

Nanopatterned Electrodes for Organic Solar Cells

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Abstract:

Transparent conductors such as indium tin oxide (ITO) are used extensively in a wide range of optoelectronic devices. ITO is used in virtually all organic photovoltaic cells, which are of interest based on their potential for low-cost manufacturing on flexible substrates. Unfortunately, the high cost and brittle nature of ITO limit its application in organic solar cells, motivating the search for transparent, conductive thin-film alternatives. To address this challenge, we investigated nanostructured thin metal films that take advantage of surface plasmon resonances that can increase transparency relative to a flat metal film of the same thickness, while retaining nearly identical electrical conductivity. Structures of interest include metal films with semi-ordered arrays of holes producing a tight mesh. The nanostructuring is performed using mask-less lithographic techniques using a block copolymer that creates nanoscale features on the substrate. Selective etching of the self-patterned polymer followed by deposition of metal on top of the structure was used to produce a surface texture that will hopefully increase the transparency of the electrode.

Introduction:

Organic semiconductors have shown to be promising for many novel solar cell designs due to their inherent flexibility and potential to be processed at room temperature and pressure [1]. One of the most difficult aspects of constructing efficient organic solar cells is finding contact materials with good conductivity and transparency as well as an acceptable work function for good carrier injection [2]. For the cathode, a very low-work-function material is typically required, and this is usually a thick layer of lithium fluoride or metal. The anode can be made of a large variety of high-work-function materials, leading to the use of doped semiconductors like ITO and highly conductive metals such as silver.

Recent research has focused on creating nanopatterned metal films which are transparent, conductive, and flexible [2]. Our experiment attempts to use polystyrene-*b*-polyisoprene (PS-PI), a self-assembling block copolymer, and reactive ion etching to transfer a periodic pattern onto a metal thin film. The periodicity of this structure is as small as 40 nm and has the possibility of enhanced solar cell efficiency through surface plasmon resonance (Figure 1) [3,4].

Experimental:

Glass substrates were cleaned with a sequence of rinsing in deionized water, acetone, and isopropanol. Polystyrene-*b*-polyisoprene purchased from Polymer Source Inc. was dissolved in toluene to create a 0.5% solution by mass. This solution was spun onto 3" x 2" glass substrates at 3000 rpm for 30 sec and annealed in vacuum for 12 hours at 125°C. After

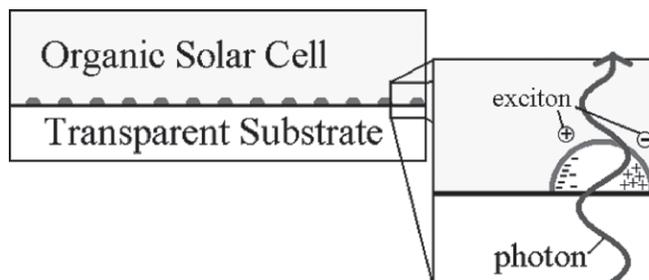


Figure 1: The surface plasmon generated in the structured metal film increases exciton generation near the electrode.

reactive ion etching with fluorine plasma for 10 sec, atomic force microscopy (AFM) was used to observe the surface pattern (shown in Figure 2). Electron beam evaporation was then used to deposit 2 nm of nickel and 15 nm of silver over the pattern. The nickel acts to increase adhesion of the silver to the sample. The pattern was then observed using AFM once again (shown in Figure 3). A 3-dimensional representation of the final structure is shown in Figure 4.

Results and Conclusions:

After spinning the PS-PI solution onto glass substrates and annealing the films, the film thickness was measured to be 50-60 nm. Etch rates of the PS-PI film under the fluorine plasma etch were measured, and results revealed a 2 nm/sec etch rate. A 10 sec etch was used to completely etch the polystyrene

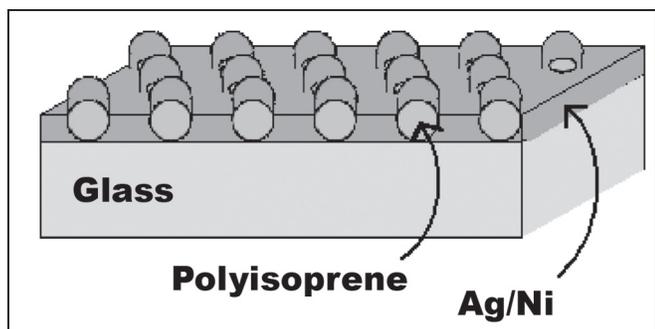
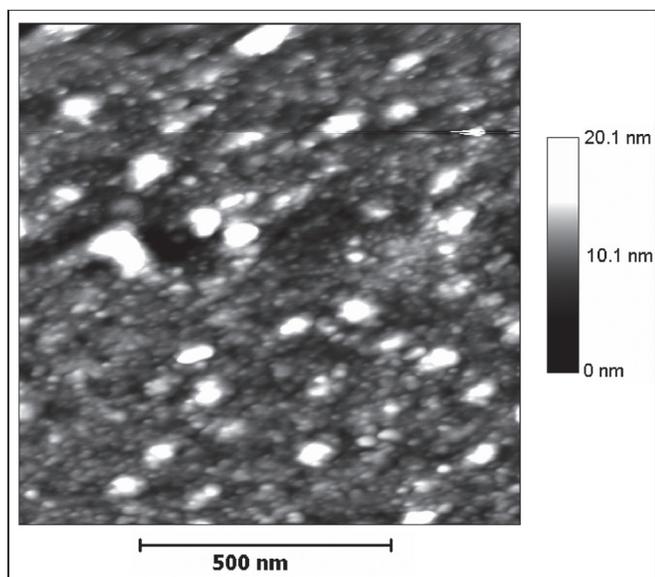
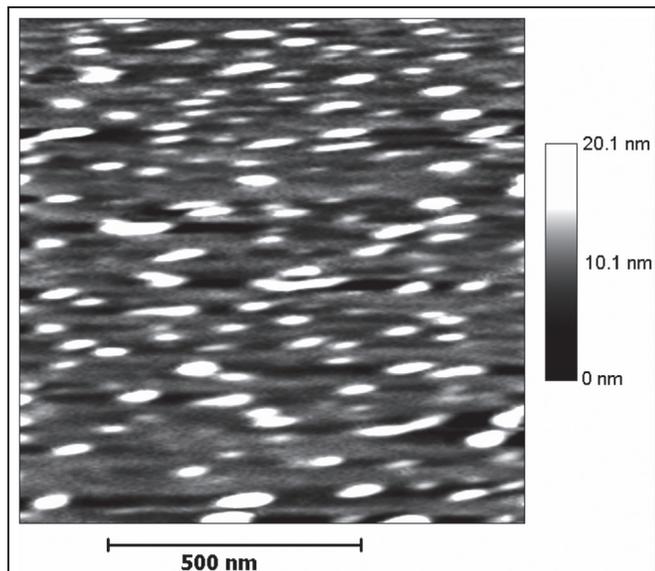


Figure 2, top: AFM image of self-assembled polyisoprene spheres after fluorine plasma etching.

Figure 3, middle: AFM image of metal film deposited on top of the polyisoprene spheres shown in Figure 1.

Figure 4, bottom: Desired final product; a thin metal film deposited on the self-assembled structure.

matrix, while leaving behind a ~ 30 nm thick layer of the more robust polyisoprene spheres. Results of the fluorine etch are shown in Figure 2. The image is slightly distorted due to sample drift, but spherical structures are clearly visible on the surface. Figure 3 was taken after e-beam evaporation of nickel and silver. The image shows that the pattern was not lost.

Sheet resistances for the structured metal film were compared to those of an identical metal film deposited on clean glass. The structured metal film had an average $R_s = 2.82 \Omega/\square$ whereas the planar metal film had an average $R_s = 2.89 \Omega/\square$. These results demonstrate that the surface texture does not reduce the film's conductivity.

Future Work:

Devices should be built using the thin films created in this experiment as electrodes in order to measure their effectiveness in enhancing solar cell efficiency. A key to this is to increase the transparency of the metal film. Since the films created in this experiment are continuous, their transparency could be increased by etching the raised polyisoprene spheres to lift off the silver from those points.

Modifications on the attained metal film structure for future work could include an increased concentration of PS-PI in the initial solution to increase the concentration of polyisoprene spheres on the surface. This would increase plasmonic effects as well as increase transparency. An inverted PS-PI structure, where the spheres are etched more rapidly than the matrix would also prove useful for new fabrication methods. This could be accomplished by using a polar solvent to invert the PS-PI or by selectively etching the other PS-PI constituent, polyisoprene.

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References:

- [1] Hadipour, A.; Adv. Funct. Mater.; 16, 1897 (2006).
- [2] Kang, M. G.; Adv. Mat.; 13, 1 (2007).
- [3] Park, M.; Science; 276, 1401 (1997).
- [4] Morfa, A. J.; Appl. Phys. Lett.; 92, 013504 (2008).