

3D Tubular Microelectrode Array Fabricated via Rotary Surface Exposure for Deep-Tissue Electrophysiological Monitoring of Organoids

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Summary:

A microelectrode array (MEA) was micro-fabricated and integrated onto the surface of a cylindrical polymer capillary for deep-tissue electrophysiological monitoring of organoids. By employing a rotary surface exposure system, platinum (Pt) functional electrodes were patterned on a 300 μm outer-diameter polyimide (PI) tube and encapsulated with biocompatible Parylene. This micron-scale tubular MEA configuration facilitates low-damage penetration into the organoid matrix, circumventing the constraints of traditional planar microelectrode arrays in accessing the internal electrophysiology of 3D tissue models.

Keywords: 3D microelectrode array, Rotary surface exposure, Tubular bioelectronics, Organoids, Deep-tissue monitoring

Background

While organoids have emerged as transformative in vitro models for recapitulating human tissue complexity, their functional characterization remains bottlenecked by destructive morphological analysis or the 2D spatial constraints of conventional planar microelectrode arrays [1]. To bridge this dimensionality gap, we present a flexible, miniaturized 3D microelectrode array (MEA) integrated onto a 300 μm polyimide (PI) tubular substrate (Fig. 1). By leveraging a high-precision rotary surface exposure process, this probe enables minimally invasive penetration into the organoid matrix, providing a robust solution for high-resolution, deep-tissue electrophysiological recordings [2]. This platform overcomes the spatial limitations of traditional technologies, offering a high-content functional analysis tool for next-generation organoid research and drug screening [3].

Description of the New Method

The fabrication strategy for the proposed 3D tubular microelectrode array (MEA) is detailed in Fig. 2, leveraging a specialized rotary surface exposure system for high-precision patterning on non-planar substrates [2]. The process sequence includes:

- a. Using a curved-surface lithography system, a photoresist film was patterned on the capillary based on the programmable microstructure of the electrode array.
- b. A 120-nanometer-thick platinum (Pt) film was

deposited via magnetron sputtering onto the surface of the capillary with the patterned photoresist.

c. The photoresist film was removed via a stripping process, yielding a patterned Pt microstructure on the capillary surface.

d. A 500-nm-thick Parylene film is deposited.

e. A 2- μm photoresist layer was spray-coated and patterned via a secondary alignment (overlay) exposure.

f. oxygen plasma reactive ion etching was employed to selectively etch the Parylene, successfully exposing the electrode sites.

g. PEDOT:PSS was selectively applied onto the exposed microelectrode sites to reduce interfacial impedance and enhance the charge injection capacity.

Results

Fig. 3 and Fig. 4 illustrate the fabrication precision after etching. SEM images (Fig. 3) show the clear surface morphology post-Parylene-C etching, while EDS mapping (Fig. 4) confirms the successful removal of the encapsulation layer and precise platinum patterning.

The interface modification is shown in Fig. 5, comparing the bare (left) and PEDOT: PSS-coated (right) electrodes. The resulting electrochemical enhancement is validated in Fig. 6. CV curves (Fig. 6a) exhibit excellent stability and high charge storage capacity over multiple cycles. Additionally, the EIS Bode plot (Fig. 6b) shows low interfacial impedance and optimized charge-transfer kinetics, providing a high-

performance platform for long-term organoid monitoring.

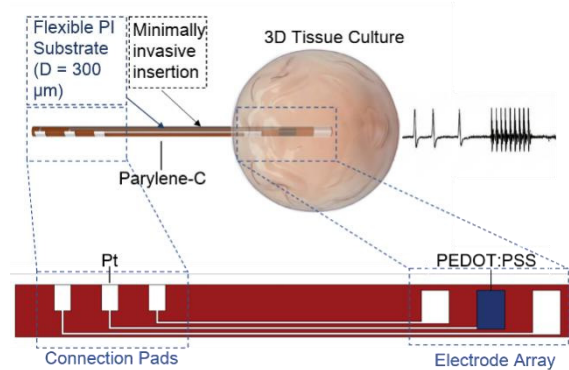


Fig. 1. Schematic of the integrated flexible PI-based microelectrode system for in-situ organoid signal recording.

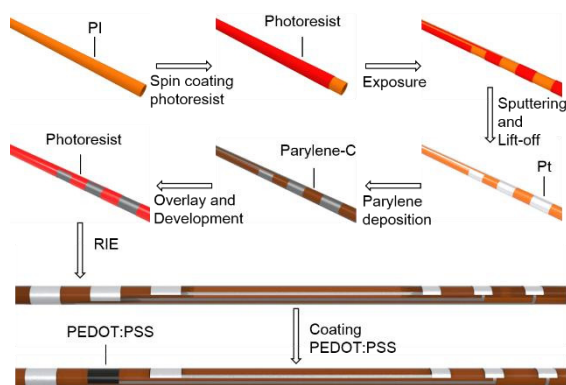


Fig. 2. Fabrication workflow of the microelectrode array on a 300 μm diameter PI substrate.

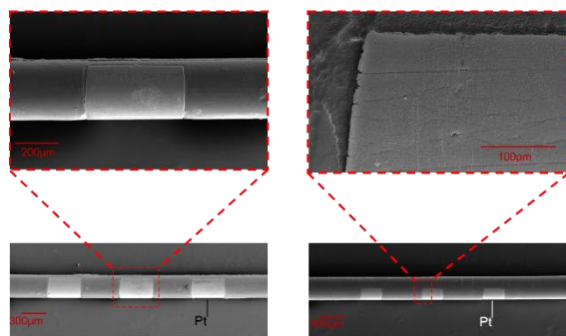


Fig. 3. Scanning electron microscopy (SEM) micrograph of the Parylene layer following the plasma etching process.

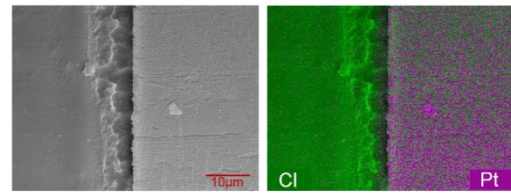


Fig. 4. Energy-dispersive X-ray spectroscopy (EDS) analysis of the substrate surface after Parylene etching.

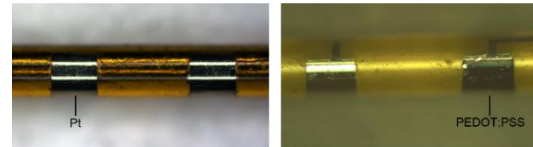


Fig. 5. Microscopic images of the electrode before (left) and after (right) PEDOT:PSS modification.

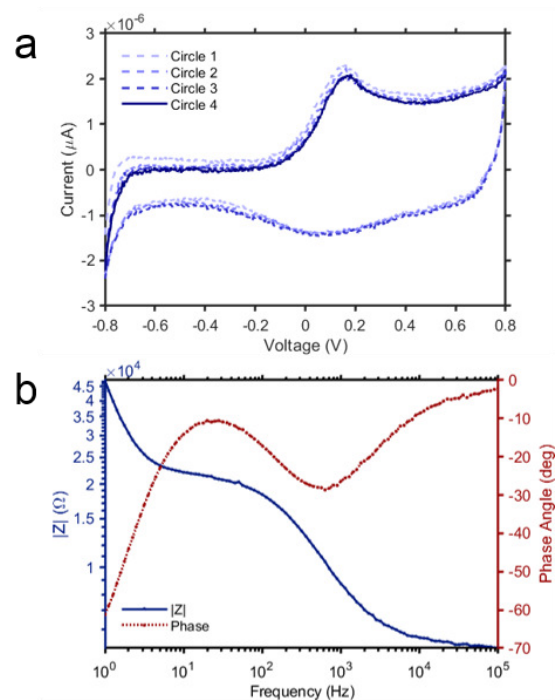


Fig. 6. Electrochemical characterization of the MEA: (a) CV curves; (b) EIS Bode plot.

References

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