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Silicon carbide and oxycarbide
a-SiC/a-SiOC

Thin-film Encapsulation for Neural Recording and Stimulation Electrodes

Background

Thin films of amorphous silicon carbide (a-SiC) and oxycarbide (a-SiOC) are insulating coatings that provide a high degree of chemical stability and impermeability to water and ions when immersed in physiological media [1,2]. The a-SiC and a-SiOC are dielectrics with electronic resistivities of $\sim10^{13}$ Ω-cm and $>10^{16}$ Ω-cm, respectively. Both are stable in acidic and alkaline media with a-SiC having a negligible etch rate in hydrofluoric acid.

Deposition

Amorphous SiC and a-SiOC are deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD) at temperatures between 100-400°C Temperatures at the higher end of this range are preferred if abrasion resistance is required.

Substrates and Geometry

SiC and a-SiOC are deposited on metal, polymer or ceramic substrates. A film thickness between 0.2 µm and 4 µm is suitable for electrical insulation and for encapsulation in aqueous electrolytes. The dielectrics can be deposited on silicon integrated circuits, flexible substrates including polyimide, liquid crystal polymer (LCP) and fluoropolymers. Suitable metal substrates include: platinum and platinum-iridium alloys, iridium, titanium, and 316LVM stainless steel or MP35N.

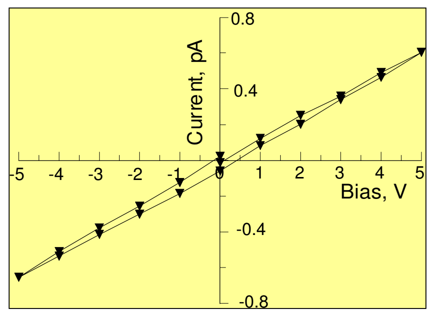
Both a-SiC and a-SiOC adhere well to silicon nitride and silicon oxide and can be combined in multilayer coatings with these dielectrics. Amorphous SiC and a-SiOC also adhere to silicon and polysilicon. Planar substrates can be coated with high uniformity over large areas. Wires, coils, and structures with open geometries may be coated with good uniformity, particularly if multiple thin coats are applied with substrate rotation between depositions. The PECVD process is less suitable for porous structures or materials with high surface roughness.

Stability in Physiological Saline

The stability of PECVD a-SiC and a-SiOC in saline is superior to that of LPCVD or PECVD silicon oxide and silicon nitride. Following are etch rates in phosphate buffered physiological saline (pH=7.4) at 37°C and under accelerated conditions at 90°C.

PECVD a-SiC No dissolution at 90°C
PECVD Si nitride 3-4 nm/hr at 90°C
LPCVD Si nitride 0.4 nm/day at 37°C
LPCVD Si oxide 1 nm/hr at 90°C
LPCVD Si oxide 0.8 nm/day at 37°C

Electrochemically estimated water transport rates of $<7\times10^{6}$ molecules/s-cm^2 are observed for 1 µm a-SiOC, compared with 5×10^{14} molecules/s-cm^2 for LPCVD SiO_2.



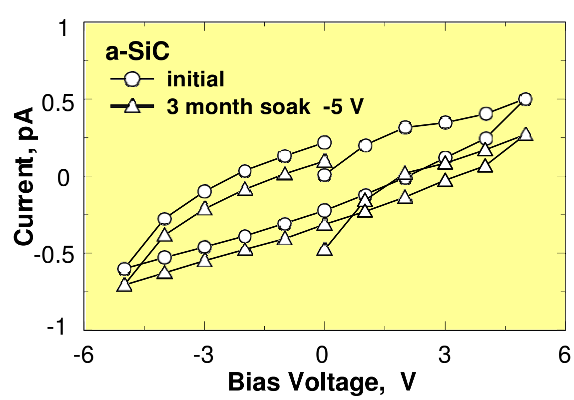
Sub-picoAmp leakage currents through a-SiC as a function of voltage bias in physiological saline. Exposed a-SiC area, 0.8 cm².

Patterning a-SiC and a-SiOC

Amorphous SiC and a-SiOC are patterned by Reactive Ion Etching (RIE) or laser ablation. RIE is preferred for planar electrode arrays. Photolithography is used to define the pattern of a-SiC or a-SiOC removal.

Sterilizing a-SiC and a-SiOC

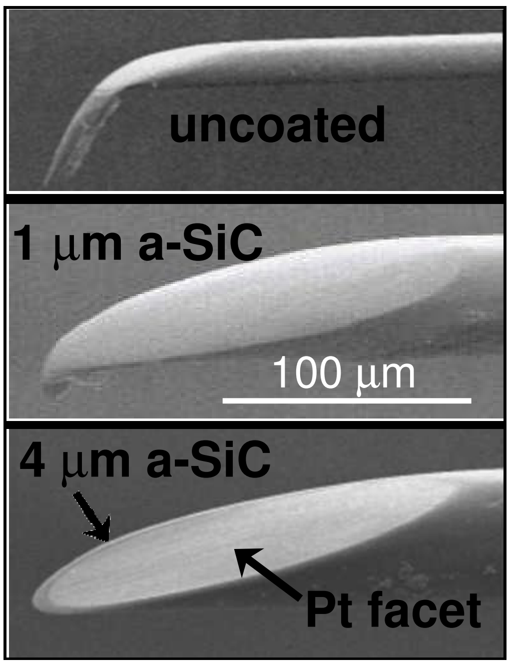
Amorphous silicon carbides are sterilized by ethylene oxide, autoclaving, dry heat, or wet chemical treatment.



Amorphous SiC retains sub-picoAmp leakage currents after 3 months at a –5 V bias in saline at 37°C

Mechanical Properties

Films of a-SiC and a-SiOC are mechanically robust and scratch resistant when deposited at temperatures of 300°C or higher. Amorphous SiC has a high stiffness, two times that of Si_3N_4 [3], and may be used to stiffen flexible substrates. The example below shows a platinum wire electrode in which a faceted electrode site is created by polishing. Without a-SiC, the soft metal bends and deforms. With a-SiC a sharp, well-defined electrode tip is obtained. The a-SiC along the shank of the electrode provides electrical isolation as well as stiffness, replacing or augmenting polymeric coatings.



a-SiC coating on a Pt wire microelectrode. The a-SiC provides stiffness the insulation.

Storing Silicon Carbide Coated Devices

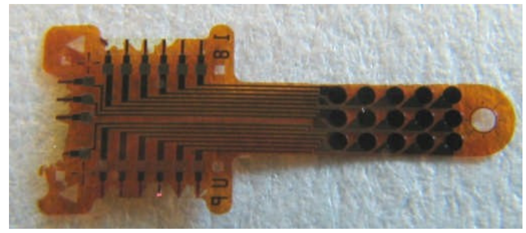
Silicon carbide coated devices may be stored dry indefinitely. Devices may also be stored wet in distilled water, saline, or buffered saline without damage to the a-SiC or a-SiOC.

Tissue Reactions

Gross tissue response to a-SiC coated substrates implanted in the subcutaneous space is minor and not statistically different from quartz and silicone controls. In cortex, a-SiC coated penetrating microelectrodes are similarly well-tolerated [1].

Silicon Carbide Coating at EIC Biomedical

EIC Biomedical will deposit and pattern silicon carbide coatings on substrates provided by the sponsor. EIC also fabricates electrode arrays incorporating silicon carbide. The a-SiC coatings impart excellent long-term stability, particularly when combined with sputtered iridium oxide (SIROF) electrode coatings.



Polyimide array with 15 SIROF electrodes after 20 weeks at 87°C in saline. The array is undamaged and the low impedance SIROF electrode properties preserved.

Services related to silicon carbide include:

- guidance in the selection of materials and the design of devices incorporating silicon carbide;
- deposition and patterning of a-SiC and a-SiOC;
- characterization of silicon carbide films by thickness measurement, scanning electron microscopy, and leakage current measurements;
- stability testing of structures and devices incorporating silicon carbide by 37°C and accelerated (87°C) long-term testing in physiological saline.

For more information about silicon carbide, please contact us at:

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1. SF Cogan, DJ Edell, AA Guzelian, Y-P Liu, R Edell, Plasma-enhanced chemical vapor deposited silicon carbide as an implantable dielectric coating, J Biomed Mater Res 67A: 856–867, 2003.
2. SF Cogan, Biomedical Device with a Protective Overlayer, U.S. Patent No. 5,755,759.
3. H. Windischmann, Intrinsic stress and mechanical properties of hydrogenated silicon carbide produced by plasma-enhanced chemical vapor deposition, J. Vac. Sci. Technol. vol 9, pp 2459-2463, 1991.

Limitations

The suitability and safety of amorphous silicon carbide and silicon oxycarbide coatings and multi-layer structures incorporating these coatings for any intended application is the responsibility of the end-user. The end-user is cautioned that the stability and performance of any silicon carbide coating will vary with the material and geometry of coated substrates, on the manner in which the silicon carbide is used, the medium in which the silicon carbide is used; and other factors that may not be readily predicted.

EIC Biomedical is a division of EIC Laboratories, Inc.