E-Beam Lithography to Improve the Performance of Organic Optoelectronics

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Abstract:

This project focused on improving the performance of a standard organic solar cell by using electron beam lithography. Roughening the bottom of an organic solar cell has been proven to increase its efficiency. Thus, we hope to achieve an increase in efficiency in a modified solar cell by making a device pattern on a silicon wafer with e-beam lithography, placing a PDMS layer to produce a stamp of this device pattern, and using the stamp in a hot press to emboss PEDOT on the underlayer of the cell. Efficiency of the un-embossed cells was verified using a computer interface, and embossing PEDOT is underway. Other methods, such as using the stamp as a cell substrate, were also considered in this project.

Introduction:

In recent years, researchers have produced organic photovoltaics as a cost-efficient alternative to silicon-based solar cells. Solar cells with deposited layers of organic material work in the same manner as silicon-based cells, except that light produces excitons, which go into the interface when split into electrons and holes. Further motivation for this project came from the work of Roman, et al., with organic solar cells. They developed a cell using an elastic polymer stamp with a rigid pattern. The stamp was then embossed on the organic material to roughen the layer. Such a technique allowed for an increase in surface area as well as light trapping and interfacial absorption. They measured a significant increase in the performance of organic solar cells. Such results motivate us to proceed with our experiment, but with using e-beam lithography to develop a grating pattern for our stamp.

Experimental Procedure:

In preparation of our embossing stamp, we used the L-Edit CAD program to design four rectangular gratings, each with its own dose, and each made up of lines at a certain thickness, repeated along a uniform spacing. This produced the grating pattern for our desired embossing stamp. A dose test was performed using a 4-inch Si wafer to determine at least two doses that would produce desirable results. Each wafer went through a two-minute pre-bake at 170°C with a one-minute cool-off. XR-1541 resist (HSQ, Dow-Corning Corporation) was then spun on a 4-inch Si wafer at 1500 rpm for 60 seconds, followed by two more 2-minute pre-bakes at 170°C each, with another one-minute cool off.

Twenty squares with nanoscale grating patterns were exposed with a range of doses using a Leica VB6 E-Beam Lithography system. Another two-minute pre-bake was performed at 170°C with a cool-off before being developed in TMAH. Finally, the wafer was rinsed for three minutes in deionized water. We inspected each dose to determine which doses were sufficient for the grating pattern. Using atomic force microscopy, we determined that a dose of 645 $\mu C/cm^2$ proved adequate for the grating pattern in two cases of line thickness and uniform spacing—one with 128 nm period and the other with 192 nm period (the second case is featured in Figure 1).

The grating pattern was then exposed on a Si wafer using the aforementioned wafer preparation and the determined dose from the dose testing. PDMS was cast onto the patterned wafer and cured in the oven at 70°C

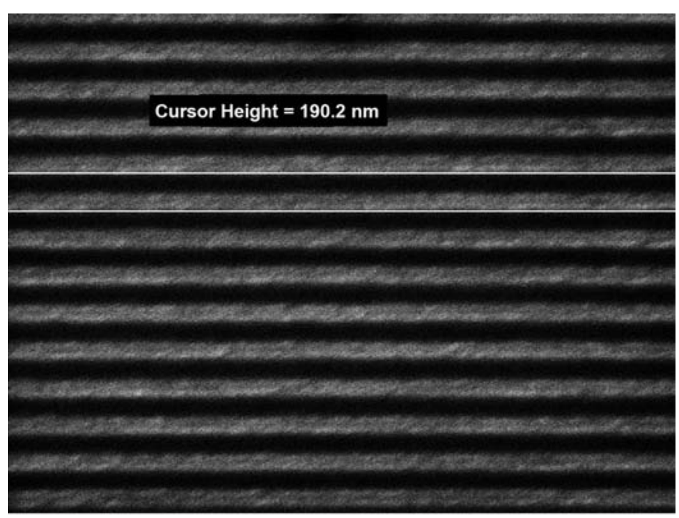

Figure 1: SEM image of grating with 192 nm period.

for 60 minutes. Alignment marks were exposed in the grating pattern, which allowed us to cut an even square around the grating pattern. In peeling the PDMS piece out of the Petri dish, we were able to make an imprint of the grating pattern on the bottom layer of the PDMS and thus produce our embossing stamp. We fabricated our solar cell by patterning indium tin oxide on a glass substrate. Approximately 250 μL of PEDOT was then spun onto the substrate at 2000 rpm. The embossing stamp was then placed on top of the PEDOT layer and placed in a hot press, where heat and pressure were applied in order to roughen the layer. After which, layers of pentacene and C60 were deposited on the cell along with a patterned Al/Cs cathode layer. Finally, the cell's performance was tested and recorded using a computer interface.

Results and Conclusion:

Complications to our experiment occurred when residue from the PEDOT layer was adhering to the embossing stamp, which we intended to reuse to produce more embossed cells. We therefore resorted to depositing an FOTS layer on the stamp to produce a hydrophobic layer in the hopes of preventing the adhering of PEDOT. Meanwhile, we tested a cell, which was made using an embossing stamp as a substrate. Using a standard solar cell as a control, we tested and analyzed the performance of the cell with the stamp.

In analyzing the photovoltaic response of both the control and the embossing stamp cell, we produced the graph shown in Figure 2. The plot for the embossing stamp cell shows how the device has shorted, whereas the control cell had a photovoltaic response with an open circuit voltage of ~0.3 V and a current density of ~3 mA/cm^2.

From this experiment, we have developed a process for making imprint masters using e-beam lithography and succeeded in making an imprint-compatible control cell.

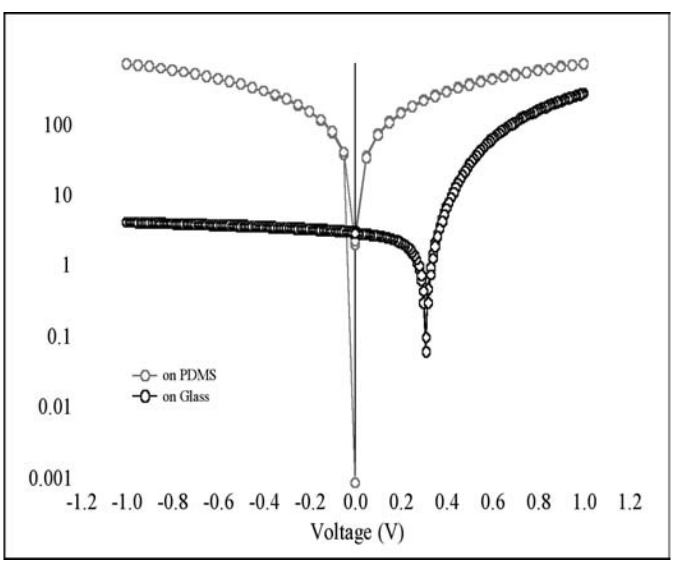

Figure 2: Semi-log plot of photovoltaic response.

Future Work:

Currently, we are using hydrophobic monolayers, such as FOTS, to imprint a grating pattern in organic thin film electrodes, such as PEDOT, to avoid the residue adhesion problem in the solar cell.

Acknowledgements:

I would like to acknowledge Alex Mayer, Dan Bernards, and Dr. George Malliaras, of the Materials Science and Engineering Dept. at Cornell University, Dr. David Tanenbaum of Pomona College, the faculty and staff of the Cornell NanoScale Facility, and the NNIN for their support of this project. Special thanks to the Intel Foundation for funding this project.

References:

[1] "Trapping Light in Polymer Photodiodes with Soft Embossed Gratings," L.S. Roman, et al., Advanced Materials, 2000, 12 (3), 189-195.