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Activated Iridium Oxide AIROF

Low Impedance Coatings for Neural Stimulation and Recording Electrodes

Background

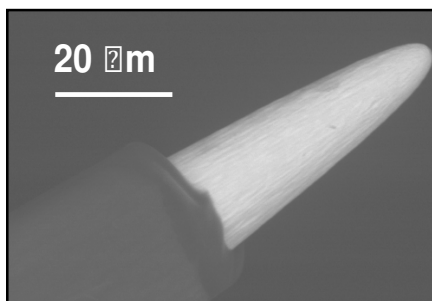
Thin films of activated iridium oxide (AIROFs) are useful as low-impedance coatings for neural stimulation and recording electrodes. With iridium oxide, charge is injected into tissue by reversible reduction and oxidation reactions that minimize electrode polarization and avoid electrochemically irreversible processes that may damage either the electrode or tissue. The use of AIROF as a neural stimulation electrode was first describe in 1983 [1]. Since then, AIROF has been used in animal studies for stimulation of the spinal cord [2], the cochlear nucleus [3], and in many studies of cortical stimulation [4]. Microstimulation in the human occipital cortex using AIROF electrodes has also been described [5].

Activating Iridium to AIROF

Activated Iridium Oxide Films (AIROFs) are formed by electrochemical treatment of iridium metal. In this process, the iridium is cycled or pulsed between negative and positive potential limits close to those for the electrolysis of water. Activation electrolytes are typically a buffered saline at pH 7.

Substrates and Geometry for AIROF Electrodes

AIROF is formed from iridium wire or on vacuum deposited iridium thin-films. There are no particular restrictions on the geometry of the iridium electrode sites or area. Electrode areas range from $\sim 100 \mu\text{m}^2$ to several square millimeters. The AIROF activation electrolytes are chemically benign and do not damage lead insulation or dielectrics on silicon microelectrode arrays.



The tip of a penetrating AIROF microelectrode for intracortical stimulation and recording. (electrode courtesy of Huntington Medical Research Institutes)

Thin films of iridium suitable for activation can be deposited on both rigid and flexible substrates at EIC Biomedical. These films can be photolithographically patterned, insulated and activated to customer specifications.

Charge Injection Capabilities

Activation of neural tissue is typically obtained with short-duration current pulses. At neural stimulation pulse parameters and electrode areas, AIROF electrodes provide charge-injection levels from $0.3\text{-}4 \text{ mC/cm}^2$, depending on the pulse-width and the electrode potential in the interpulse region [6]. AIROF charge capacity is increased by applying a positive potential bias in the interpulse region. The comparison below demonstrates the benefit of biasing AIROF electrodes and the advantage of AIROF in providing higher charge injection than PtIr alloys.

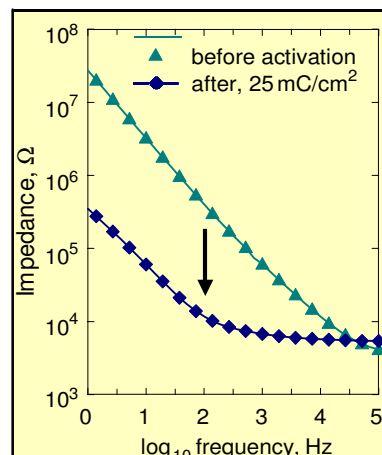
Bias, V	$Q_{inj} \text{ mC/cm}^2$	
	AIROF	PtIr
0.0	0.35	0.09
0.3	1.03	0.17
0.5	2.12	0.23
0.7	3.76	0.29

Charge injection capacity of AIROF and PtIr microelectrodes versus bias (V versus Ag|AgCl) in the interpulse region. Electrode Area = $1000 \mu\text{m}^2$; pulsedwidth = 0.4 ms , pulse frequency = 50 Hz .

The capacitance of AIROF depends on the degree of iridium activation and varies from $100\text{-}600 \mu\text{F}/\mu\text{m}^2$ with $\sim 200 \mu\text{F}/\text{mm}^2$ (30 mC/cm^2) being typical for neural stimulation.

Impedance

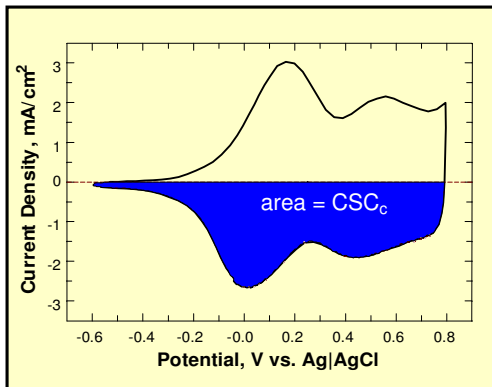
AIROF decreases electrode impedance by at least a factor of ten relative to an uncoated metal electrode at frequencies of 10^3 Hz or lower. The magnitude of the decrease depends on electrode area and the frequency range of interest.



Activation of iridium to AIROF decreases electrode impedance over a broad frequency range. Impedance data for a $2000 \mu\text{m}^2$ electrode activated to a total charge capacity of 25 mC/cm^2 .

Charge Storage Capacity

Activation to AIROF is quantified by the Cathodal Charge Storage Capacity (CSC_c), which is determined from the time integral of current density during a slow-sweep-rate cyclic voltammogram. The CSC_c for neural stimulation ranges from 15-80 mC/cm^2 , and is typically between 25-40 mC/cm^2 .



AIROF CV
showing the
 CSC_c in blue

Polarization

Electrode polarization during current pulsing is greatly reduced by AIROF coatings. Reduced polarization decreases power requirements for delivering stimulation pulses, avoids irreversible and potential harmful reactions at the electrode-tissue interface, and permits recording of evoked activity with stimulation electrodes.

Electrochemical Characterization

Detailed electrochemical characterization of AIROF coatings is performed to ensure quality and compliance with customer specifications, including:

Cyclic Voltammetry - determines the quantity of AIROF on an electrode.

Impedance Spectroscopy - assesses the recording and sensing performance as a function of frequency as well providing an indication of charge-injection capability.

Charge-injection Capacity - voltage transients are measured during stimulation pulsing to determine AIROF polarization, which is then compared with established polarization limits for avoiding electrode damage or harmful irreversible reactions at the electrode.

Optical and scanning electron microscopy are used to determine the morphology and uniformity of AIROF

AIROF Stability

AIROF tolerates sonication and repeated drying and rehydration, provided electrolytes are thoroughly washed from the AIROF with distilled water before drying. AIROF is resistant to strong acids, bases, and solvents. Long-term stability studies of AIROF electrodes are conducted at EIC Biomedical to establish performance and stability

using pulsing conditions relevant to the intended research or clinical use of the electrodes.

Sterilizing AIROF

AIROF is sterilized in ethylene oxide or by autoclaving. AIROF should not be subjected to dry heat over 125°C.

Storing AIROF Electrodes

AIROF electrodes can be stored dry indefinitely but may require some period of electrolyte immersion to obtain their low impedance state if subjected to elevated temperatures during dry storage. AIROF may also be stored wet in distilled water, saline, or buffered saline.

AIROF Coatings at EIC Biomedical

EIC Biomedical works with sponsors to develop AIROF electrodes including:

- deposition of iridium metal films for activation;
- selection of AIROF activation parameters;
- activation of sponsor-supplied iridium electrodes;
- electrochemical characterization and long-term pulsing and stability.

For more information about AIROF, please contact us at:

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1. Robblee LS, Lefko JL, Brummer SB. 1983. Activated Ir: An electrode suitable for reversible charge injection in saline. *J. Electrochem. Soc.* 130:731-3
2. Grill WM, Bhadra N, Wang B. 1999. Bladder and urethral pressures evoked by microstimulation of the sacral spinal cord in cats. *Brain Research.* 836:19-30
3. DJ Anderson, K Najafi, SJ Tanghe, DA Evans, KL Levy, J F Hetke, X Xue, JJ Zappia, KD Wise, Batch-Fabricated Thin-Film Electrodes for Stimulation of the Central Auditory System, *IEEE Trans. Biomed. Eng.*, vol. 36, pp. 693-704.
4. McCreery DB, Yuen TG, Bullara LA. 2000. Chronic microstimulation in the feline ventral cochlear nucleus: physiologic and histologic effects. *Hear Res.* 149:223-38
5. FT Hambrecht, Visual prostheses based on direct interfaces to the visual system, *Bullier's Clinical Neurol.*, vol. 4, pp. 147-165, 1995.
6. Cogan SF, Troyk PR, Ehrlich J, Plante TD. 2005. In vitro comparison of the charge-injection limits of activated iridium oxide (AIROF) and platinum-iridium microelectrodes. *IEEE Trans. Biomed. Eng.* 52:1612-4

Limitations

The suitability and safety of AIROF coatings for any intended application is the responsibility of the end-user. The end-user is cautioned that the long-term stability and performance of AIROF varies with the material, geometry and size of substrates, on the manner in which the AIROF is used, the medium in which the AIROF is used; and other factors that may not be readily predicted.

EIC Biomedical is a division of EIC Laboratories, Inc.