

# Effects of Phase Separation on Charge Mobility in Polymer Solar Cells

Andrey Malyutin

Chemistry, Kalamazoo College

**NNIN REU Site: Center for Nanotechnology, University of Washington, Seattle, WA**

*NNIN REU Principal Investigator(s): Prof. David S. Ginger, Department of Chemistry, University of Washington*

*NNIN REU Mentor(s): Obadiah G. Reid, Department of Chemistry, University of Washington*

*Contact: malyutinag@gmail.com, ginger@chem.washington.edu, obadiah@gmail.com*

## Abstract:

One of the limiting factors in polymer solar cell performance is charge carrier mobility through the cell. Recently, it has been reported that the hole mobility in certain blends can be enhanced by adding additional electron transport material. Our hypothesis is that the phase segregation process induces local ordering which increases hole mobility. We study how the hole mobility changes as a function of blend composition and domain size in solar cells with active layers consisting of various mixtures of [6,6]-phenyl C61-butyric acid methyl ester (PCBM) (electron acceptor) and poly[2-methoxy-5-(3,7-dimethyloctyloxy)-*p*-phenylene vinylene] (MDMO-PPV) (electron donor). We show that charge carrier mobility increases as the ratio of PCBM to PPV in the active layer increases. We present AFM images of each blend, and show that phase separation between the two molecules and increase in feature size of PCBM are correlated with the increase in hole mobility.

## Introduction:

Solar energy will play a significant role in future energy production. However, the present generation of silicon solar cells cannot compete on \$/kWh basis with energy generated from fossil fuels. Polymer solar cells made from a donor/acceptor blend are one potential inexpensive alternative to silicon based devices because they can be processed from solution under standard conditions. However, their performance is not yet adequate for widespread applications [1].

The most efficient polymer solar cells fabricated to date have an active layer consisting of a mixture of two organic compounds, one acting as an electron donor and other as electron acceptor (in our case PPV and PCBM respectively). It has been observed that as concentration of PCBM increases hole mobility also increases [2]. We measured hole mobility in blends with varying PCBM concentration and observed topographical features using atomic force microscopy (AFM). From this data we propose that as concentration of PCBM increases, there is an increase in ordering of the PPV structures, which allows for more efficient charge transport through the cell.

## Experimental Procedure:

Devices were fabricated on indium tin oxide (ITO) coated glass substrates, with active areas defined by the overlap of patterned ITO and evaporated electrodes. Substrates were cleaned by sequential sonication in acetone and isopropyl alcohol (20 min), followed by an air plasma treatment (5 min). Immediately after plasma cleaning a 40 nm thick layer of poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate)

(PEDOT:PSS) was spin coated onto the substrate, and the devices were annealed in nitrogen atmosphere for 30 min at 130°C. The active layers were spin coated onto the substrates from warmed solutions (45°C) at speeds between 2000 and 4000 RPM. The devices were completed with 40 nm thick thermally evaporated gold top contacts.

The active layer solutions were prepared in chlorobenzene with an MDMO-PPV concentration of 8mg/mL, and MDMO-PPV:PCBM ratios of 1:0, 2:1, 1:1, 1:2, and 1:4. The solutions were heated (40-50°C) and stirred for 6+ hours before spin coating. Device measurements were made in a nitrogen atmosphere, using a custom-built sample chamber and a source-measure unit (Keithley 2100). We made current density-voltage (J-V) measurements, applying varying potential to individual pixels until a curve exhibiting space-charge limited current properties was obtained. The topography and thickness of each device was measured by tapping mode atomic force microscopy (Asylum Research MFP-3D).

$$J = \frac{9}{8} \epsilon \epsilon_0 \mu e^{0.89 \gamma} \left(\frac{V}{L}\right)^{1/2} \frac{V^2}{L^3}$$

Equation 1: Modified Mott-Gurney Law.

## Results and Conclusions:

We calculated the hole mobility for our devices from the J-V data using the modified Mott-Gurney law (Equation 1). Figure 1 shows a representative J-V curve and the fit using Equation 1. Figure 2 shows the calculated hole mobility at PCBM

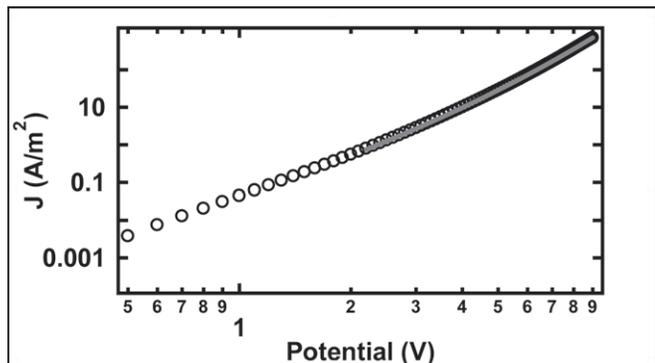


Figure 1: J-V graph with modified Mott-Gurney Law fit.

concentrations of 0%, 33%, 50%, 67%, and 80% for five sets of devices. Each set shows a different trend, but on average the hole mobility increases with increasing PCBM concentration. Figure 3 shows AFM topography measurements of the 67% and 80% PCBM blends. For mixtures with 0%, 33%, and 50% concentration of PCBM topography images are nearly identical to the 67% mixture, with no distinguishable features. Active layers with 80% PCBM show very well defined PCBM formations (high regions).

The mobility data in Figure 2 shows an average trend of increasing hole mobility with PCBM content, and this correlates with an increasing degree of phase separation between PPV and PCBM measured by AFM. This observation supports our hypothesis, that increasing amount of PCBM in the active layer increases the ordering of PPV structures, allowing for more efficient charge transport. However, there is significant variation in calculated hole mobility from set to set, which makes it difficult to draw firm conclusions.

### Future Work:

We would like to further characterize our samples and explore affects of phase separation on charge carrier mobility by using conductive atomic force microscopy (c-AFM). Using this technique will both enable us to resolve smaller structural features, and provide a direct mapping of hole transport through the film. In addition, using other solvents, such as

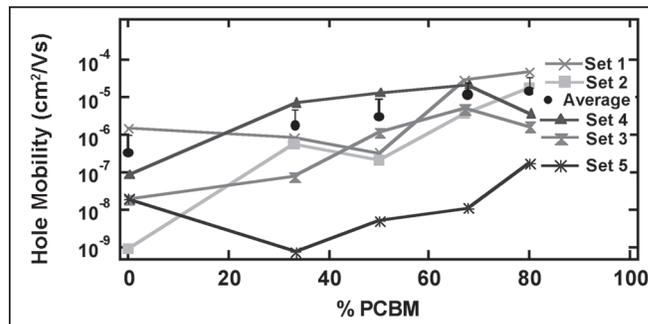


Figure 2: Five sets of PPV:PCBM in CLB devices.

dichlorobenzene and xylenes, or organic materials, such as P3HT instead of MDMO-PPV, will produce different phase separation and allow us to study how it affects the mobility. Preparing samples in a glove box might also prove useful, as exposure to ambient atmosphere may affect the performance and reproducibility of our devices [3].

### Acknowledgments:

I would like to thank Prof. David S. Ginger, Obadiah Reid, and the rest of the Ginger Lab, National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program, National Science Foundation, Ethan Allen, and the University of Washington.

### References:

- [1] Shaheen, S.; Ginley D.; Jabbour, G. "Organics-Based Photovoltaics: Toward Low-Cost Power Generation", MRS Bulletin, Vol.30, pg. 10-19, 2005.
- [2] Tuladhar, S. M.; Poplavskyy, D.; Choulis, S. A.; Durrant, J. R.; Bradley, D. D. C.; Nelson, J. Advanced Functional Materials 2005, 15, (7), 1171-1182.
- [3] Alexeev, A., Loos, J., "Conductive atomic force microscopy (C-AFM) analysis of photoactive layers in inert atmosphere", Organic Electronics, Vol. 9, pg. 149-154, 2008.

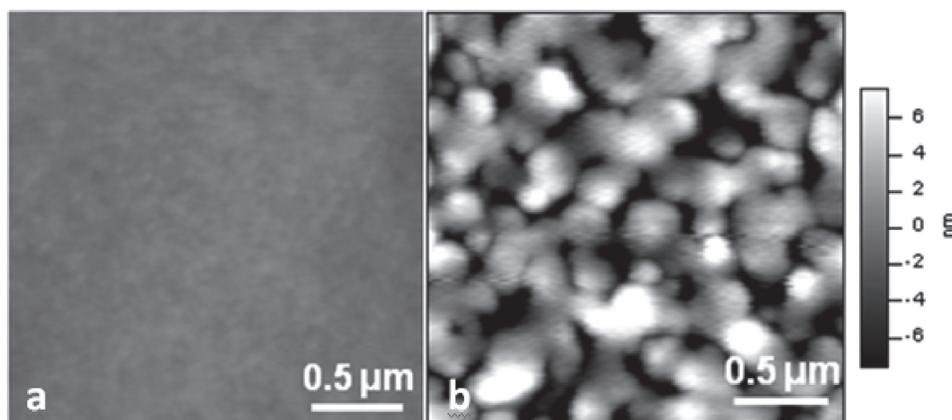


Figure 3: AFM images of devices with PCBM concentration of (a) 67% and (b) 80%.