Application of Copper Atomic Layer Deposition to Solar Cells

Kyle Stachowiak[1], Brian Willis[2]

[1]Vanderbilt University Department of Chemical and Biomolecular Engineering

[2]University of Connecticut Department of Chemical and Biomolecular Engineering

Scitech Associates, LLC

Market

Energy harvesting: **Solar Cells**

- Lately, the solar sector has rebounded strongly and displayed potential for further growth
- Solar prices continue to approach grid parity
- Increasing efficiency abets decreasing costs

Fig. (1): Array of solar cells

Additional markets:

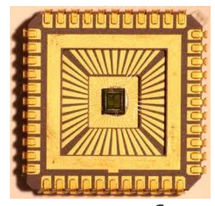


Fig (2): Microchip used in micro-electronics

- Communications
  - Increase data transfer capacity
- Microelectronics
  - Nanoscale integrated circuits

Technology

Solar Collection: **Rectenna**

- Optical rectification diode
- Serves two purposes: collects solar radiation and converts to useable DC current by way of electron tunneling
- Effectiveness driven by pointed geometry of the rectenna device

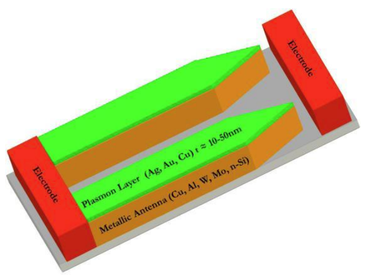


Fig. (3): Overhead view of rectenna and electrodes

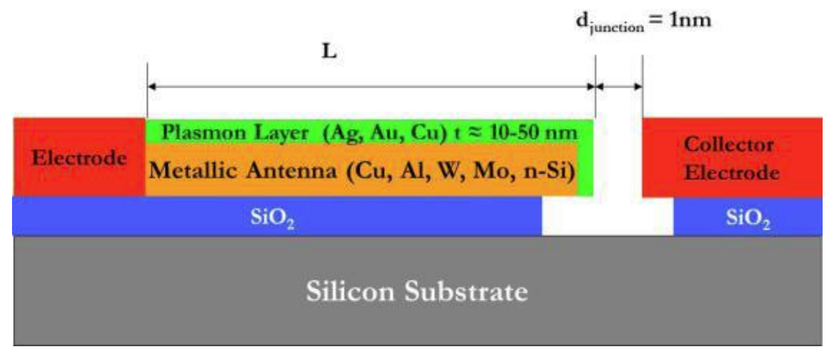


Fig. (4): Side view of rectenna and solar cell components

Manufacture: **Atomic Layer Deposition (ALD)**

- Highly selective growth of atomic layers of metals on substrates
- More controlled version of chemical vapor deposition (CVD)

This work endeavors to optimize the copper ALD process for the manufacture of ideal and reproducible rectenna devices for solar cells.

Concept

- Plasmonic enhancement occurs at sharp edges
- Enhanced field at tip leads to better electron transport and increased efficiency

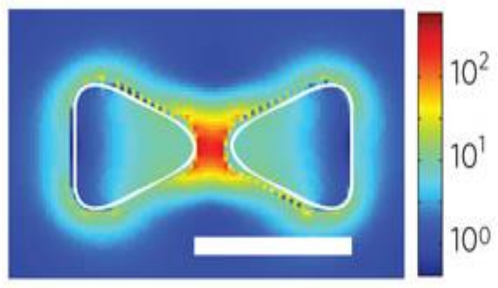
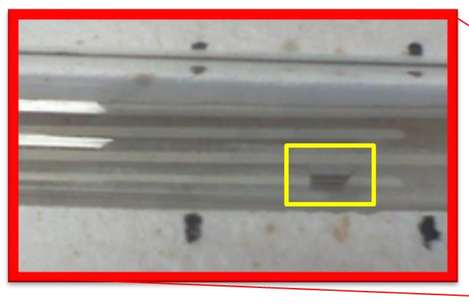


Fig. (5): Example of enhanced field generated by pointed tips

Methods

- Atomic Layer Deposition Experimental Setup



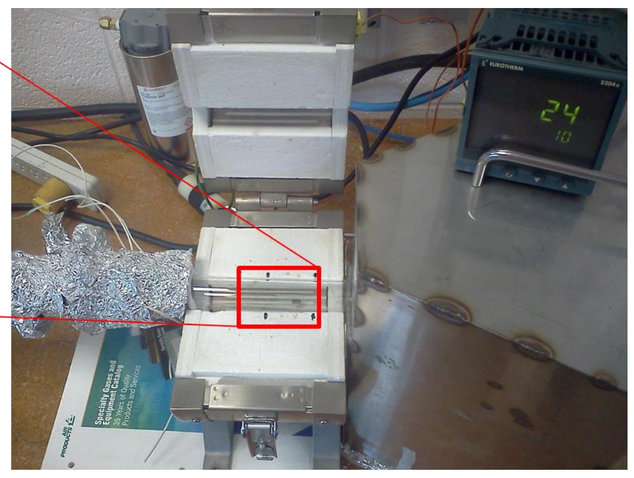
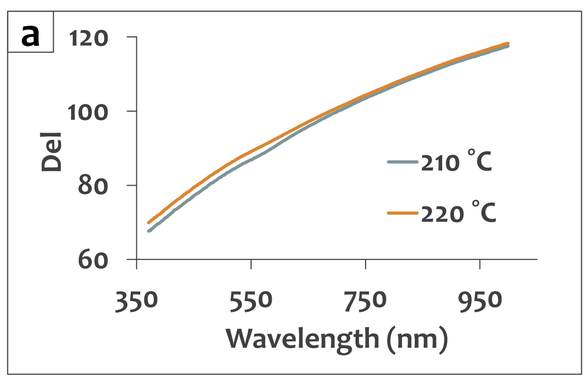
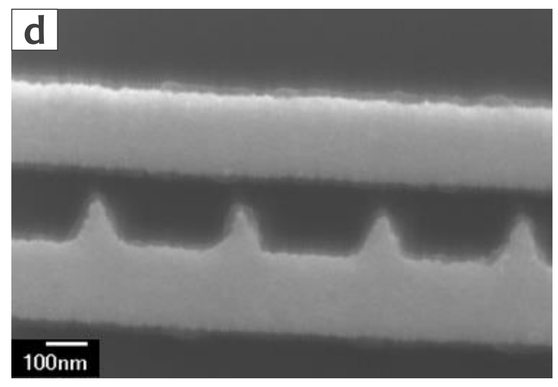


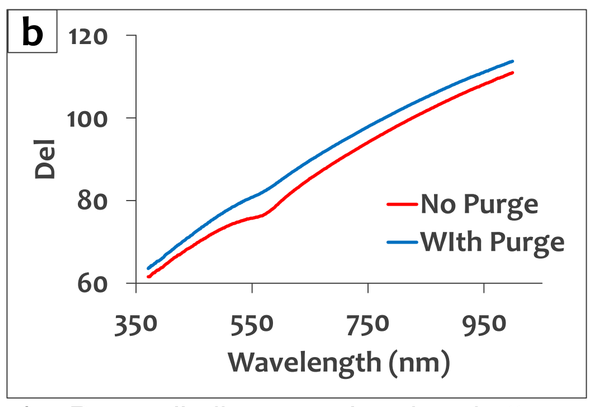
Fig. (5): Experimental setup with palladium coated sample highlighted

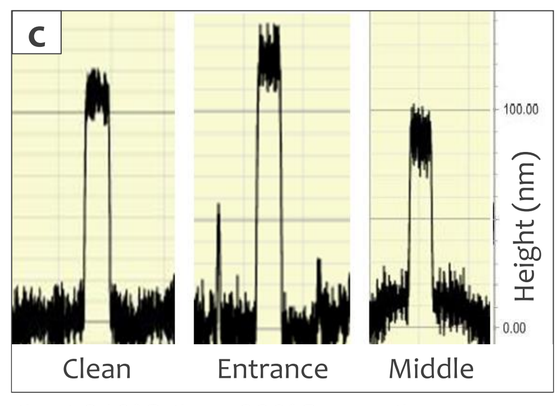
- Variable Conditions
  - Temperature
  - Time length of 2nd purge
- Measurement techniques
  - SEM imaging (growth, uniformity analysis)
  - Ellipsometry (purity of deposited layer analysis)
  - DEKTAK profiling (growth, uniformity analysis)

Results









a) Pure palladium samples show better growth at 210˚C than 220˚C over the same number of cycles.
b) The copper growth is much greater when no 2nd purge is used. The dip in the Del line at ~550nm indicates that the layer is pure copper.
c) Surface profiles of device samples showing the different step heights of features of a clean sample, and samples placed at the entrance and near the middle.
d) Scanning electron microscope image of sample substrates mimicking the rectenna device before copper is applied by ALD

Location	Height	Growth	Growth/Cycle	Copper on Pd	Copper on SiO_2
Entrance	118.3 nm	18.3 nm	.037 nm/cycle	23%	0%
Exit	109.5 nm	9.5 nm	.019 nm/cycle	20%	0%

Table 1: Samples closer to entrance show greater copper growth, suggesting that CVD could play a role in the process. The growth rate per cycle is consistent with what is expected of a copper ALD reaction however.

Conclusions

- CVD plays a role when no 2nd purge stage is used
  - Occurs due to mixing of H_2 and Cu in reactor
  - The effects of short times (1-2 seconds) for 2nd purge should be examined in future experiments
- Temperature of reactor is highly important
  - Layer desorption significant at higher temperatures
  - Loss of selectivity occurs at higher temperatures

Acknowledgements

- National Science Foundation: Research Experience for Undergraduates Program
- Scitech Solar: Dan Cutler
- UConn: Professors: Brian Willis, Rich Dino, Jeff McCutcheon
  Graduate Students: Jie Qi, Xiaoqiang Jiang, Kan Fu

Citations:
Fig 1: http://solarenergypanelshop.com/wp-content/uploads/Monocrystalline-Solar-Panel.jpg
Fig 2: http://www.sjalander.com/research/images/chip2006.jpg Fig 3,4: Scitech Solar
Fig 5: Kinkhabwala, A., Yu, Z., Fan, S., Avlasevich, Y., Müllen, K., Moerner, W.E.
Large single-molecule fluorescence enhancements produced by a bowtie nanoantenna. (2009) Nature Photonics, 3 (11), pp. 654-657.

Student Contact: kyle.j.stachowiak@vanderbilt.edu
Advisor Contact: bgwillis@engr.uconn.edu