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Sputtered Iridium Oxide SIROF

Low Impedance Coatings for Neural Stimulation and Recording

Background

Thin films of iridium oxide are useful as low-impedance coatings for neural stimulation and recording electrodes. With iridium oxide, charge is injected into tissue by reduction and oxidation reactions that minimize electrode polarization and avoid electrochemically irreversible processes that may damage either the electrode or tissue. The most extensive clinical use of iridium oxide is as a coating for cardiac pacing [1]. Various forms of iridium oxide have been used in animal studies for stimulation in the spinal cord [2] and the cortex [3]. Microstimulation in the human occipital cortex using iridium oxide electrodes has also been described [4].

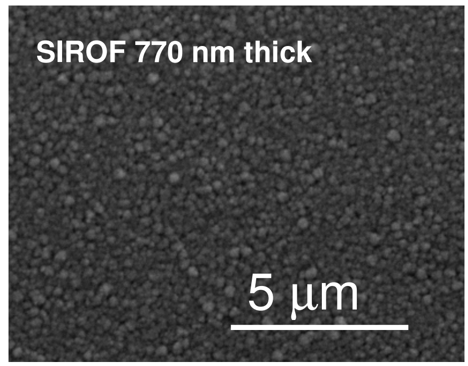
Iridium oxide films formed by sputtering are termed SIROFs (Sputtered IRidium Oxide Films). SIROF is formed from iridium metal by sputtering in an oxidizing plasma.

Substrates and Geometry for SIROF Coating

SIROF may be deposited on a variety of metals and metallic conductors including:

- Gold, platinum and platinum-iridium alloys;
- Titanium and tantalum;
- Stainless steel, Elgiloy, and MP35N;
- Silicon, conductive oxides and conductive nitrides.

SIROF is deposited on planar and nonplanar substrates including wire, coils, and cylinders. SIROF is compatible with photolithographic processing and can be patterned on planar surfaces with high spatial resolution. Since SIROF is deposited at low temperatures, flexible substrates such as polyimide, Parylene-C and liquid crystal polymer (LCP) are also suitable for SIROF coating. Typical electrode areas for SIROF range from ~100 μm^2 on photo-lithographically patterned substrates to several square centimeters on large planar surfaces. For neural recording and stimulation, SIROF film thickness is typically 300-1000 nm (0.3-1 µm), depending on the desired charge-injection capacity and impedance of the coating. SIROF is macroscopically smooth, but on a microscopic scale has a slightly nodular surface morphology that becomes more pronounced as film thickness increases [5].



SIROF morphology viewed by scanning electron microscopy

Impedance

SIROF will reduce 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 SIROF thickness, electrode area and the frequency range of interest.

Polarization

Electrode polarization during current pulsing is greatly reduced by SIROF 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 neural activity with stimulation electrodes.

Charge Injection Capabilities

Activation of neural tissue is typically obtained with short-duration current pulses. For typical neural stimulation pulse parameters and electrode areas, SIROF coatings provide charge-injection levels of 1-8 mC/cm^2. The capacitance of SIROF is thickness dependent and ranges from 250-1000 $\mu F/mm^2$. The charge-injection capacities below are for a 2000 μm^2 SIROF neural stimulation electrode subjected to cathodal current pulses.

Pulse width, ms	Charge capacity, mC/cm^2
0.2	3.5 ± 0.2
0.4	4.9 ± 0.5
0.6	6.3 ± 0.4
0.8	6.8 ± 0.8
1.0	7.6 ± 0.6

SIROF charge capacity is increased by the use of a positive potential bias. The optimum bias is 0.6 V vs. Ag|AgCl. Even in the absence of a bias, SIROF provides a factor of ten higher capacity than similarly sized noble metal electrodes.

Electrochemical Characterization

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

Cyclic Voltammetry Determines the quantity of SIROF 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 SIROF 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 SIROF

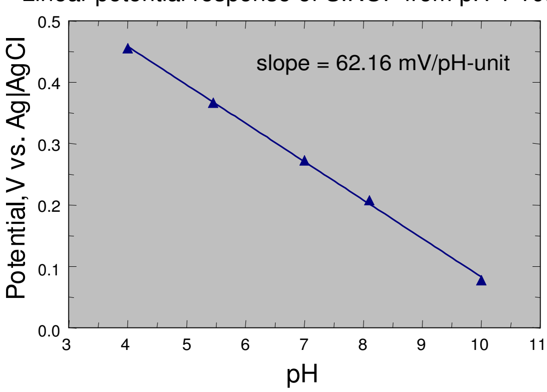
SIROF Stability

SIROF tolerates sonication and repeated drying and rehydration. SIROF passes tape adhesion testing and is resistant to abrasion. SIROF is resistant to strong acids, bases, and solvents. SIROF coatings have been extensively tested by accelerated pulsing. Long-term stability studies are conducted with SIROF to establish the stability on customer-supplied electrodes.

pH Response

SIROF has a near-Nernstein pH response and may be used as a pH electrode.

Linear potential response of SIROF from pH 4-10.



Sterilizing SIROF

SIROF is sterilized in ethylene oxide or by autoclaving. SIROF should not be subjected to dry heat over 150^{o}C.

Storing SIROF Electrodes

SIROF 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. SIROF may also be stored wet in distilled water, saline, or buffered saline.

SIROF Coatings at EIC Laboratories

EIC Laboratories works with customers to incorporate SIROF deposition into electrode and device fabrication process and assists in the selection of SIROF properties and testing to meet customer requirements. SIROF coating is performed in a cleanroom under rigorous process control. SIROF coating services may include:

- photomask design and photolithography;
- SIROF deposition in accordance with customer-specific Process Specifications;
- scanning electron microscopy of coated electrodes;
- electrochemical characterization: cyclic voltammetry, impedance spectroscopy, charge injection capacity, long-term pulsing and stability.

For more information about SIROF, please contact us at:

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Limitations

The suitability and safety of SIROF 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 SIROF will vary with the material, geometry and size of coated substrates, on the manner in which the SIROF is used, the medium in which the SIROF is used; and other factors that may not be readily predicted.

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