Ion Transport Through Porous Graphene

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Abstract:

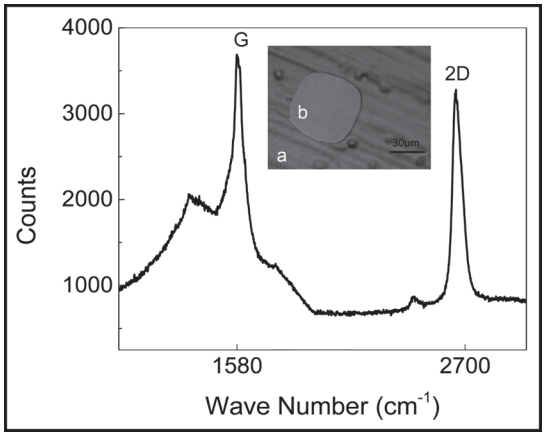
Graphene is a two-dimensional carbon material that is only one atom thick with exceptional strength and remarkable gas separation properties [1-3]. Graphene membranes have great potential for applications in DNA sequencing, desalination and water filtration, as well as lab on a chip processes. The focus of this project was to investigate the potential of graphene membranes for liquid separations. A microfluidic device was designed and fabricated to test graphene's separation properties in liquids. Chemical vapor deposition (CVD) graphene was freely suspended over a thin copper foil and attached to a polydimethysiloxane (PDMS) microfluidic substrate. Suspended graphene was fabricated via standard photolithography while a PDMS substrate was fabricated via soft lithography techniques. To observe the permeability of graphene membranes, pressurized deionized water was introduced onto the underside of a graphene membrane through a microfluidic channel and the graphene membrane deflection was measured via atomic force microscopy (AFM) in air. Future work includes electrical testing of water and ionic transport across porous monolayer graphene membranes.

Introduction:

Graphene is a two-dimensional material made of carbon, the same material as the three-dimensional graphite that can be found in pencils. This material is only one atom thick, yet for being so thin, it has exceptional strength. In fact, it is the thinnest and strongest material known [1]. It has been found to have remarkable gas separation properties, and be impermeable to all molecules including helium when in its pristine form [2, 3]. Graphene membranes also have great potential for applications involving liquid separations such as DNA sequencing, desalination, and water filtration, as well as lab on a chip processes [4]. The focus of this project was to investigate the potential of graphene membranes for liquid separations.

Experimental Procedure:

In order to investigate the potential of graphene membranes for liquid separations, first the suspended graphene membrane was fabricated. Graphene was grown on a thin copper foil via CVD. The copper was then patterned using standard photolithography techniques and etched by floating the copper in a 0.1M solution of ammonium persulfate. After floating in the etchant for three hours, the copper was inspected every half hour for the next one to nine hours until the copper with graphene on it became a



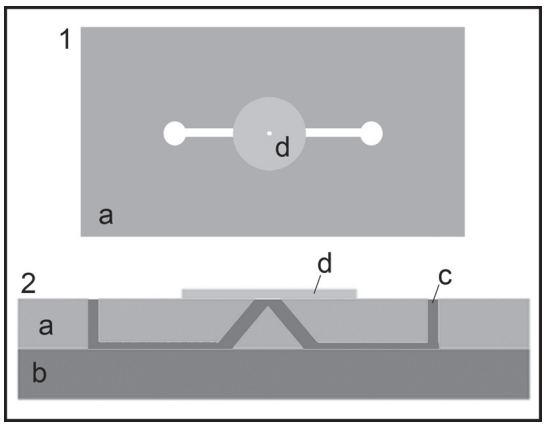


Figure 1, top: Optical image of the copper foil (a) containing suspended CVD graphene (b); Raman spectrum of the suspended CVD graphene.

Figure 2, bottom: (1) Top view of final device. (2) Side view of final device. Key: (a) PDMS (b) glass slide (c) DI water (d) copper.

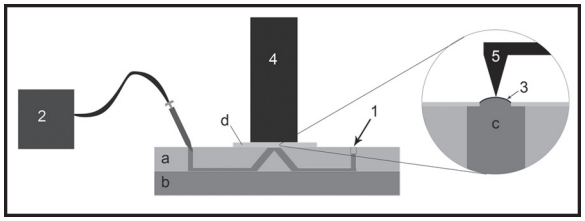


Figure 3: Experimental setup: One end of the channel was plugged with a piece of PDMS (1) and a pump was inserted in the other side of the channel (2). The deflection of the graphene membrane (3) was monitored using the AFM (4) by having the AFM tip (5) move across the surface of the membrane. Key: (a) PDMS (b) glass slide (c) DI water (d) copper.

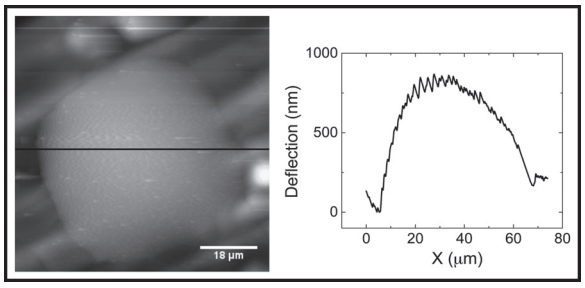


Figure 4: AFM data.

copper disc approximately 7 mm in diameter with a hole in the center approximately 15 μm in diameter, over which graphene was suspended. This copper disc was then critical point dried to avoid damaging the graphene membrane. Raman spectroscopy was used to confirm that graphene was suspended, as indicated by the G peak at approximately 1580 cm^{-1} and the 2D peak at approximately 2700 cm^{-1}, as shown in Figure 1.

The copper disc containing suspended graphene was then adhered to a microfluidic channel made from PDMS. The microfluidic channel was fabricated via standard soft lithography techniques and measured 50 μm deep and 500 μm wide with through holes 1.5 mm in diameter. The final device is shown in Figure 2.

Next, the graphene membrane was pressurized from below by pumping deionized water into the microfluidic channel. To do so, one end of the channel was plugged with a piece of PDMS and a syringe pump introduced deionized water to the other end of the channel, as shown in Figure 3. The effects of this pressurization were monitored using both optical and atomic force microscopy, as shown in Figure 4.

Results and Conclusions:

Initial tests were observed using only an optical microscope and revealed that when the underside of the membrane was pressurized to large values, the graphene quickly burst due to the large pressure difference. To decrease the pressure differential across the membrane, subsequent tests were carried out by pressurizing the graphene membranes at a slower rate. For the duration of these tests, the top surface of the graphene was monitored using AFM, as shown in Figure 3. AFM data revealed that when pressurized from below, the graphene membrane bulged up in response to the increased pressure difference, as shown in Figure 4. Changes in pressure were reflected in the deflection of the membrane. The ability to image the pressurized graphene membranes without the obvious penetration of water across the membrane is an indication that the CVD graphene membranes fabricated via the method described above are indeed impermeable to the transport of water.

Future Work:

The next step in this project will be to etch pores in the CVD graphene membrane using UV-ozone etching. The introduction of pores will allow for exploration into how water moves across porous graphene membrane as well as exploration into ion transport and molecular separation.

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References:

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