Characterization of the Diffusivity of Conductive Polymers in Nanochannel Confinement

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Abstract:

The fabrication of nanochannels for analyzing molecular behavior at the single-molecule level is a rising phenomenon in material science. This methodology has been applied in research areas including the controlled transport of biological species, nanoelectromechanical systems (NEMS) studies, and the stabilization of the release rates of small molecules in drug delivery. Interest in the distinctive mechanical, electrical, and optical properties of the conductive polymer poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS), widely used in organic electronics (sensors, solar cells, LED), induces further research concerning this molecule under a nano-confining environment. In this work, we fabricate nanochannels on a quartz substrate using electron beam lithography, and furthermore, use these nano-devices to characterize the diffusivity of PEDOT:PSS. Observation under an optical microscope allows for characterization of the molecule's diffusivity, while images obtained from the SEM will confirm existence of these molecules confined in the nanochannels. The ability to characterize PEDOT:PSS in such nano-confinement will impose a strong foundation on further research on this conductive polymer.

Introduction:

The study of diffusion in nanochannel confinement is a rising phenomena in nanotechnology research. Nanochannels provide an environment in which biological species can be controlled at the single-molecule level. Furthermore, they are easily integrated with other detection device units such as nanowires, transistors, and optical waveguides [1]. The diffusion of molecules into nanochannels is commonly used in research areas including deoxyribonucleic acid (DNA) stretching studies.

We have applied this idea for characterizing the polymer, PEDOT:PSS. PEDOT:PSS is a conductive, transparent polymer with unique electrical and optical properties, making it ideal for organic electronics research [2]. However, there is no research on the diffusivity properties of PEDOT:PSS. Therefore, in this work, we have designed and fabricated a nanochannel device for characterizing the diffusivity properties of PEDOT:PSS under nanoscopic confinement.

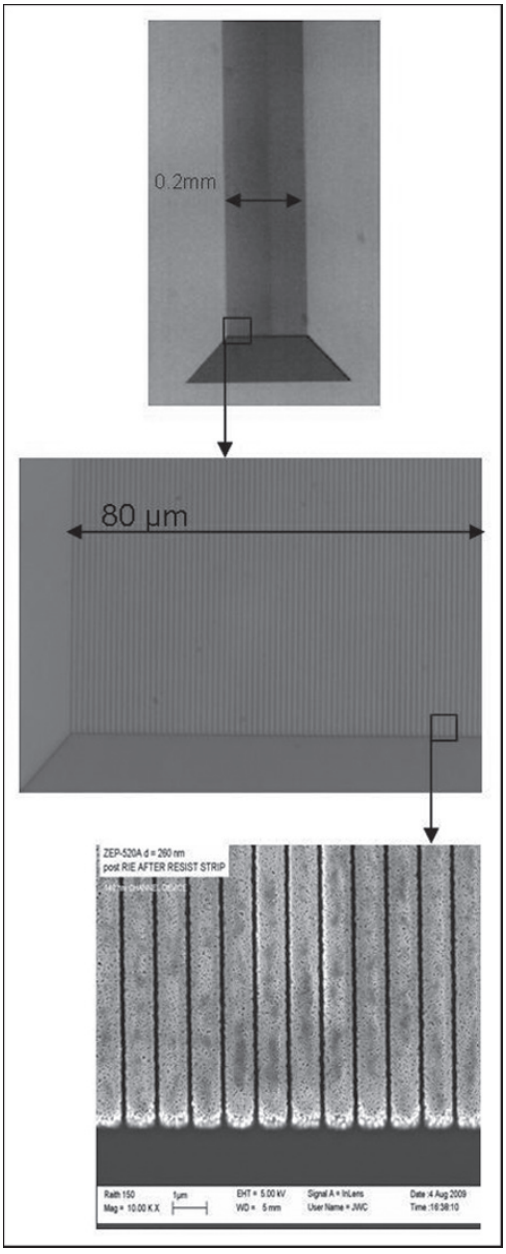

Figure 1: Top: Optical image of 120 nm channel width nanochannel device. Middle: Optical image of 120 nm channel width nanochannel. Bottom: SEM image of 140 nm channel width nanochannel device at 10KX magnification (5KV).

Experimental Procedure:

A 100 mm wafer was first spin-coated with ZEP-520A photoresist (~ 300 nm thickness). Next, a 20 nm layer of the conductive polymer,

Espacer 300Z, was spin-coated onto the wafer to prevent any charging of the quartz substrate while exposed under the electron beam [3,4]. The pattern that was to be written on the wafer was created using the RAITH 150 Software. The nanochannel device we designed and used in this work can be seen in Figure 1a.

The wafer consisted of a set of ten of the nanochannel devices. Each consisted of various channel widths ranging from 20 nm to 200 nm in increments of 20 nm. There were two sets of these patterns to show consistency. They were then written onto the ZEP-coated quartz substrate using the RAITH electron beam (e-beam). Following the e-beam exposure, the espacer was removed using a spin-rinse dryer, and the wafer was developed in xylenes. When submerged in xylenes, the areas of the ZEP resist that were exposed to the electron beam during exposure, were removed. Finally, the substrate was etched using the AMT etcher (oxide etcher) creating a 500-600 nm depth for the nanochannels. The ZEP resist was stripped by submerging the wafer in sulfuric acid for 20 minutes and the fabrication process was complete.

To characterize the diffusivity properties of PEDOT:PSS using these nanochannel devices, using a syringe, we deposited the PEDOT:PSS solution into the trapezoidal area of the nanochannel device. As the solution diffused into the nanochannels, its diffusion and mobility could be characterized in various ways.

Results and Discussion:

After the first e-beam write, there were three major issues that we encountered. First, there was poor adhesion of the ZEP resist. Weak bonding between the resist and the quartz substrate caused areas of deformation in the pattern. Our solution to this problem was to prime the wafer with hexamethyldisilazane (HMDS) to create better adhesion of the ZEP resist. Secondly, we noticed stitch breaks in the pattern. The e-beam writes in 40 μm write fields. At every shift in write field, due to the properties of the quartz substrate, the wafer would begin charging and slightly deflect the electron beam, causing a shift in the pattern write. To compensate for this charging, we coated a second layer of espacer. Finally, we noticed that after the e-beam write, the strips of ZEP resist between the nanochannels were so thin (< 300 nm) that during development, they would be easily shifted off of the pattern leaving hairy-like structures of ZEP resist on the wafer surface. The solution to this issue was to increase the spacing between the nanochannels to one micron.

After making these adjustments, the patterns were written again under the e-beam. Results can be observed at different magnifications in Figure 1. The write was successful and we had completed nanochannel devices to be used for diffusion characterization.

Following the etching of the pattern and stripping of the photoresist, the nanochannel devices were used for the diffusion tests. Preliminary diffusion results show the PEDOT:PSS solution diffused into the channels of the nanochannels devices with channel widths of 180 nm and 200 nm. The results of the diffusion using the nanochannel devices with channel widths of 180 nm can be seen in the optical image in Figure 2.

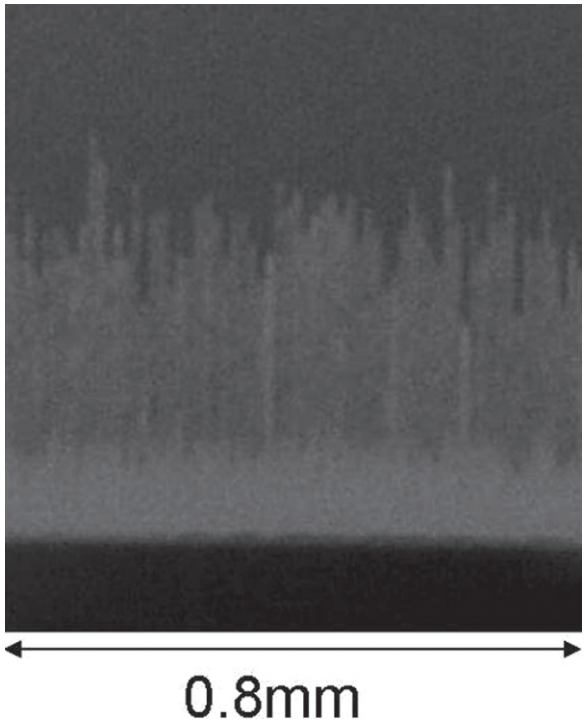

Figure 2: Optical image of 180 nm channel width nanochannel device after preliminary diffusion test.

Conclusions and Future Work:

We successfully fabricated a nanochannel device on a quartz substrate to be used for diffusion purposes. Moreover, we were able to begin preliminary diffusion work with PEDOT:PSS using these nanochannel devices. In the future, we would like to attempt to fabricate these nanochannel devices on other substrates. We would also like to characterize the diffusion properties of other polymers and DNA, using these nanochannel devices.

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