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Dynamic Electrochemical Simulation and Testing of Micromachined Electrodes for Neural Stimulation

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With microfabrication technology, neural electrode arrays with an electrode size and spacing of a few microns can be easily produced. Although microelectrodes can be used to detect neural signals in the central nervous system, their small electrode surface area severely limits the amount of charge that they can inject for neural stimulation. If excessive charge is driven through the small electrode, accelerated electrode dissolution occurs and tissues damage may also occur. Such charge-injection limits impose practical restrictions how small the stimulating electrodes can be made.

In retinal prostheses, high electrode density and high charge injection are both critical. While the traditional method of increasing electrode charge-injection capability is to coat the surface with roughened platinum or iridium oxide, we present a different approach – increase the electrode surface area with electroplated micro-post structures (Fig 1, 2). A major concern for such an approach is that because of the prominent topology, severe current concentrations can occur at the sharp edges of the micro-post structures.

To study the distribution and concentration of current, the electrode current and voltage are simulated in two dimensions using both SPICE and Ansys. With SPICE, the 2-D electrode geometry netlist is generated with a C++ script (Fig 3) and plotted in Sigmaplot. The electrode surface is modeled with parallel resistive and capacitive elements. The resistance and capacitance values are extracted from experimentally measured stimulation waveforms. Because Ansys lacks an electrical capacitive model element, equivalent thermal conductance and thermal capacitance models have been used instead.

Both SPICE and Ansys simulations show (Fig 4, 5) that while current concentration occurs in the electrolyte, the current density on the electrode interface varies by less than 10%. The short stimulation pulse (1 ms) makes the electrode behave capacitively, thus promoting a uniform current distribution. This result suggests that prominent electrode surface topologies can be tolerated without significant concern for accelerated electrode dissolution. Accelerated dissolution tests are currently being performed to confirm the simulation results.

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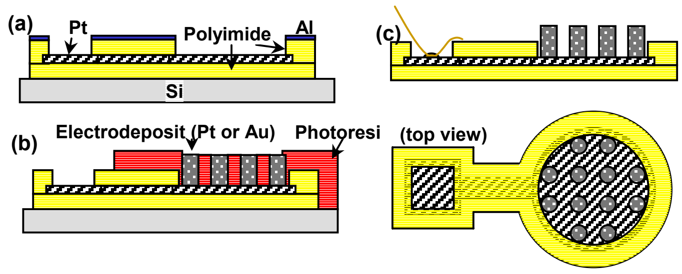

Fig 1. Electrode micro-fabrication process.

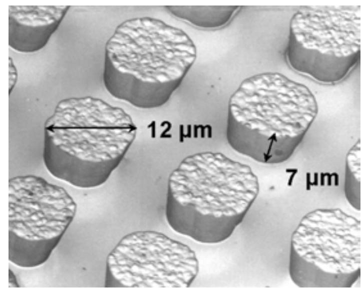

Fig 2. SEM image of a micromachined electrode with an array of micro posts.

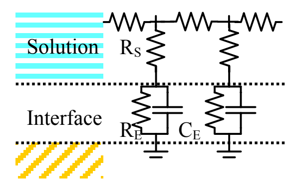

Fig 3. Small portion of the circuit used in SPICE to model the electrode-electrolyte interface.

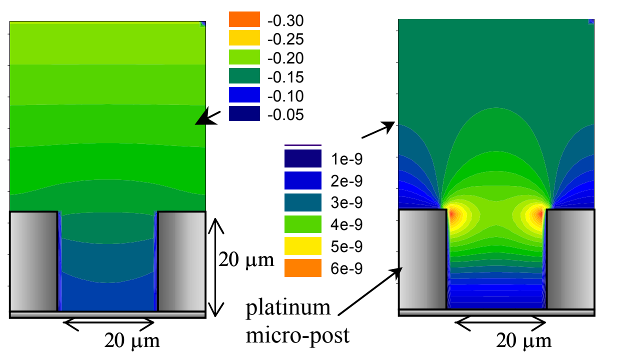

Fig 4. SPICE simulation of 2-D electrode voltage (left) and current (right) distributions at the micro-posts. These results are taken at 35 μsec driven with 0.1 μA.

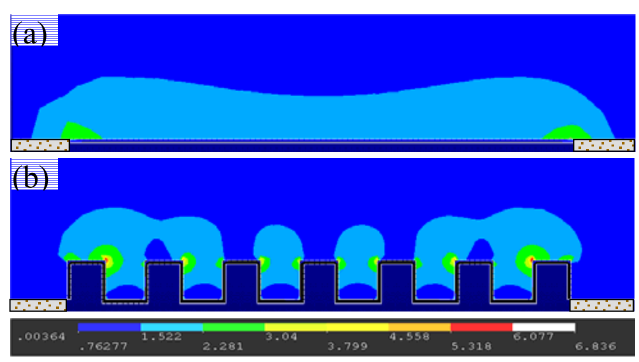

Fig 5. Current distribution simulation (Ansys) of (a) a flat electrode, and (b) an electrode with 9 micro-posts.

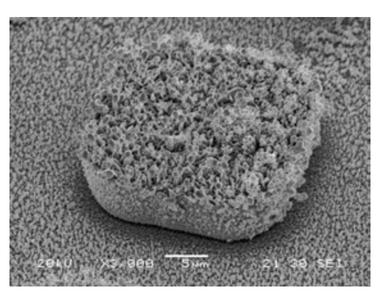

Fig 6. SEM image of a gold micro-post subjected to dissolution testing.