Nanoscale roughened thin film electrodes for neural probe and bio-sensing applications

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For next-generation prostheses, miniaturization of electrodes is required to improve the selectivity and spatial resolution of implantable devices. Miniaturization puts strict requirements on electrode performance and electrode materials for electrophysiological stimulation and recording. The surface of an implantable electrode can be optimized with respect to the desired functionality and the environment in which it will be implanted. Surface modification of an electrode can be used to tailor such properties as interface impedance, interface adhesion, hydrophilicity and biocompatibility.

This work presents a method for thin-film electrode surface modification that 1) enables reductions to interfacial impedance; 2) improves adhesion with subsequent depositions. This treatment increases the effective surface area of our electrodes while keeping their original footprints intact. This method was developed for roughening of sputtered thin-film metal electrodes, but should also work on thin-film metal from other deposition methods like evaporation.

This thin film roughening method was adapted from a technique developed for roughening of thick metal foils that lead to a discovery of Surface-enhanced Raman spectroscopy. Roughening is achieved by application of repetitive oxidation-reduction pulses that led to surface oxide formation and dissolution. Roughening of thin-film platinum electrodes by electrochemical pulsed etching was investigated by studying effects of control parameters: pulse amplitude, frequency, duration, composition of electrolyte and surface templating. Compared to common application in roughening of thick metal foils in sulfuric acid media, an optimal pulse frequency for roughening of thin films was found to be about four times lower than that of thick foils. The effect of this frequency difference was attributed to the adsorption of sulfate ion hindering oxide formation and dissolution at the grain. This method enabled an increase in the effective surface area of macro-electrodes by a factor of 21 due to grain boundary dissolution.

Even greater increases in surface area without grain boundary dissolution was achieved by roughening in non-adsorbing electrolyte: aqueous solution of perchloric acid. Use of this method increased the effective surface area by a factor of 44 due to re-deposition of Pt crystals (20-30nm in size) on the macro-electrodes.

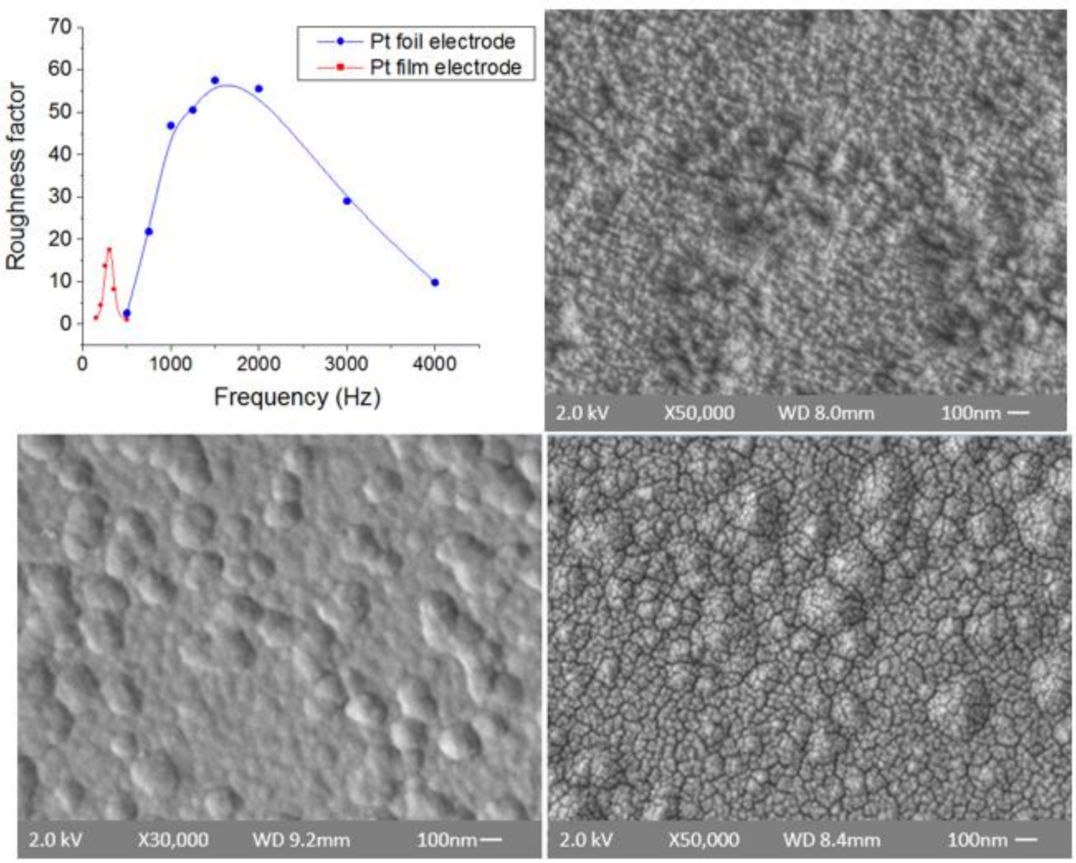
Non-destructive nano-scale roughening of micro-electrodes (up to 20μm in diameter) for biosensors was enabled through surface templating. Thin-film microelectrodes were selectively roughened by electrochemical etching after self-assembly of a nano-sized liquid crystal polymer surface template. Nanoscale roughening was verified by atomic-force microscopy.

Improved stimulation performance was confirmed on macro-electrodes by recording voltage transients as a response to current pulse stimulation waveform and performing lifetime testing under accelerated conditions. Improved recording characteristics of macro- and micro-electrodes were confirmed by impedance spectroscopy.

Roughened micro-electrodes were tested on a biosensor for glucose detection, in which an enzyme coating catalyzes oxidation of glucose to peroxide and gluconic acid. Monitoring of glucose level was verified by demonstrating peroxide detection via amperometric oxidation.

Electrochemical deposition of active material is often necessary for improving the performance and lifetime of implantable devices. Platinum-iridium alloy and PEDOT films were deposited over roughened and flat substrates and electrode performance was monitored under accelerated lifetime testing conditions.

We demonstrated that the performance of our roughened electrodes is enhanced compared to smooth sputtered thin-film metal electrodes for a range of applications, including stimulation, recording and biosensing.



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