Fabrication of Nano Ion Pumps for Retinal and Neural Prosthesis

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Abstract:

In some cases, permanent vision loss may be treated using retinal prostheses; however, current methods of neural stimulation pose potential health risks. To overcome these risks, an approach based on ion stimulation rather than electrical stimulation may be more appropriate. To this end, fabrication techniques were investigated for anodized aluminum oxide (AAO) membranes for use in electrically-gated, ion-selective nanoscale pumps. Additionally, track-etched polycarbonate (PC) membranes were functionalized using crown-ether compounds and their ion selectivity was characterized. Fabrication of AAO membranes was successfully completed, and a K^+-selective compound was determined.

Introduction:

Age-related macular degeneration is the leading cause of permanent vision loss in the United States [1]. It and similar conditions may be treated using retinal prostheses [2]; however, current prostheses rely on electrical stimulation, which can be neurotoxic and can lead to tissue-damaging electroplating [3]. To overcome these risks, an approach based on ion stimulation may be used. In this route, neural firing is triggered via injection of sequestered potassium cations (K^+). This method has been shown to be viable, and the activation threshold and response latency in rabbit retinal cells has been investigated [4, 5].

To facilitate implementation of this approach, fabrication techniques for an electrically-gated, ion-selective nanoscale pump were investigated. In order to fire neurons when desired, the pump must be capable of both sequestering and releasing ions as directed; this is accomplished using a gating system in which ions are driven through a membrane by an applied voltage across the device. The membrane must also be ion-selective so only usable K^+ ions are stored and released; this will be accomplished through functionalization of pores in the membrane. An overview of the device is shown in Figure 1.

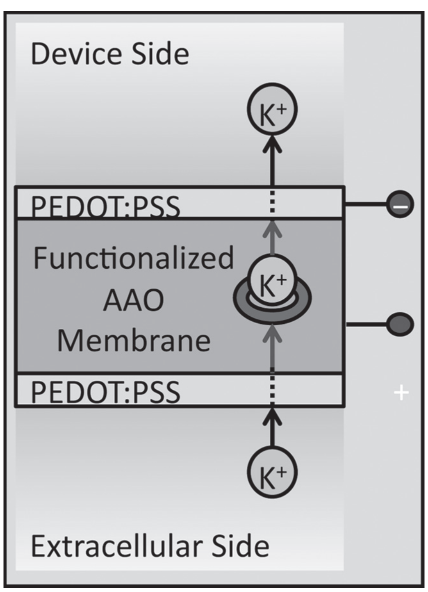

Figure 1: General structure and operation of the device. Ion flow is driven by a potential applied across the membrane. PEDOT:PSS is a conductive polymer. K^+ ions are selectively allowed through the membrane due to functionalization.

In this study specifically, fabrication techniques were investigated for anodized aluminum oxide (AAO) membranes, which are used in the pumps due to their biocompatibility, previously investigated preparation, and ability to be functionalized for ion selectivity. Additionally, track-etched polycarbonate (PC) membranes were functionalized with crown-ethers and their ion selectivity was characterized using cyclic voltammetry.

Experimental Procedure:

The general fabrication procedure for a suspended AAO membrane is shown in Figure 2. A dielectric barrier layer was first deposited on one side of a double-side polished silicon wafer using atomic layer deposition (ALD). Next, Al

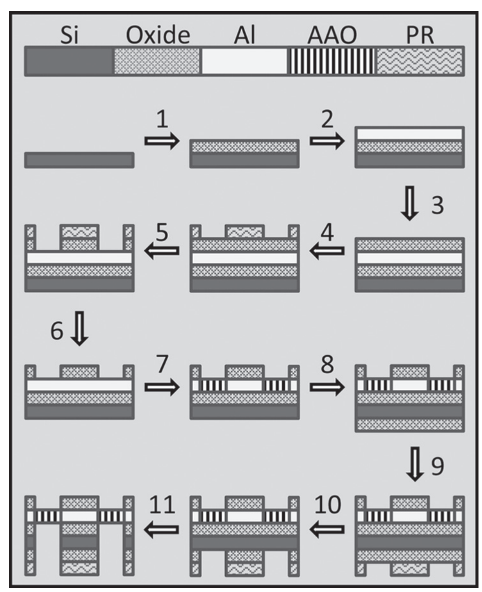

Figure 2: Fabrication Scheme. 1. ALD, 2. E-beam, 3. ALD, 4. Photolithography, 5. ICP-RIE, 6. Clean, 7. Anodization, 8. Photolithography, 9. ICP-RIE, and 10. Bosch etch.

was deposited using electron beam evaporation followed by another ALD dielectric layer. A mask of photoresist (PR) was created and the dielectric was etched in the open windows using inductively coupled plasma reactive-ion etching (ICP-RIE). The exposed aluminum was then anodized in a solution of sulfuric acid. On the backside, dielectric barrier layers were added via ALD, masked, and etched using ICP-RIE to provide windows for the Bosch etch. Finally, the wafer underwent a Bosch etch until AAO membranes were suspended over each window. A phosphoric acid etch was used to open nanopores blocked by barrier layers.

Functionalization studies were completed on track-etched polycarbonate (PC) membranes treated with crown ethers. Membranes were mounted between two polymer gaskets between two reservoirs. Reservoirs were loaded with 0.01 M solutions of NaCl, KCl, and $CaCl_2$ and electrodes were inserted. Applied potentials ranged from -4 V to 4V.

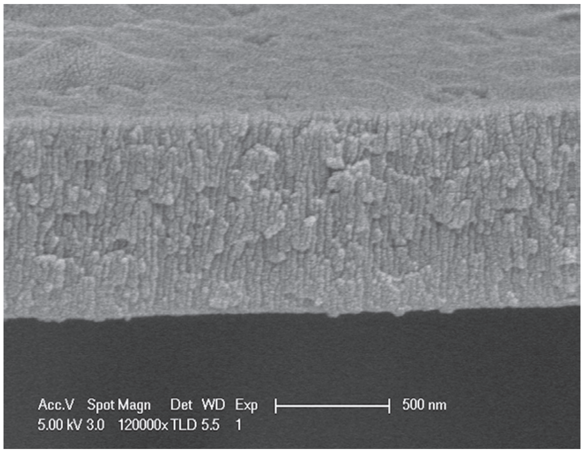

Figure 3: SEM image of AAO membrane cross-section.

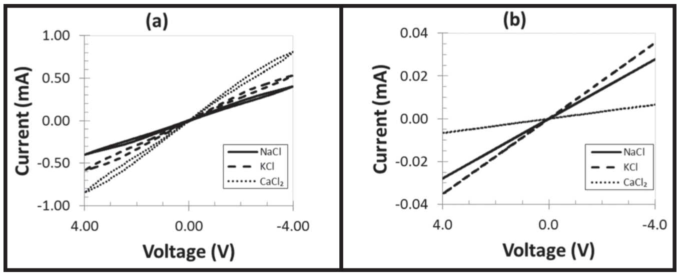

Figure 4: Each plot shows the resulting current as a varying potential is applied across the membrane. (a) untreated PC membrane, (b) 18-crown-6 treated membrane.

Results and Conclusions:

Using the techniques described above, AAO membranes containing nanopores were successfully fabricated. Figure 3 shows the cross-section of such a membrane imaged on a scanning electron microscope (SEM). From this image, it can be seen that the nanopores extend completely through the membrane and are open on both ends.

Figure 4 shows the result of one functionalization study. The figure compares cyclic voltammetry results for PC membranes that are untreated and treated with a specific crown ether compound. Functionalization with this compound results in selectivity for K^+. Results from the untreated membrane roughly align with expectations based on diffusion coefficients; in the untreated membrane, however, more K^+ is transported than Na^+, and comparatively little Ca^{2+} is transported.

Future Work:

In the near future, functionalization studies will be performed using AAO membranes prepared using the techniques investigated in this project. Beyond this, work will begin on fabricating complete pump devices.

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