

## II.2.1 Nanostructured Photovoltaic Cells

### Investigators

Michael D. McGehee, Assistant Professor, Materials Science and Engineering; Yuxiang Liu, Vignesh Gowrishankar, Jarrett Dumond, Shawn Scully, Kevin Coakley, Graduate Researchers

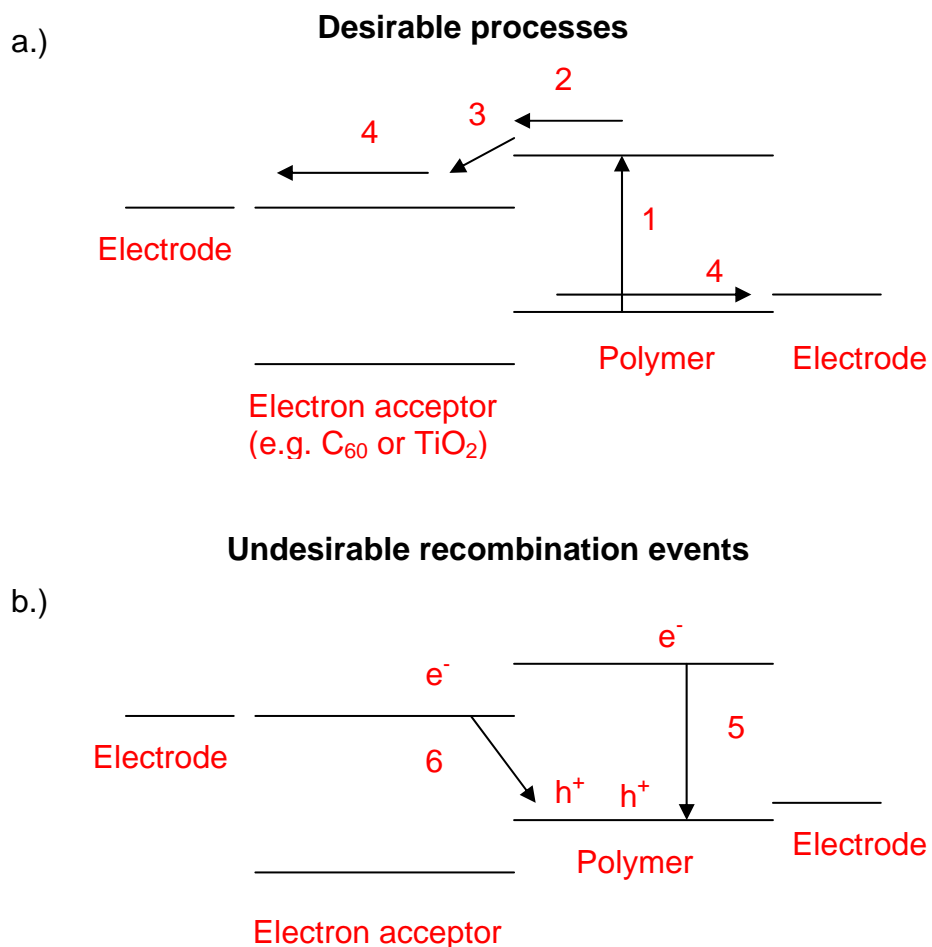
### Introduction

This project involves making efficient photovoltaic (PV) cells with semiconducting polymers that could be deposited in reel-to-reel coaters. Careful analysis and optimization of each process that occurs in bulk heterojunction PV cells will be carried out and devices based on ordered interpenetrating networks of organic and inorganic semiconductors will be created. Specifically this research will lead to devices that will efficiently split excitons and carry charge to electrodes, that will have improved packing of the molecules in the organic semiconductor to enhance its ability to carry charge, and that will have a modified organic-inorganic interface to prevent recombination of electrons and holes. It is anticipated that charge recombination in the cells will be almost completely eliminated and energy conversion efficiencies in the range of 10-15% will be obtained.

### Background

Currently the best commercially available PV cells are made of crystalline silicon and have an energy conversion efficiency of 12%. The cost of these cells is \$3 per Watt of power generated under solar AM 1.5 conditions. These costs need to be reduced by an order of magnitude to around \$0.3 per Watt for PV cells to be competitive with other energy generation systems and be manufactured on a large scale. A revolutionary breakthrough in reducing the costs of PV cells may be achieved if the semiconductor were deposited from solution onto large flexible substrates in reel-to-reel coating machines similar to those used to make food packaging. Manufacturing costs would be much lower because reel-to-reel coaters use very little energy and have an exceptionally high throughput. Installation costs would be lower because lightweight flexible PV cells could be handled more easily than heavy silicon panels. Since organic semiconductors, such as conjugated polymers, can be deposited from solution, they are very attractive for PV applications. Research on organic PV cells has shown that it is important to have two semiconductors with a large interfacial area so that photogenerated excitons can be split by electron transfer.[1-4] PV devices with interpenetrating networks of two semiconductors are known as bulk heterojunction cells.

The processes involved in operating a bulk heterojunction PV device are shown in Figure 1. To optimize performance of these cells, the desirable processes (1. light absorption, 2. exciton diffusion, 3. forward electron transfer, and 4. charge transport) should be maximized, while the undesirable recombination processes (5. geminate recombination and 6. back electron transfer) should be limited. This can be achieved by improving charge carrier mobility and slowing down the rate of back electron transfer so that photogenerated charge carriers can escape from the film before recombination occurs, while maintaining a thick enough film to allow most of the light to be absorbed.



**Figure 1:** A schematic diagram of the energy levels in an organic heterojunction photovoltaic cell and the electronic processes (defined in the text) that occur in one.

### Results and Future Plans

Since the project began in January of 2004, we have focused our research on making inorganic semiconductor films with straight pores, improving exciton transport to organic-inorganic interfaces and increasing the charge carrier mobility of conjugated polymers confined to nanopores. These are important steps towards our long-term goal of enabling the reel-to-reel manufacturing of bulk heterojunction PV cells. We are currently preparing to submit these results for publication and when post them here when they have been published.

## Conference Presentations

1. "Ordered Bulk Heterojunction Photovoltaic Cells," M.D. McGehee, K.M. Coakley, Y. Liu, C. Goh, Materials Research Society Meeting, San Francisco, CA, April 12-16, 2004.
2. "Improving the Efficiency of Bulk Heterojunction Photovoltaic Cells," M.D. McGehee, K.M. Coakley, Y. Liu, C. Goh, American Chemical Society Meeting, Anaheim, CA, March 30- April 2, 2004.

## References

1. Yu, G., Gao, J., Hummelen, J. C., Wudl, F. and Heeger, A. J., Polymer Photovoltaic Cells: Enhanced Efficiencies Via a Network of Internal Donor-Acceptor Heterojunctions, *Science* **270**, 1789-91 (1995).
2. Shaheen, S. E., Brabec, C. J., Sariciftci, N. S., Padinger, F., Fromherz, T. and Hummelen, J. C., 2.5% Efficient Organic Plastic Solar Cells, *Appl. Phys. Lett.* **78**, 841-843 (2001).
3. Huynh, W. U., Dittmer, J. J. and Alivisatos, A. P., Hybrid Nanorod-Polymer Solar Cells, *Science* **295**, 2425-2427 (2002).
4. Peumans, P., Yakimov, A. and Forrest, S., Small Molecular Weight Organic Thin-Film Photodetectors and Solar Cells, *J. of Appl. Phys.* **93**, 3693-3723 (2003).
5. Coakley, K. M., Y., L., McGehee, M. D., Frindell, K. M. and Stucky, G. D., Infiltrating Semiconducting Polymers into Self-Assembled Mesoporous Titania Films for Photovoltaic Applications, *Adv. Funct. Mater.* **13**, 301-306 (2003).
6. Coakley, K. M. and McGehee, M. D., Photovoltaic Cells Made from Conjugated Polymers Infiltrated into Mesoporous Titania, *Appl. Phys. Lett.* **83**, 3380-2 (2003).
7. Hamley, I., Nanostructure Fabrication Using Block Copolymers, *Nanotechnology* **14**, R39-R54 (2003).
8. Masuda, H., Nishio, K. and Baba, N., Fabrication of Porous Titania Films Using Two-Step Replication of Microstructure of Anodic Alumina, *Jpn. J. Appl. Phys.* **31**, L 1775- L 1777 (1992).
9. Odom, T., Love, C., Wolfe, D., Paul, K. and Whitesides, G., Improved Pattern Transfer in Soft Lithography Using Composite Stamps, *Langmuir* **18**, 5314-5320 (2002).
10. Savenije, T. J., Warman, J. M. and Goossens, A., Visible Light Sensitisation of Titanium Dioxide Using a Phenylene Vinylene Polymer, *Chem. Phys. Lett.* **287**, 148-53 (1998).
11. Forster, T. (1965) in *Modern Quantum Chemistry, Istanbul Lectures*, ed. Sinanoglu, O. (Academic Press, Vol. Part III: Action of Light and Organic Crystals, pp. 93-138.
12. Bozano, L., Carter, S., Scott, J., Malliaras, G. and Brock, P., Temperature- and Field-Dependent Electron and Hole Mobilities in Polymer Light-Emitting Diodes, *Appl. Phys. Lett.* **74**, 1132-1134 (1999).
13. Sirringhaus, H., Tessler, N. and Friend, R., Integrated Optoelectronic Devices Based on Conjugated Polymers, *Science* **280**, 1741-1744 (1998).

## Contacts

Michael McGehee: mmcgehee@stanford.edu