

Flexible Parylene-based Microelectrode Technology for Intraocular Retinal Prostheses

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Abstract—We present the first flexible microelectrode arrays designed for intraocular implantation that utilize parylene C as their primary structural and insulating material. These electrodes are fabricated as a key component of an intraocular retinal prosthesis comprising a radio-frequency coil for power and data transfer, a packaged high lead-count telemetry-recovery and driving ASIC, and a high density epiretinal stimulating microelectrode array for the treatment of age-related blindness in humans. Electrochemical tests have demonstrated that these thin-film platinum electrodes perform optimally for neuronal stimulation. A novel ergonomic MEMS geometry for a complete intraocular system with capsular retaining wings that enables all the components of the system to be implanted and retained within the lens capsule and vitreous cavity of the eye is also presented. The efficacy of this geometry when compared with a previous model without capsular retaining wings has been verified by surgical implantation in animal models.

BACKGROUND

Low-resolution retinal prostheses have shown great promise in enabling subjects blind from such diseases as retinitis pigmentosa and age-related macular degeneration to perceive visual data [1]. Few researchers contest the hypothesis that a higher density of electrodes placed on the macula would afford the wearer a more useful visual map of the environment, likely restoring such abilities as facial recognition and coarse reading. This next-generation retinal prosthesis requires a high-density flexible retinal electrode array and cable, a flexible radio-frequency (RF) coil for wireless power and data recovery, and a high lead-count package for integration of these components with the driving application-specific integrated circuitry (ASIC) and discrete components, in order to establish such high-resolution macular stimulation capability. We have previously demonstrated a parylene-based drop-chip technology for scalable interconnection of ASICs and discrete components with thin-film wires [2], as well as flexible parylene-based multi-metal layer RF coils for wireless telemetry [3]. Here, we discuss the fabrication and testing results for parylene-based electrode arrays. The fabrication process and geometries for the parylene electrode arrays described herein are compatible with those for these other system components.

CURRENT RESULTS

Parylene-based electrode arrays are fabricated as shown in Fig. 1. Briefly, photoresist is optionally spun on a standard silicon wafer. $\sim 8 \mu\text{m}$ of parylene C is then vapor-deposited on the entire wafer. A photoresist mask is patterned for a subsequent metal liftoff forming the contacts, conductive lines, and electrodes. $\sim 7 \mu\text{m}$ of parylene C is then deposited, and a photoresist mask is used

in oxygen plasma to remove the parylene covering the electrodes and any contacts, as well as to form the overall electrode geometry. Finally, the electrodes are peeled from the wafer in an acetone or water bath and undergo post-processing to prepare them for implantation. A 16×16 electrode array of $125 \mu\text{m}$ diameter thin-film Ti/Pt electrodes and lines of $12 \mu\text{m}$ pitch fabricated in this manner is shown in Fig. 2a, with the electrode geometry clearly depicted in the scanning electron micrograph in Fig. 2b. Figs. 3a and 3b depict test electrodes used for electrochemical characterization, and Fig. 4 graphs a typical cyclic voltammogram (CV) for an electrode undergoing saline soak tests under normal test conditions (showing nominal electrical behavior of the platinum electrode under test). Based on initial implantation tests of a surgical test structure simulating the geometries of all the required components of an intraocular retinal prosthesis (Figs. 5a and 5b), an improved ergonomic geometry has been developed that addresses the problem of traction of the RF coil region through the posterior capsulotomy into the vitreous cavity because of the flexible cable and electrode array. Our new design (Fig. 6) has capsular retaining wings that maintain the RF coil within the lens capsule while the other components course through the vitreous cavity to the retina. The implementation of this geometry with test electrodes and traces to monitor for surgical damage is shown Figs. 7a and 7b. Fig. 8 depicts a typical surface profile of the electrodes under test in this surgical test structure, with the electrodes recessed approximately $7 \mu\text{m}$ within the parylene.

The advantages of the use of parylene as the bulk-material for such a system, when compared with technologies based on the use of other materials such as polyimide [4] and silicon (developed for other purposes) [5] include parylene's pinhole-free conformality, its low water permeability when compared with polyimide [6], its proven intraocular [2] and United States Pharmacopoeia (USP) Class VI biocompatibility, its transparency, and its flexibility and mechanical strength (Young's modulus $\sim 4 \text{ GPa}$). The geometry for the prosthesis has been optimized to ensure mechanical stability under the conditions of chronic implantation. Combined with our other parylene-based components, these arrays complete the triad of technologies necessary to fabricate a high-resolution intraocular retinal prosthesis.

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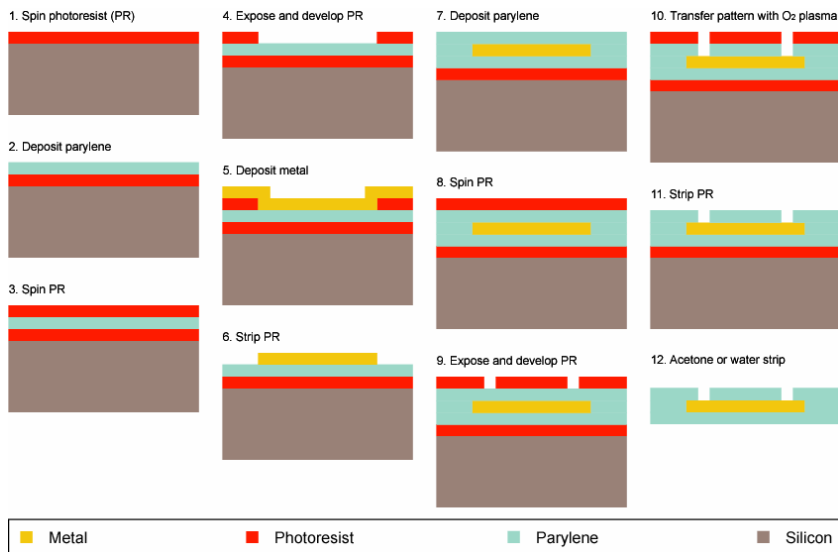


Fig. 1. Microfabrication process for flexible parylene intraocular electrode arrays.

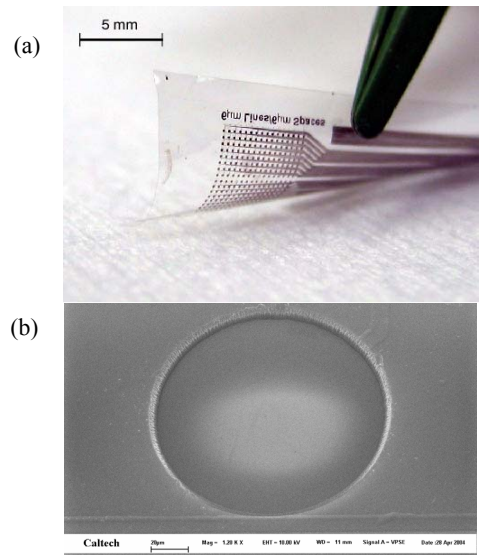


Fig. 2. (a) A 256 Ti/Pt electrode array and (b) SEM micrograph detailing electrode geometry.

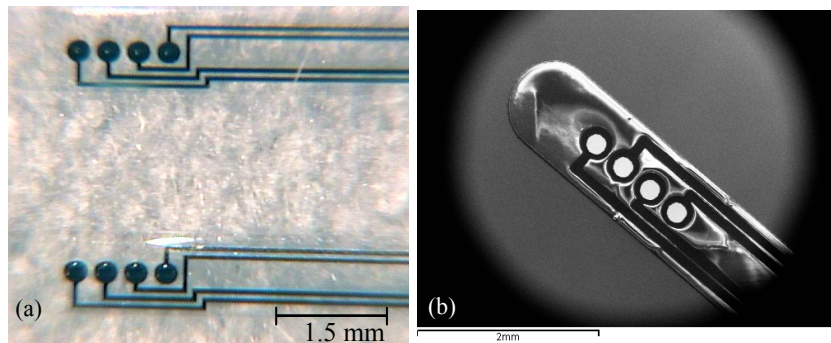


Fig. 3. (a) 50 and 200 μm diameter test electrodes for electrochemical measurements and (b) SEM micrograph of electrode array depicting 200 μm diameter 5000 \AA thick Pt electrodes.

Cyclic Voltammogram of 50 μm Diameter Parylene Test Electrode (20nm Ti / 200nm Pt)

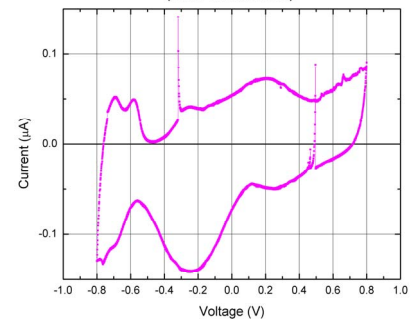


Fig. 4. Cyclic voltammogram of 50 μm diameter test electrode in 0.1 M PBS electrolyte.

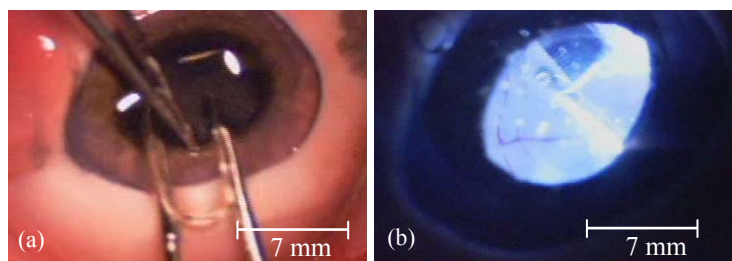


Fig. 5. Surgical implantation under (a) anterior and (b) intravitreal illumination.

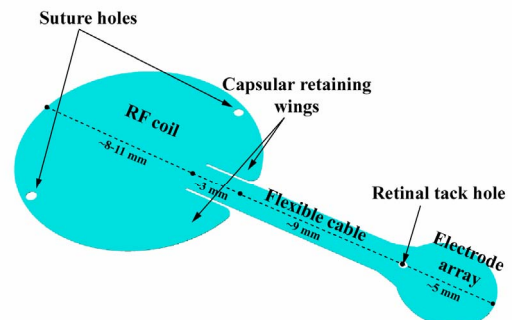


Fig. 6. Ergonomic bioconforming geometry for an intraocular retinal prosthesis.

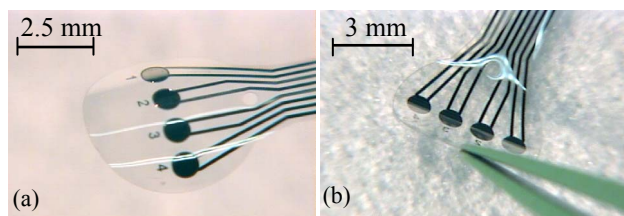


Fig. 7. Contoured surgical test structures for mechanical and electrical characterization; (a) retinal aspect and (b) vitreal aspect of electrode array region.

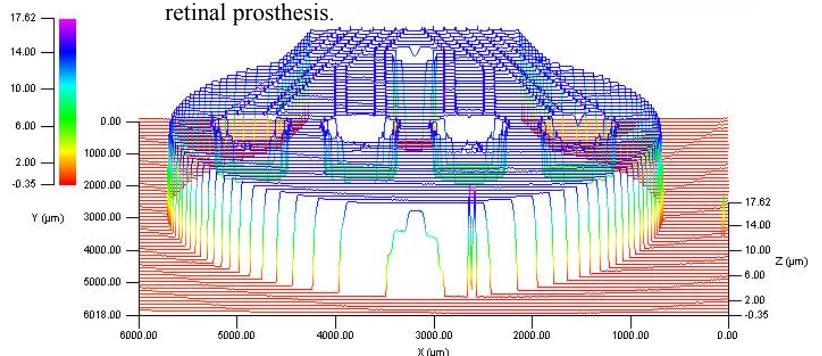


Fig. 8. Surface profile of retinal aspect of electrode array region of surgical test structure.