

PEDOT:PSS coated Fully Printed Microelectrode Arrays for Neural Interfacing

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Summary:

Inkjet printing enables scalable fabrication of flexible microelectrode arrays, but commonly used printable inks rely on suboptimal electrode materials. Here, gold electrodes on flexible substrates were coated with electropolymerized PEDOT:PSS, significantly reducing impedance and enhancing charge injection capability. Electrochemical characterization together with neuronal recording and stimulation demonstrate improved interface performance. These results highlight the potential of inkjet printed PEDOT:PSS coated electrodes for high performance neural interfacing.

Keywords: Inkjet printing, Microelectrode array, PEDOT:PSS, Neural interface, Flexible electronics

Introduction

Microelectrode arrays (MEAs) are widely used in neural interfaces for recording and stimulation of electrogenic activity [1]. Conventional fabrication techniques, such as photolithography, offer high precision but are often costly and limited in design possibilities. Inkjet printing has emerged as a promising alternative for the fabrication of flexible and customized electronic devices, enabling rapid prototyping and reduced manufacturing complexity [2].

However, printed metal electrodes can present challenges in terms of electrochemical performance, which may limit their suitability in neural recording and stimulation. Conductive polymers such as PEDOT (poly(3,4-ethylenedioxythiophene)) are known to significantly improve electrode-electrolyte interface properties by lowering impedance and increasing charge transfer capability [3].

In this work, we improved the impedance characteristics of fully inkjet-printed gold MEAs on flexible substrates by functionalization with PEDOT:PSS. We demonstrate their suitability for recording and stimulation of single unit neural activity in the ex vivo retina.

Methods

Gold MEAs, with electrode diameters ranging from 40 to 80 μm , were fabricated on flexible Polyethylene Naphthalate (PEN) substrates via inkjet printing. Both the gold and an epoxy-based SU-8 dielectric ink were deposited using commercial Dimatix Samba Materials Cartridges with a 2.4 pL drop volume. Following fabrication, the electrodes were coated with PEDOT:PSS via

electropolymerization. The deposition was performed using a potentiostat in chronopotentiometry mode, applying constant current densities of 10-20 $\mu\text{A}/\text{mm}^2$ for 1 minute. The aqueous electropolymerization solution consisted of 0.01 M 3,4-ethylenedioxythiophene and 1 wt% poly(sodium-p-styrenesulfonate).

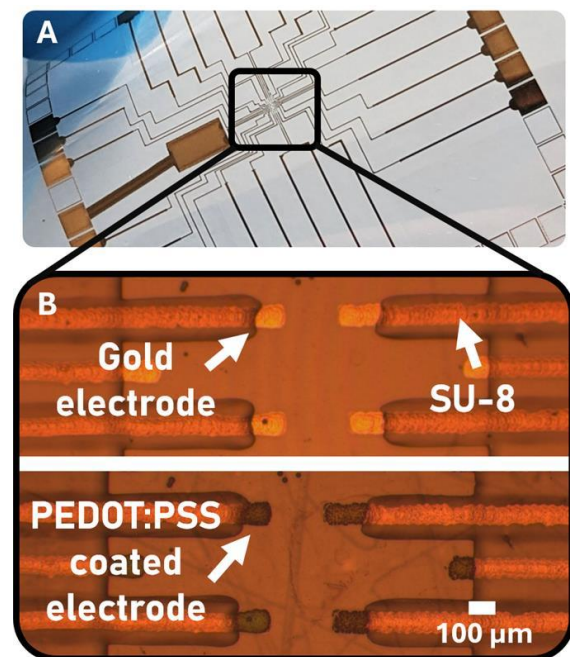


Fig. 1. Fabrication and morphology of the microelectrode array. (A) Photograph of an inkjet-printed flexible microelectrode array (MEA). (B) Magnified view of an individual electrode before (top) and after (bottom) PEDOT:PSS deposition.

Results

The deposition of PEDOT:PSS offers significant advantages over bare gold, primarily by reducing electrode impedance, which directly impacts recording performance. To quantify this, we performed electrochemical impedance spectroscopy (EIS) before and after deposition. The results show that the PEDOT:PSS coating substantially reduced impedance across the frequency spectrum (Figure 2). Specifically, at 1 kHz, the baseline impedance of the bare gold electrodes was 26 k Ω , which decreased approximately fivefold following PEDOT:PSS electro-deposition. Furthermore, the coated electrodes demonstrated greater consistency, as evidenced by the reduced impedance variation between individual recording sites (Figure 2, bottom).

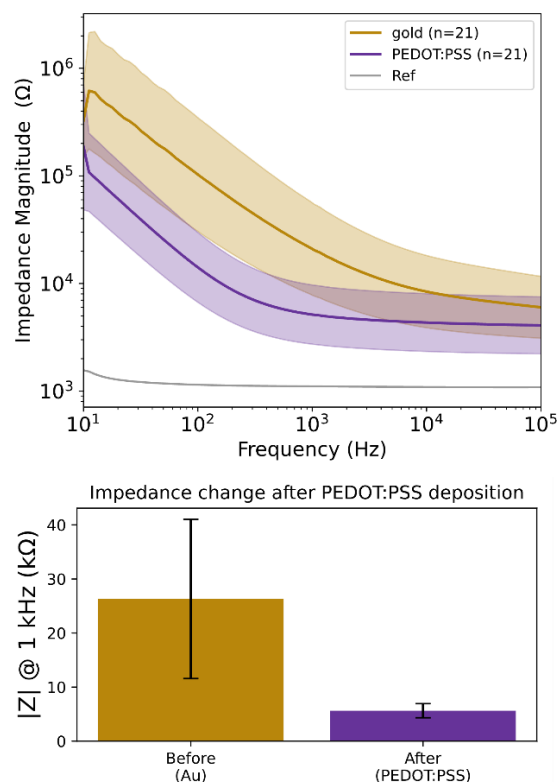


Fig. 2. Electrochemical impedance spectroscopy (EIS). (Top) Impedance magnitude of bare gold vs. PEDOT:PSS-coated electrodes. (Bottom) 1 kHz impedance comparison ($n = 21$), showing reduced magnitude and variability with PEDOT:PSS.

To confirm that these electrochemical improvements translate to functional performance, we conducted neuronal recordings and electrical stimulation experiments using ex vivo photo-degenerated retinæ. We recorded spontaneous activity from retinal ganglion cells (RGCs) (Fig. 3A), where PEDOT:PSS-coated MEAs yielded single-cell extracellular voltage waveforms with high signal-to-noise ratio. We then performed subretinal stimulation with PEDOT:PSS electrodes while simultaneously recording with patch-clamp electrodes, delivering voltage-

controlled square-wave pulses. The recorded RGCs showed reliable activation with sub-millisecond precision (Figure 3B), with activation thresholds consistently below 1 V (Figure 3C), superior to printed gold electrodes [4].

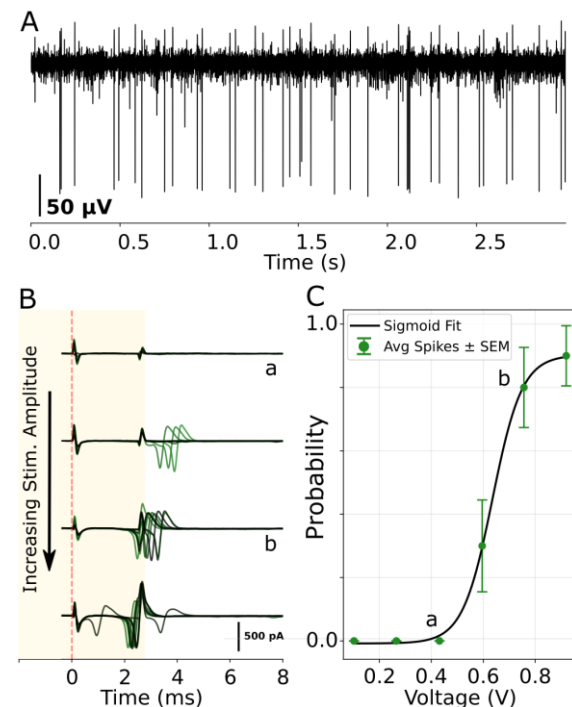


Fig. 3. Functional characterization of the PEDOT:PSS-coated electrodes. (A) Spontaneous retinal ganglion cell (RGC) activity. (B) RGC responses to stimulation, with increased spike count and reduced latency at higher strengths. (C) Sigmoidal stimulus-response curve with activation threshold < 1 V.

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