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Neural Prostheses: Device Coatings and Testing

Stimulation and Recording Electrode Coatings
Polymer and Thin-film Encapsulation
Coatings and Characterization from EIC Biomedical

Neural Recording and Stimulation Electrodes

EIC Biomedical provides electrode coatings and electrode characterization services for application in medical devices and biomedical research. The company specializes in electrochemically active coatings that provide a low impedance interface to the body. Applications include neural recording and stimulation in the brain, sensory prostheses for vision and hearing loss and peripheral nerve stimulation [1].

Electrode Coatings

Metals
- **Iridium**
- **Platinum**
- **PtIr-alloys**
- **Gold**
- **Titanium, Tantalum**

Iridium Oxides
- **Sputtered iridium oxide (SIROF)**
- **Activated iridium oxide (AIROF)**
- **Electrodeposited iridium oxide (EIROF)**

Other Coatings
- **Titanium nitride (fractal)**
- **Poly(ethylenedioxythiophene) PEDOT**

Electrode coatings can often be deposited on customer-supplied electrodes and electrode arrays. EIC Biomedical also offers electrode coatings on a variety of substrates including silicon, glass, polyimide, Parylene-C, liquid crystal polymer, and metal wire and foil. On planar substrates electrode coatings and interconnect metallization are patterned by standard photolithographic and thin-film processing techniques.

Encapsulation Materials

EIC Biomedical provides a wide range of encapsulation coatings for implantable devices including polymer and inorganic dielectrics. The inorganic dielectrics include amorphous silicon carbide (a-SiC) and oxycarbide (a-SiOC) both of which show superior stability and barrier properties in physiological saline environments [2].

Encapsulation Coatings

Polymers
- **Polyimide**
- **Parylene-C**
- **Silicones**

Inorganic Dielectrics
- **Silicon carbide (a-SiC)**
- **Silicon oxycarbide (a-SiOC)**
- **Silicon nitride and silicon oxide**

Testing Capabilities

Extensive electrochemical testing is available at EIC Biomedical. Standard electrochemical testing includes:

- Cyclic voltammetry
- Electrochemical impedance spectroscopy
- Voltage transients and charge-injection capacity during stimulation pulsing
- Long-term *in vitro* pulsing for electrode stability studies
- Corrosion and dissolution rate measurements
- Potentiodynamic polarization
- Chronoamperometry for biosensor studies

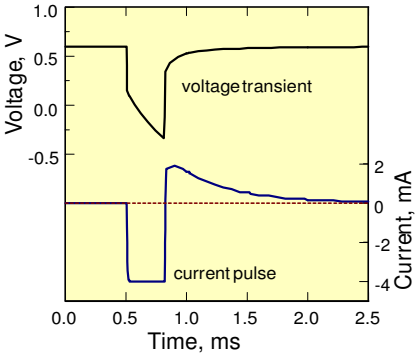
Analytical techniques for electrode and coating characterization also include:

- Scanning electrode microscopy with energy dispersive x-ray chemical analysis
- Surface profilimetry
- IR and UV-VIS spectroscopy, NMR, HPLC, GCMS

Charge-injection capacities (Q_{inj}) of stimulation electrode coatings

Electrode	Q_{inj}, mC/cm^2	Ref	Comments
Sputtered iridium Oxide (SIROF)	2-8	1	deposited by sputtering onto most conductive substrates
Activated iridium oxide (AIROF)	1-5	1, 4	formed electrochemically from iridium metal
Electrodeposited iridium oxide (EIROF)	1-5	3	suitable for coating gold, Pt, PtIr, carbon, and stainless steel.
Platinum	0.05 – 0.15	4	noble metal of choice for large area electrodes
Titanium Nitride	~1	5	deposited by sputtering onto most conductive substrates

Analyzing voltage transients



Long-term Testing

Electrodes are tested for extending periods at 37°C in electrolytes that closely match the inorganic constituents of interstitial and cerebrospinal fluid [6]. Stimulation electrodes are pulsed with multichannel stimulators provided by EIC Biomedical when appropriate or with pulse generators provided by the customer. Electrodes are periodically characterized by CV, EIS, and potential transient measurements and test electrolytes can be analyzed for electrode dissolution products.

EIC Biomedical also provides long-term and accelerated testing of electrode structures and encapsulation. Encapsulation is characterized by leakage current measurements at 37°C in buffered physiological saline, often under continuous voltage bias.

Coating and Testing at EIC Biomedical

EIC Biomedical works to develop coating and testing programs that precisely meet customer needs, including:

- consulting on materials selection and test methods
- development of written specifications and procedures
- electrode coating and patterning
- electrochemical and physical characterization process documentation and reporting.

For more information, please contact us at:

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Limitations

The suitability and safety of coatings provided by EIC Biomedical for any intended application is the responsibility of the end-user. The end-user is cautioned that the long-term stability and performance of any coating will vary with the material, geometry and size of coated substrates, on the manner in which the coatings are used, the medium in which the coatings are used; and other factors that may not be readily predicted. Likewise, test results provided by EIC Biomedical will not establish the suitability or safety of test articles for medical or other applications. The use of test results and test articles for any intended application is the responsibility of the end-user. The end-user is cautioned that the results of *in vitro* testing do not establish *in vivo* safety.

1. Cogan SF, Neural Stimulation and Recording Electrodes. *Annu Rev Biomed Eng.* 10:275-309, 2008.
2. Cogan SF, Edell DJ, Guzelian AA, Liu Y-P, Edell R, Plasma-enhanced chemical vapor deposited silicon carbide as an implantable dielectric coating, *J Biomed Mater Res* 67A: 856 –867, 2003.
3. Meyer RD, Cogan SF, Nguyen TH, Rauh RD, Electrodeposited Iridium Oxide for Neural Stimulation and Recording Electrodes, *IEEE Trans. Neural Sys. and Rehab. Eng.* vol. 9:1-10, 2001.
4. Cogan SF, Troyk PR, Ehrlich J, Plante TD. In vitro comparison of the charge-injection limits of activated iridium oxide (AIROF) and platinum-iridium microelectrodes. *IEEE Trans. Biomed. Eng.* 52:1612, 2005.
5. Weiland JD, Anderson DJ, Humayun MS. 2002. In vitro electrical properties for iridium oxide versus titanium nitride stimulating electrodes. *IEEE Trans. Biomed. Eng.* 49:1574— 79.
6. Cogan SF, Troyk PR, Ehrlich J, Gasbarro CM, Plante TD. The influence of electrolyte composition on the in vitro charge-injection limits of activated iridium oxide (AIROF) stimulation electrodes. *J Neural Eng.* 4:79 -86,2007.

Additional information and literature sources.

From EIC Biomedical see,

Sputtered iridium oxide, DS01-2008A-0 SIROF

Activated iridium oxide, DS02-2008A-0 AIROF

Silicon carbide dielectrics, DS03-2008A-0 SiC

Electrodeposited iridium oxide, DS04-2008A-0 EIROF

Evaluation and Testing, DS06-2008A-0

Multielectrode polyimide arrays, DS07-2009A-0 MEA

Useful additional scientific literature

Merrill DR, Bikson, Jefferys JGR. Electrical stimulation of excitable tissue: design of efficacious and safe protocols. *J. Neurosci. Methods.* 141:171-98, 2005.

Robblee LS, Rose TL. Electrochemical guidelines for selection of protocols and electrode materials for neural stimulation. In *Neural Prostheses: Fundamental Studies*, ed. WF Agnew, DB McCreery. Englewood Cliffs, NJ: Prentice Hall. pp. 25-66, 1990.

Prochazka A, Mushahwar VK, McCreery DB. Neural Prostheses. *J. Physiol.* 533:99-109, 2001.

Neuroprosthetics: Theory and Practice (Series on Bioengineering & Biomedical Engineering - Vol. 2), by KW Horch (Editor), G. Dhillon (Editor) World Scientific Publishing Company (April 2004)

Polikov VS, Tresco PA, Reichert WM. Response of brain tissue to chronically implanted neural electrodes. *J. Neurosci. Methods,* 148:1-18, 2005.

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