

Characterization of Degradation Mechanisms in Neural Recording Electrodes*

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Understanding the nature of specific neural activity is essential to the progression of research in the field of brain disorders and diseases, as well as neuroprosthetics. Microelectrodes are the primary measurement devices used to transduce neural activity into electrical signals to help neuroscientists study dynamic brain function. Advances in signal processing and packaging currently allow neural recording for periods as long as a year by use of chronically implanted electrodes in freely behaving animals. Stability of the electrode impedance is required for optimum signal recording over the length of the recording interval. While electrode-tissue interaction plays a major role in the quality of the recorded signal, delamination or degradation of the dielectric coating also interferes with signal recording. Therefore, to improve the signal recording process, it is useful to understand how the electrode design and component materials affect the signal over the course of time.

Commercially available platinum iridium microelectrodes coated with parylene-C were studied to assess the coating response to the test solutions described in Table I. HCl and H₂O₂ were chosen to simulate a chemical environment that could be present *in vivo* during signal measurement. Electrical characteristics of eight microelectrodes were evaluated by electrochemical impedance spectroscopy (EIS), where changes in the coating and metal surface corresponded to changes in the impedance spectrum. Electrodes of varying nominal impedance were immersed in test solutions and measured periodically over 26 days. (Nominal impedance was specified by the manufacturer as $\pm 20\%$ at 1 kHz.) A three electrode cell was used with a Ag/AgCl reference electrode. A platinum wire served as the counter electrode, and the working electrode was the microelectrode under investigation. The applied AC signal was 10 mV over a frequency range of 100 mHz to 100 kHz. Each electrode was inspected by SEM to visually assess the physical condition of the coating and electrode surface after electrochemical testing.

Table I. Test solutions in which the microelectrodes were immersed.

Test solutions based on Ringer's solution (an aqueous solution of NaCl, KCl, and CaCl ₂)	Test solutions based on phosphate buffered saline, 1X (PBS)
Ringer's solution	PBS
Ringer's solution + HCl (0.18 %)	PBS + HCl (0.18 %)
Ringer's solution + H ₂ O ₂ (0.71 %)	PBS + H ₂ O ₂ (0.71 %)

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An untested electrode was imaged to obtain a baseline condition for comparison against tested electrodes, shown in figure 1. The parylene coating is relatively smooth and the interface with the metal is intact. At the conclusion of the test period, all electrodes showed some degree

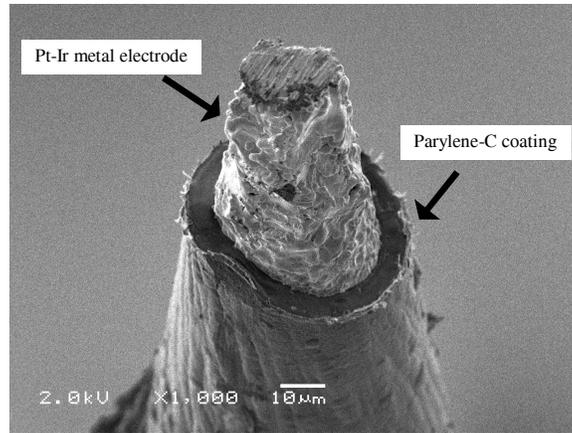


Figure 1. New (untested) microelectrode tip with parylene coating.

of damage, with the exception of the electrode immersed in PBS. Damage was confined to within approximately 40 μm of the electrode tip for all damaged electrodes. This observation implies that the electric field was involved in the mechanism for degradation, and that it was not purely chemical. The most severely damaged electrodes were those immersed in solutions containing H_2O_2 . Failure was immediate, as indicated by the low impedance values over the entire frequency range from day 1 through day 26, as shown in figure 2b where Z is the impedance and θ is the phase angle. SEM images revealed that the parylene coating was cracked and had separated significantly from the metal electrode surface, as shown in figure 2a. Cracking of the parylene coating to a lesser degree was also observed on electrodes immersed in PBS with HCl and in Ringer's solution, both with and without HCl. Figure 3a shows some cracking and delamination of the parylene coating, while figure 3b shows the impedance spectrum for an electrode immersed in Ringer's solution. The decrease in impedance is attributed to the greater area of metal electrode exposed to the test solution as a result of delamination. Figure 4a is an image of an electrode immersed in Ringer's solution with HCl added. While the metal/parylene interface is still intact, surface cracking of the parylene coating is apparent. Furthermore, the metal electrode tip showed signs of etching, resulting in a smoother surface, which corresponded to the slight increase in impedance observed in the impedance spectrum in figure 4b.

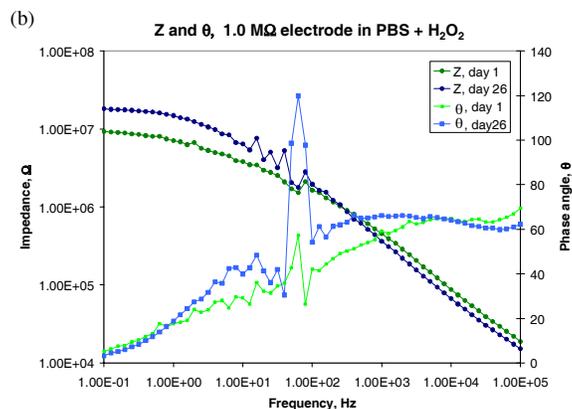
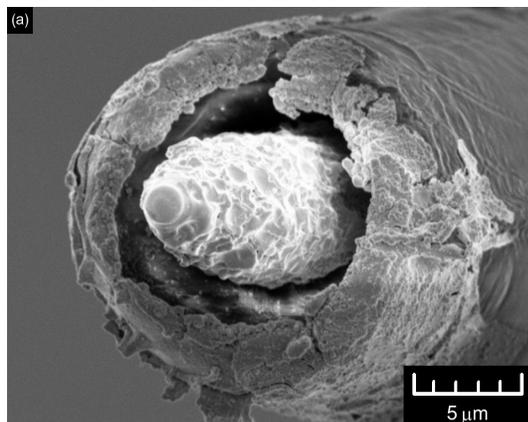


Figure 2. A 1.0 M Ω electrode immersed in PBS + H₂O₂; (a) severe cracking and separation of the parylene coating from metal electrode, (b) impedance spectra measured on day 1 and day 26 showing impedance lower than the specified value of 1.0 M Ω at 1 kHz.

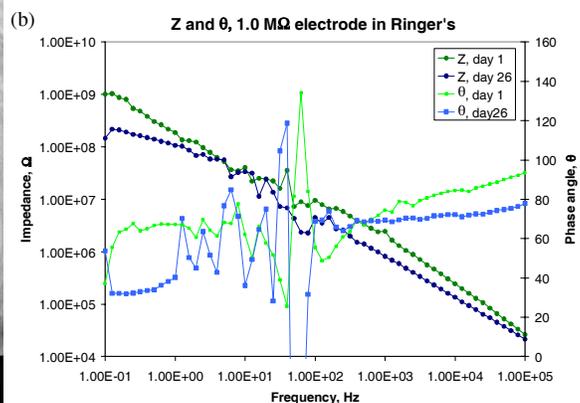
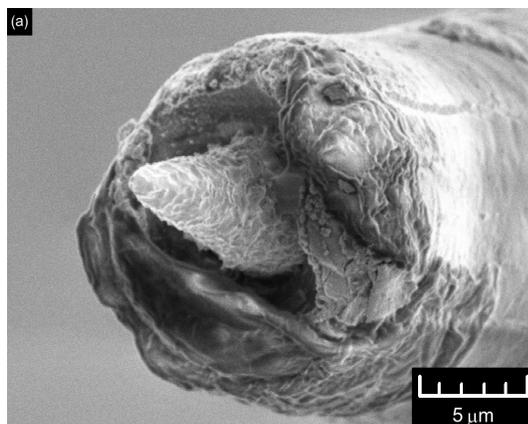


Figure 3. A 1.0 M Ω electrode immersed in Ringer's solution; (a) some cracking and separation of parylene coating from metal electrode, (b) impedance spectra measured on day 1 and day 26 showing a decrease in impedance.

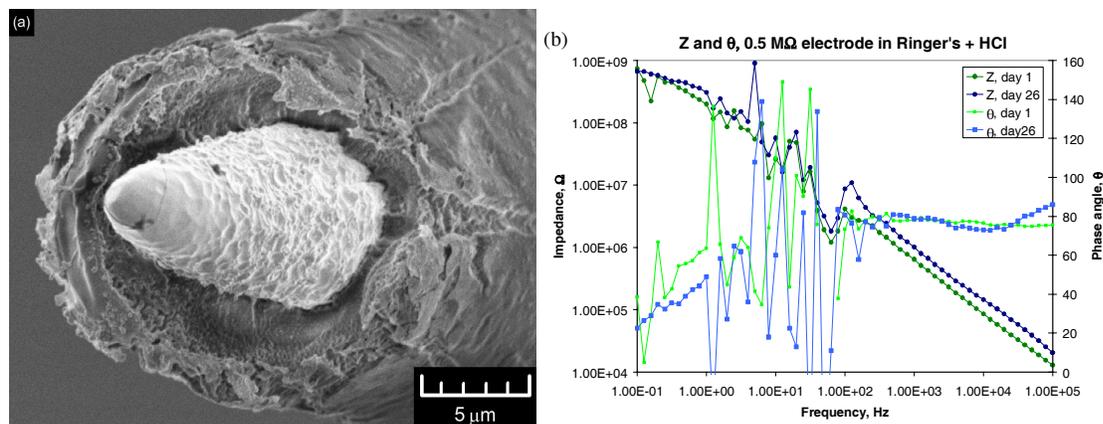


Figure 4. A 0.5 MΩ electrode immersed in Ringer's solution + HCl; (a) cracking of the parylene coating and etching of the metal electrode, (b) impedance spectra measured on day 1 and day 26 showing a small increase in impedance.

Test solutions based on Ringer's solution were more aggressive than those based on PBS. This could be due to the higher concentration of Cl⁻ ions present in the Ringer's solution, which may be more reactive with the parylene coating in the presence of an electric field. Ringer's solution with H₂O₂ created a particularly aggressive mixture causing gas to evolve upon immersion before electrical connections to the cell were made. Even in relatively benign solutions (Ringer's solution), the parylene coatings were damaged after 26 days of immersion. It is speculated that the damage would become more catastrophic over a longer test period. Results presented here suggest that the materials used in the construction of these types of electrodes may decrease the quality of recorded signals independent of the electrode-tissue interactions experienced *in vivo*.