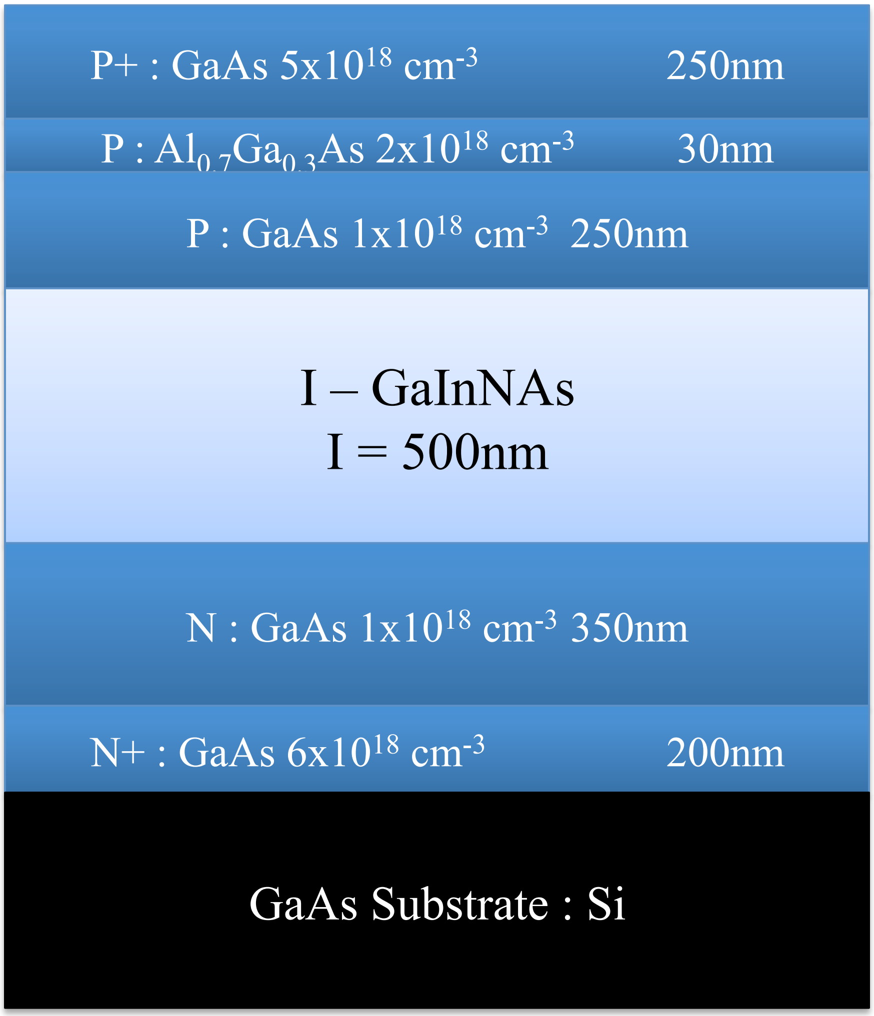


Hydrogenation by Amethyst Research Inc.

Penetration depth approximately 2μm

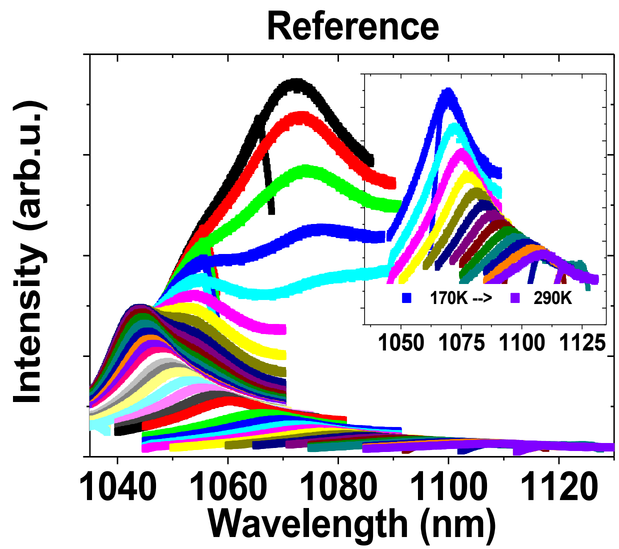
Hydrogen concentration: $1.1 \times 10^{15} cm^{-2}$

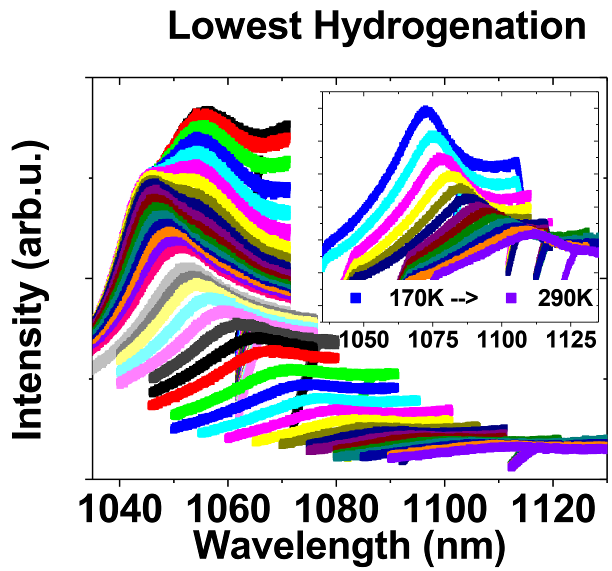
Structure of the Solar Cells

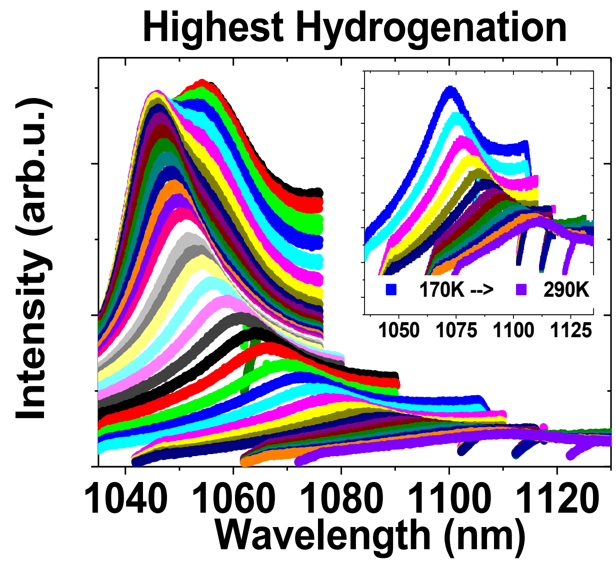


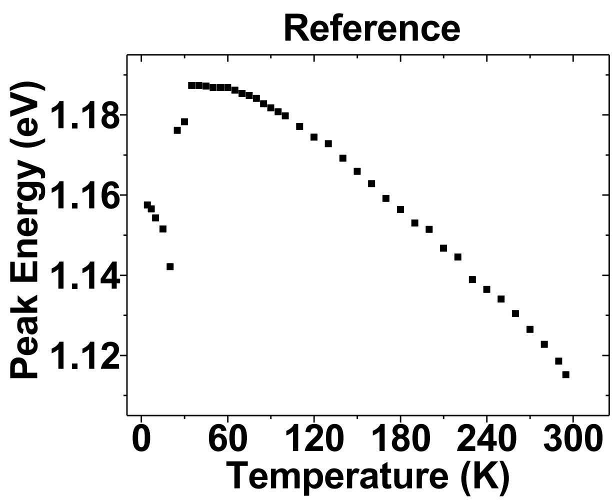
- pin
- GaInNAs Solar Cell
  I=500nm

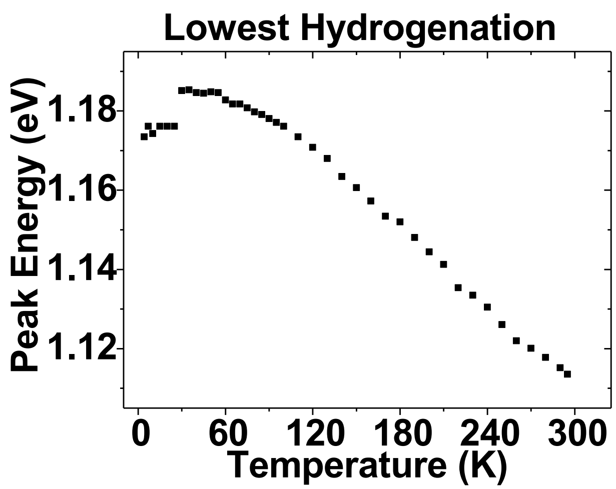
l = 500nm GaInNAs Solar Cell Temperature Dependence

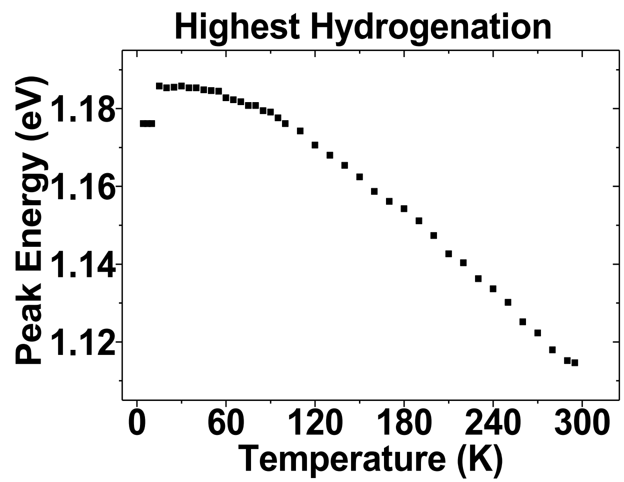




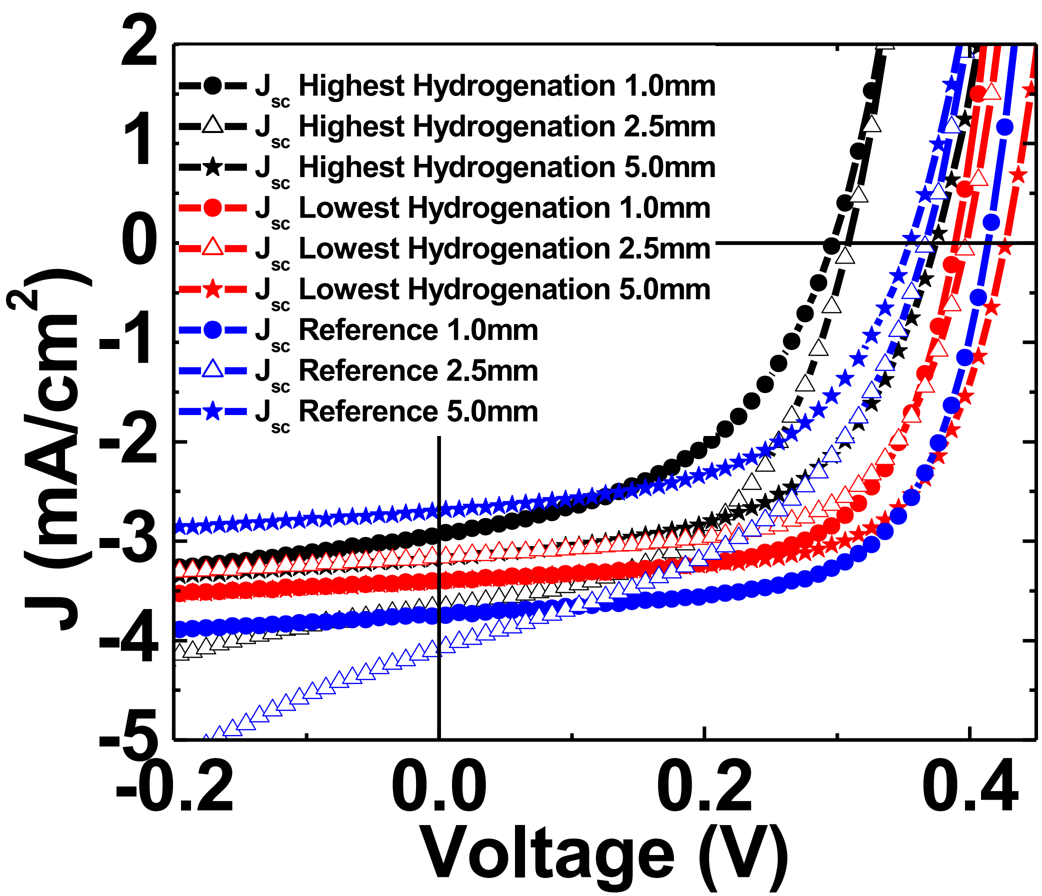


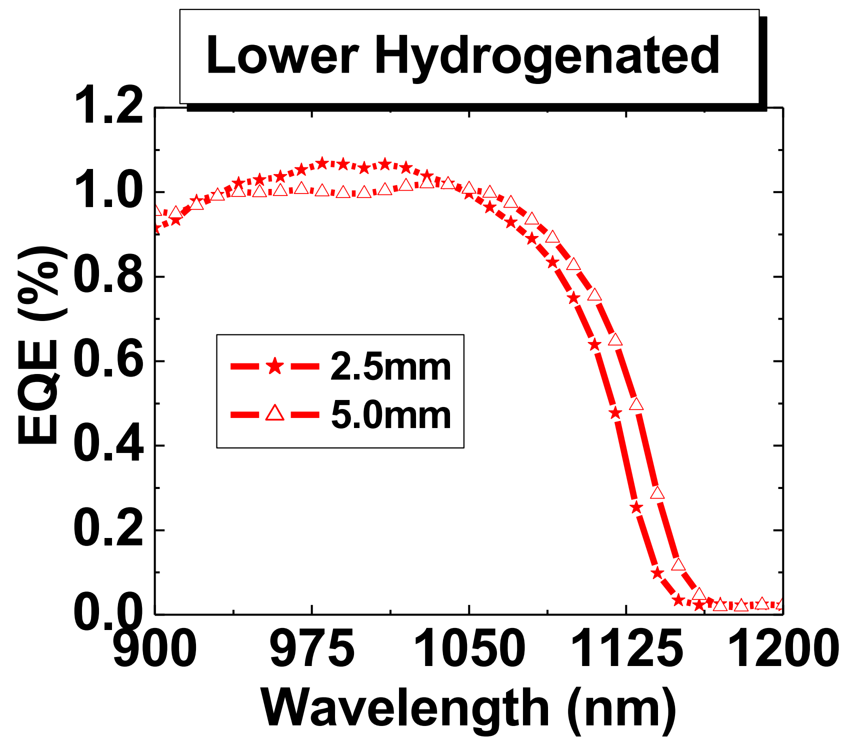






I = 500nm GaInNAs Solar Cell
JV and EQE





Summary

- Removal/reduction of defects in GaInNAs observed in both bulk materials and non-optimized solar cells.

- The passivation process shows the removal of low-energy defects and impurities can be achieved without removing substitutional nitrogen: depends on hydrogen/defect contraction ratio

- Selective passivation has potential to improve the efficiency of GaInNAs based solar cells be selectively passivating deleterious non-radiative centers, including nitrogen clusters and unwanted impurity states improving carrier collection

Acknowledgments

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