ELECTROCHEMICAL CHARACTERIZATION OF A 3D PARYLENE SHEATH CORTICAL PROBE

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ABSTRACT

We developed a 3D Parylene sheath cortical probe for the purpose of advancing neuronal recording reliability and longevity. Our approach is to improve probe-tissue integration through a unique 3D open-lumen probe structure and the application of biofunctional coatings to mitigate adverse immune reactions and promote neuronal growth. We present the use of electrochemical (EC) testing to confirm probe integrity and interrogate changes to electrode performance that may arise as a result of the post-fabrication 3D sheath structure modification and the application of biofunctional coatings.

KEYWORDS: Neuroprosthetics, microelectrodes, electrochemical impedance spectroscopy

INTRODUCTION

Silicon-substrate and microwire intracortical recording probes suffer from loss of signal over time as a result of tissue inflammation and the body's immune response [1-2]. By fabricating our probe on a Parylene C substrate, we aim to mitigate the damage to cortical tissue associated with hard, rigid probes [3]. This biocompatible material also allows for the creation of a 3D open-lumen structure, which is shaped by thermoforming a Parylene microchannel around a microwire mold. Thermoforming is conducted at 200°C for 48 hours in a vacuum environment after the standard microfabrication process. Eight Pt electrodes are arranged on the probe, four inside and four outside of the sheath [4] (*Fig. 1*). Electrochemical impedance spectroscopy (EIS) was used to measure changes to the electrode properties due to the modified probe geometry as well as the application of heat.

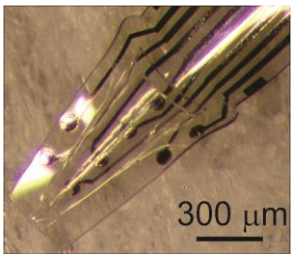

Figure 1: Fabricated probe

The design of the sheath structure works in conjunction with biofunctional coatings to attract neuronal growth into the open-lumen of the probe, thereby bringing neurons in close proximity with recording sites, isolating signaling, and anchoring the probe to the cortical tissue. The role of these coatings in altering electrode function was also studied with EIS.

METHODS AND RESULTS

Following microfabrication but prior to thermoforming, electrodes were EC cleaned by cycling the potential from -0.2 to 1.2V vs Ag/AgCl (3M NaCl) at 250 mV/s for 30 cycles in 0.5M H_2SO_4 with a Pt counter electrode. The effect of this cleaning process is demonstrated in EIS measurements taken before and after EC cleaning (*Fig. 2*). EIS was performed in 1×PBS with a 10 mV rms perturbation signal and frequency range of 1-100,000 Hz. A Pt counter and Ag/AgCl (3M NaCl) reference were used. The removal of contaminants from the electrode surface correlates to the slight reduction of the impedance magnitude as well as the correction of the phase curve from multiple to the expected single time constant curve. Following EC cleaning, the resulting EIS curves confirm probe integrity and indicate impedances capable of recording neuronal signaling.

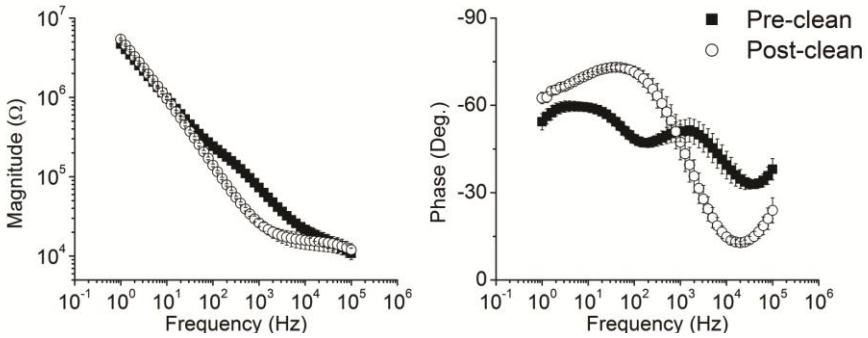

Figure 2: Impedance magnitude and phase both before (black squares) and after (white circles) EC cleaning. Mean ± SE, n=8 different electrodes.

To investigate the effects of the thermoforming process, EIS curves were taken at two points during the process: (1) after mechanically opening the Parylene microchannel with the microwire mold, but prior to heat treatment and (2) after heat treatment (*Fig. 3)*. Mechanically opening the sheath caused only a slight shift in the impedance curves, which may be explained by the broader conductive path afforded to the inner electrodes upon widening of the sheath. After heat treatment, impedance magnitude increases, suggesting changes to the electrode surface following thermal processing. Electrodes appear to possess increased roughness by scanning electron microscopy and further analysis is underway to identify the cause.

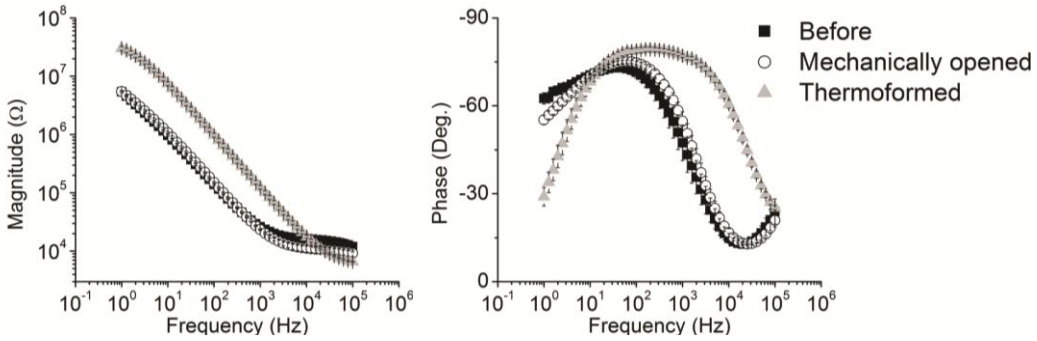

Figure 3: Impedance magnitude and phase before thermoforming process (black square), after mechanical opening of sheath (white circle) and after complete thermoforming process (gray triangle). Mean ± SE, n=8 different electrodes.

Probes were coated with biofunctional coatings consisting of an extracellular matrix, Matrigel, loaded with either the immunosuppressant dexamethasone complexed with cyclodextrin (Dex), or neurotrophic factors nerve growth factor (NGF) and neurotrophin-3 (NT-3), and then immersed in 1×PBS at 37°C. The normalized change in impedance from pre-coat values was monitored over the course of three days (*Fig. 4).*The control and neurotrophic factor samples exhibited a gradual impedance drop over time as the coatings eluted off of the electrode surface. The sample coated with dexamethasone, however, showed a steady increase in impedance. This may be attributed to the tendency of the immunosuppressant coating to swell in the presence of water, resulting in a thicker coating covering the electrode and impeding charge transfer [5].

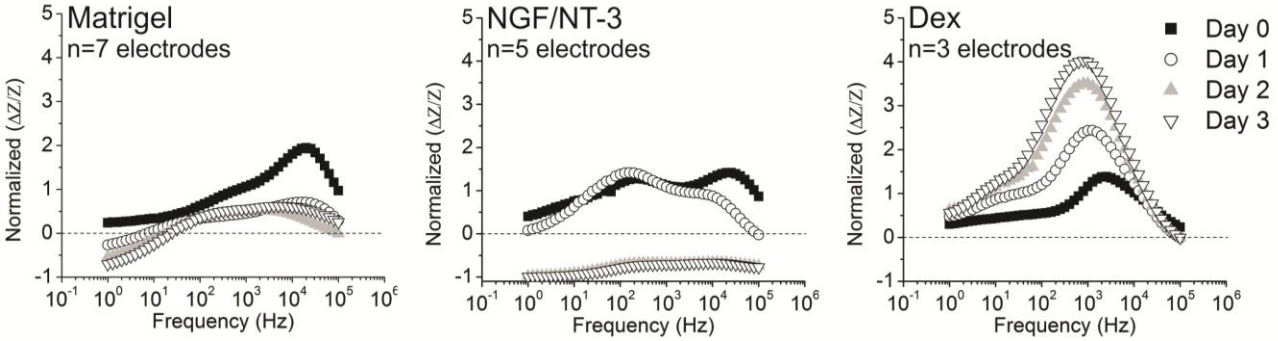

Figure 4: Normalized impedance with respect to pre-coat impedances, monitored over three days: Day 0 (black square), Day 1 (white circle), Day 2 (gray up triangle), and Day 3 (white down triangle).

CONCLUSION

Electrochemical techniques were used to validate that our cortical probe possesses the desired electrochemical properties for neuronal recording. Our results indicate that, in addition to standard cleanroom cleaning procedures, EC cleaning provides a useful extra measure to remove electrode contaminants following microfabrication. Additionally, while the thermoforming and coating processes can lead to increased electrode impedance, values remain below 1MΩ and are expected to perform well *in vivo* [6].

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