ARRAYED 3D PARYLENE SHEATH PROBES FOR NEURAL RECORDINGS

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ABSTRACT

Parylene C arrayed neural probes possessing 3D sheath structures that can be decorated with neurotrophic factors for attracting and promoting neural tissue ingrowth are presented for long-term intracortical neural recording. 3D sheath structures were constructed through thermoforming of surface micromachined Parylene microchannels around a solid microwire mold. Multiple Pt electrodes were patterned along the sheath lumen and exterior. Electrochemical characterization of the electrodes confirmed impedance values (25-150 kΩ at 1 kHz) suitable for neural recordings. Sheath probes were temporarily stiffened for a successful implantation demonstrated in agarose brain tissue model.

KEYWORDS: Parylene C, Thermoforming, Neural Probe, Neuroprosthetic, Brain-machine-interface

INTRODUCTION

Achieving long-term reliable neural recordings for brain-machine interfaces is an ongoing challenge. Commercial probe technologies in the forms of microwire arrays or micromachined Si probes (Utah and Michigan) experience loss of neural signal recording over time; this loss may be attributed to aggressive foreign body response, mechanical mismatch aggravated by brain micromotion, and the resulting gliosis shielding recording sites from neuronal activity [1].

The neurotrophic electrode, however, has achieved long-term neural recordings in humans on the order of years [2]. This success is attributed to the release of neurotrophic factors from the probe into the surrounding tissue that attracts neural tissue ingrowth into the conical device towards recording electrodes. These probes are manually assembled which suffers from poor reproducibility and thus has limited its adoption.

Microfabrication technologies overcome manufacturing challenges and achieve batch fabricated devices with consistent repeatability and fine features. Recording sites constructed with thin film metal electrodes increases the number and density of recording sites per probe for greater spatiotemporal signal. Probes constructed from flexible polymer materials can partially alleviate the mechanical mismatch. Finally, promotion of tissue integration post-implantation can be achieved with slow release of neurotrophic coatings. Therefore, to achieve long-term neural recordings, we previously introduced flexible Parylene neural probes possessing multiple Pt recording sites with novel 3D sheath structures that can be decorated with neurotrophic factors for neural tissue ingrowth (Fig. 1) [3]. Here, improved sheath probe designs in the forms of 2×2 and 1×2 arrays are described. Sheath probe arrays maximize neural signal inputs and accessible brain volume per device.

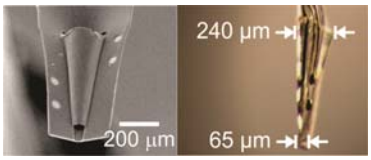

Figure 1: SEM (left) and profile view (right) of Parylene sheath probe. The 3D sheath structure allows for ingrowth of neural processes.

METHODS

Materials

Parylene C, a USP Class VI biocompatible polymer that can be processed with standard micromachining technologies, was used to construct the sheath probes. Parylene C (E~3 GPa) is significantly more compliant than traditional probe materials such as Si or glass (E~100-200 GPa). Thin-film Pt, a non-corrosive and inert metal widely used in neural interfaces was selected for recording site construction, simplifying sheath probe fabrication since no adhesion layer between Pt and Parylene was required [4].

Device design

Probes consist of sheath structures with four Pt electrodes (45 µm diameter) on each of the inner and outer surfaces (eight total electrodes). Sheath dimensions and electrode placement were selected to match the anatomy of rat barrel motor cortex to target recordings of vibrissal (whisker)-related neuronal activity. Probes were arrayed in a 2×2 or 1×2 arrangement for maximal access to neural signals; allowing simultaneous recordings from multiple vibrissal-related sites per device.

Device fabrication

A bare Si wafer with native oxide was used as a carrier substrate during the microfabrication process and aided in the subsequent release of Parylene probes from the wafer. The Si wafer was first coated with 5 µm Parylene. Electrodes, traces, and contact pads were liftoff patterned using AZ 5214 E-IR and e-beam deposited Pt (2000 Å). Parylene insulation (1 µm) was then deposited, patterned, and plasma etched, exposing recording sites and contact pads. Next, AZ 4620 (9.6 µm) was patterned and covered with 5 µm Parylene to create sheath structures. Selective plasma etching of Parylene exposed

peripheral electrodes, contact pads, and sheath openings while simultaneously defining each individual probe. Finally, the probe was lifted from the wafer surface and an acetone soak released the sheath structure.

3D Parylene sheath thermoforming

A microwire mold was aligned and inserted into the Parylene microchannel under a microscope. The assembly was then placed into a vacuum oven and the Parylene was thermoformed at 200 °C and held for 48 hours followed by a controlled cool down. Nitrogen purging prevented Parylene oxidative degradation by minimizing oven oxygen content. The microwire was then removed and the sheath retained its 3D structure. The thermal annealing process also served to improve adhesion between Parylene layers.

RESULTS

Arrayed devices were successfully fabricated and thermoformed (Fig. 2). Thermoformed Parylene sheaths were mechanically robust and could withstand repeated indentation demonstrating that probe structures will not collapse upon implant. Electrical connections were made with use of a ZIF connector (Fig. 3a). Electrochemical characterization of Pt recording sites through electrochemical impedance spectroscopy (EIS) and cyclic voltammetry (CV) demonstrated good neural recording properties with acceptable electrode impedances and electrochemical surface properties matching that of bulk Pt wires, respectively.

An insertion technique that temporarily stiffened the sheath probes for implantation was developed since the Parylene probes were too compliant for direct insertion into neural tissue (Fig. 3b and 3c). Each sheath probe was individually affixed to a microwire with polyethylene glycol (PEG). The assembly was then attached to a stereotactic tool and inserted into 0.5% agar solution, brain tissue model. A saline flush released the sheath probes by dissolving the PEG and the microwires were removed; leaving the sheath probes implanted (Fig. 3d).

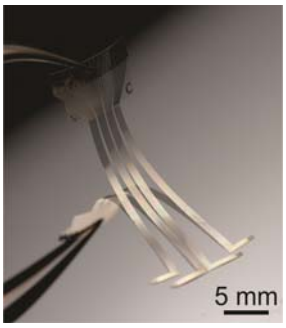

Figure 2: Released 2×2 sheath probe array.

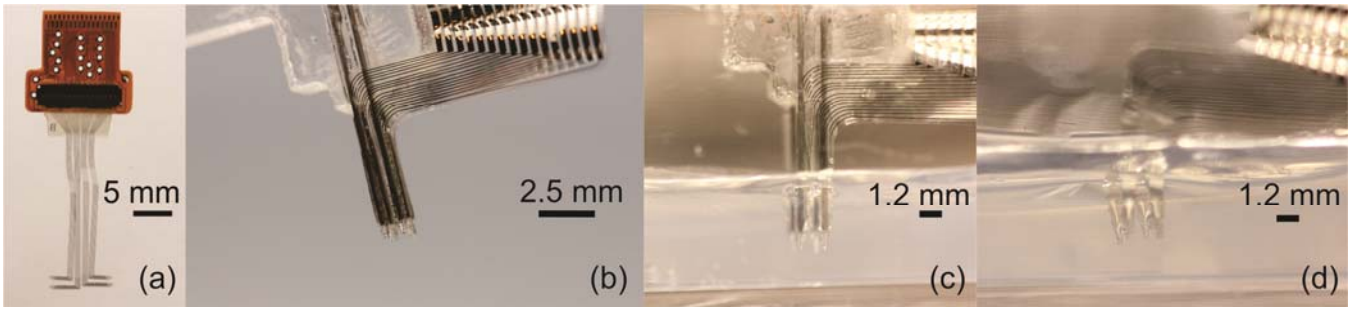

Figure 3: (a) Electrical packaging of 2×2 arrayed sheath probes with a ZIF connector to a PCB. (b) 1×2 array attached to microwires on an introducer tool with PEG. (c)2×2 array inserted into brain tissue mimic while affixed to microwires. (d) Array remained implanted after probe release and microwire removal.

CONCLUSION

3D Parylene sheath probes were arrayed in 2×2 and 1×2 architectures for long-term neural recordings over multiple sites of interest and large areas. Biocompatible materials were selected for maximizing long-term recording success. Probes featured multiple Pt recording sites on both interior and exterior sheath surfaces. Electrochemical characterization of the thin-film Pt confirmed acceptable properties for neural recordings. An implantation method was developed and successfully demonstrated in brain tissue mimic; thus this technique is easily translated for *in vivo* implantations.

Future work entails development of deposition processes for decorating neurotrophic factors onto probe surfaces and long-term cortical recordings from rat. This probe architecture will also be investigated for peripheral and central nervous system recording applications.

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