Optimization of Ohmic Contacts and Current Spreading Layers for GaN Based Solar Cells

Micah S. Points

Electrical Engineering, University of Texas at Austin

NNIN REU Site: Nanotech @ UCSB, University of California, Santa Barbara, CA

NNIN REU Principal Investigator(s): Steven P. DenBaars, Department of Electrical and Computer Engineering and Materials Department, University of California, Santa Barbara

NNIN REU Mentor(s): Samantha Cruz, Materials Department, and Carl Neufeld, Department of Electrical and Computer Engineering, University of California, Santa Barbara

Contact: mpoints@mail.utexas.edu, denbaars@engineering.ucsb.edu, sccruz@umail.ucsb.edu

Abstract:

Single-junction solar cells are approaching thermodynamic limits with peaked energy conversion efficiencies of ~25%. These solar cells are limited to a theoretical efficiency of ~30% because single-junction solar cells, like silicon (Si) and gallium arsenide (GaAs), can only efficiently absorb photons with energy near the bandgap energy (E_g) of the material. Multi-junction solar cells avoid this limit by stacking several materials with different bandgaps, each absorbing a small portion of the solar spectrum at a higher efficiency. The theoretical efficiency of multi-junction solar cells is as high as 86% for an infinite stack. Bandgaps of indium gallium nitride (InGaN) alloys can span the solar spectrum enabling the design of nearly ideal multi-junction solar cells. The focus of this project is to optimize the p-ohmic contacts to InGaN/GaN solar cells to enhance device performance. Thin conductive films were used as current spreading layers in order to decrease contact resistance and enhance carrier collection. Devices with fill factors over 80% and with open circuit voltages near 2V were achieved. Performance was found to be more affected by the absorbance properties of the contact layers than their contact resistances.

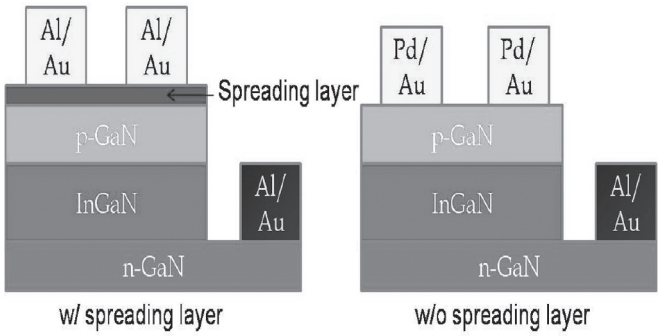

Figure 1: Device structure.

Introduction:

There are only a few reports of InGaN solar cells [1] and there is much to be studied before high efficiency multi-junction solar cells can be achieved. For high efficiency cells, there is a balance between creating electron hole pairs and extracting usable photocurrent. P-type GaN is a difficult material to contact because of its large bandgap and lower hole mobility. A possible solution is to use a contact spreading layer for increased carrier collection. The device structure is shown in Figure 1. The problem with depositing anything on the cell is that it will decrease the amount of incident light transmitted into the cell. For solar cells we must balance transparency and conductivity.

Experimental Procedures:

In this project, we studied three contact schemes: one with no contact spreading layer and a Pd/Au (300Å/3000Å) grid contact, and two spreading layers, Ni/Au, and Ni/Ni/ITO (100Å/2500Å). For Ni/Au, the Ni was held constant at 50Å, but the Au thicknesses were 10Å, 50Å, and 100Å. Contacts were made by electron beam evaporation on nominally 10% InGaN that was grown using metal oxide chemical vapor deposition (MOCVD) by Michael Iza of the Materials Department at UCSB. The Al/Au (300Å/3000Å) n-contacts were also electron beam deposited.

Those with contact spreading layers used Al/Au (300Å/3000Å) for grid contacts. The devices defined by mesa etching had an area of 250,000 μm^2 and grid spacings of 25 μm, 50 μm, 100 μm, and 166 μm. We used linear transfer length method (TLM) measurements to determine p-GaN specific contact resistance. Concurrently, sapphire substrates had the Ni/Au and Ni/ITO deposited on them. These were used to test the light transmission of each spreading layer. Current-voltage measurements were made using an Oriel solar simulator with a Xe lamp coupled to a fiber optic cable. All light measurements were conducted using an AM0 filter and were considered concentrated. Figures of merit from the current-voltage measurements were: short circuit current density, J_{sc}, open circuit voltage, V_{oc}, and fill factor, FF. The FF relates the maximum working power density achievable by the solar cell and the power defined by the J_{sc} and V_{oc}.

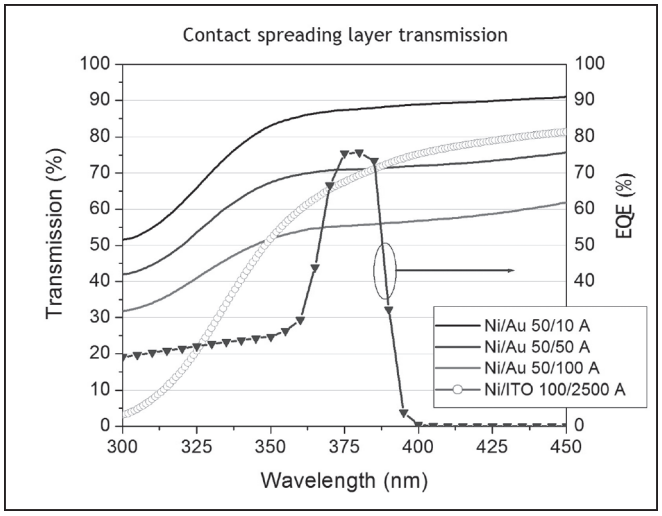

Figure 2. Optical transmission of contact layers.

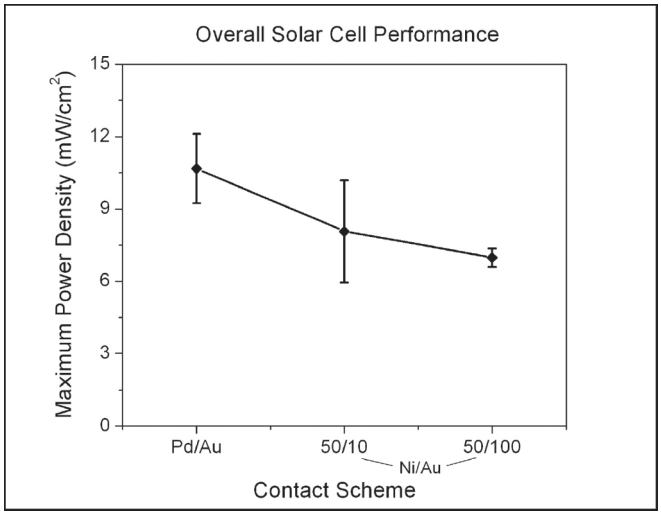

Figure 4: Maximum working power density.

Results and Conclusions:

The transmission test (Figure 2) shows that the Ni/Au 50Å /10Å sample had the highest transmission percentage. The Pd/Au sample was not tested because we assumed that the transmission was ~ 100% since no spreading layer was used. The Ni/ITO transmission was worse than both the Ni/Au 50Å/10Å and the Ni/Au 50Å/50Å samples in the region where the solar cell has peak External Quantum Efficiency (EQE).

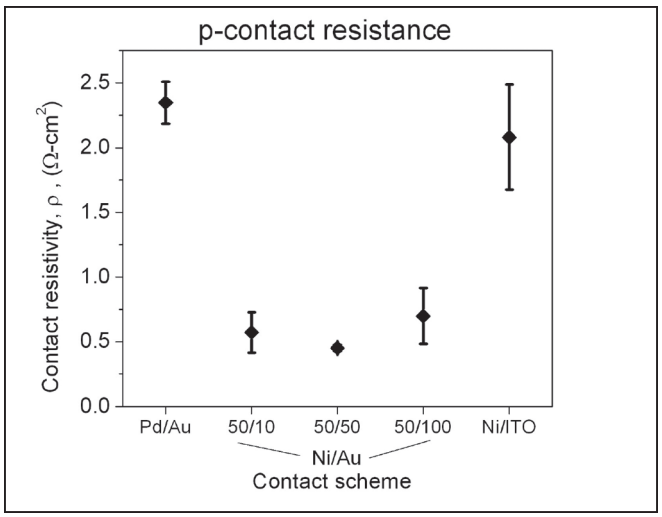

Figure 3. Specific contact resistivity of contact layers to p-GaN.

Figure 3 shows the average p-contact resistance of the samples. The Ni/Au contact schemes had lower specific resistivity (~0.5 Ω/cm^2) than Pd/Au or Ni/ITO. Since FF is affected by series resistance and leakage current, the low series resistance compared with Pd/Au and Ni/ITO allowed the Ni/Au samples to have FF near 80% while the Pd/Au was closer to 56%. The contact layer seems to have a beneficial effect on the series resistance.

The product of FF, J_{sc} and V_{oc}, or maximum power density, gives us the cell power efficiency when divided by the power of the incident light. Pd/Au has the higher measurements for J_{sc}, 0.8 mA/cm^2, and V_{oc}, 2.4V averages, even though FF was lowest. The Pd/Au sample has the higher power density maximum (Figure 4) at approximately 10.5 mW/cm^2.

The results show that the metal contact spreading layer decreases series resistance and increases FF. It also decreases the amount of light that reaches the solar cell shown by the decrease in transmission. This decrease in usable light reduces the photogenerated current density which lowers the J_{sc} and V_{oc}. This decrease eliminates the benefits of the lower series resistance and decreases the efficiency of the solar cell. Therefore, the Pd/Au contact scheme performed better in these circumstances with higher efficiency.

Future Work:

The use of different metals for ohmic contacts to p-GaN for solar cells should be studied. Determining whether different surface treatments prior to deposition of the metal can help lower resistance can also be investigated. In this project we used a 1:3 mixture of HCl and deionized water, other treatments such as boiling aqua regia may improve the contact between the metal and p-GaN.

Acknowledgments:

I would like to thank my PI Dr. DenBaars, my mentors Samantha Cruz and Carl Neufeld, and our site coordinator Angela Berenstein, for their assistance during my project. I would also like to thank the Solid State Lighting and Energy Center, the National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program and the National Science Foundation for the opportunity to take part in this program.

References:

[1] Jani, Omkar et al., "Design and Characterization of GaN/InGaN Solar Cells", Applied Physics Letters, 91, 132117 (2007).