

Bespoke Laser Fabrication of High-Density PEDOT:PSS MEAs for Low-Impedance Cortical Neuronal Recordings

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Summary:

We explore a cleanroom free fabrication route to prototype high density PEDOT:PSS microelectrode arrays with 256 recording sites for neuronal interfacing. Electrochemical impedance spectroscopy indicates low-impedances around 30 k Ω at 1 kHz, consistent with PEDOT:PSS microelectrodes suitable for extracellular recordings. Preliminary tests with primary rat cortical neurons show detectable spontaneous activity on multiple channels but also highlight limitations in long term stability and cell culture performance that motivate further optimisation of the materials stack.

Keywords: laser microfabrication, PEDOT:PSS, microelectrode arrays, electrochemical impedance spectroscopy, neuronal recordings

Background, Motivation and Objective

Microelectrode arrays (MEAs) are key bioelectronic tools to monitor the electrical activity of electrogenic cells and neuronal networks with high spatial and temporal resolution [1]. However, conventional MEA fabrication relies on multi-step cleanroom processes and photolithography, which are costly, rigid in design, and poorly suited to rapid on-demand prototyping of customised layouts [2]. Each new electrode configuration typically requires a dedicated mask set and full process run, making it difficult for research laboratories to iterate quickly on electrode density, geometry, or contact routing. Conducting polymers such as PEDOT:PSS have enabled low-impedance electrodes for high-quality extracellular recordings, while also offering mechanical compliance closer to that of soft tissues. Yet PEDOT:PSS is most often integrated through standard microfabrication routes [3], limiting its accessibility to facilities with established microfabrication infrastructure. There is thus a strong demand for rapid and bespoke cleanroom-free fabrication strategies that combine high-density layouts, low-impedance PEDOT:PSS microelectrodes and robust neuronal recordings on a single platform, while remaining compatible with stable long-term operation in electrolyte and cell culture. The objective of this work is to explore a bespoke laser-based fabrication process for high-density PEDOT:PSS MEAs and to provide a proof-of-concept assessment of its electrochemical and electrophysiological performance with primary cortical neurons. We specifically aim to investigate whether a laser route can (i) pattern the full MEA circuitry

and define 30 μm -diameter PEDOT:PSS recording sites (Fig. 1A–C), and (ii) yield electrode impedances and neuronal recordings compatible with standard in vitro network studies (Fig. 1D–F), while identifying limitations that motivate further materials and process optimisation. By doing so, we highlight laser microfabrication as a promising route for cleanroom-free, on-demand prototyping of advanced bioelectronic interfaces.

Description of the New Method or System

We developed a dual-wavelength laser microfabrication platform that combines an infrared beam for rapid large-area material removal with a UV beam for high-resolution patterning and selective ablation, all operated without cleanroom facilities. Glass substrates are first coated with a Ti (PVD) followed by PEDOT:PSS (dropcasted) stack. The MEA circuitry, electrode sites and contact pads are then defined entirely by laser ablation steps (Fig. 1A,B). An insulating PDMS passivation layer is spin-coated on top and a final laser ablation step opens the recording sites and contact pads through the passivation layer (Fig. 1C).

This laser process is used here to prototype 256-electrode high-density MEAs with a radial routing layout, distributing 252 recording channels and four reference electrodes over a 49 × 49 mm footprint using LaserDesk software, as illustrated in Fig. 1A. The close-up view in Fig. 1C highlights the regular array of exposed PEDOT:PSS microelectrodes and their alignment with the underlying titanium tracks.

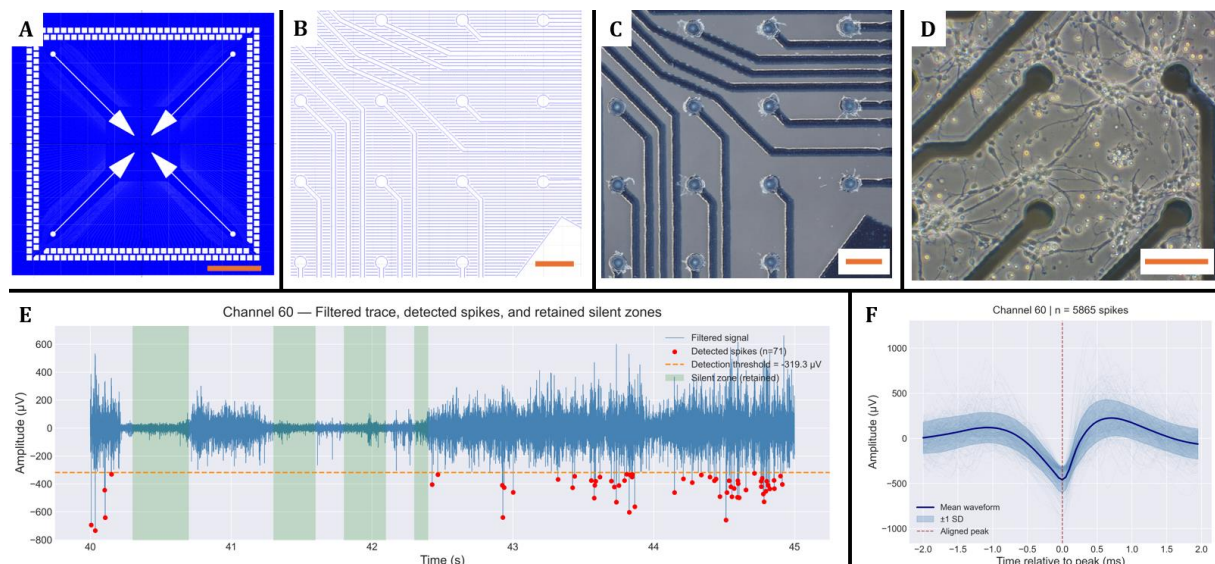


Fig. 1. (A) Entire MEA layout in LaserDesk software; the blue region indicates the ablated area (scale bar 10 mm). (B) Close-up of the central electrode array with 25 electrodes/mm² and approximately 30 μ m electrode diameter (scale bar 100 μ m). (C) UV-opened electrodes with PDMS passivation (scale bar 100 μ m). (D) Primary cortical neurons at DIV8 cultured on the MEA (scale bar 100 μ m). (E) Bandpass filtered (300–5000 Hz) extracellular recording on channel 60 over 5 s, with detected spikes highlighted in red and the threshold indicated by the dashed line. (F) Mean spike waveform on channel 60 ($n = 5865$ spikes); shading indicates ± 1 SD and the dashed line marks the negative peak at 0 ms.

Results

Electrochemical impedance spectroscopy (EIS) was used to characterise the electrical performance of the laser-fabricated PEDOT:PSS microelectrodes in phosphate-buffered saline (PBS). Mean electrode impedances at 1 kHz are on the order of 30 k Ω for 30 μ m-diameter sites, within the expected range for PEDOT:PSS microelectrodes of similar dimensions and indicative of suitability for extracellular measurements. These measurements provide a first quantitative link between the device architecture in Fig. 1A, B and its electrical behaviour, while leaving possibility for further optimisation of the materials stack and encapsulation.

Preliminary biological tests were performed with primary rat cortical neurons cultured directly on the laser-fabricated MEAs (Fig. 1D). By eight days in vitro, spontaneous bursting activity was observed on multiple channels, and bandpass-filtered traces showed clearly identifiable spikes with representative average spike waveforms on selected electrode (Fig. 1E,F). For more mature cultures beyond two weeks in vitro, however, limitations became apparent, with a degradation of network stability that we attribute to long-term PEDOT:PSS behaviour in immersion and to the intrinsic hydrophobicity of the

PDMS passivation layer, which is less critical for indirect microfluidic contact but becomes determinant for in vitro neuronal cultures. To address these issues, we have begun exploring surface functionalisation strategies for PDMS such as polydopamine coatings, initial results are mixed but encouraging and motivate ongoing efforts to improve the electrode stack and passivation layer in future work.

References

- [1] A. Angelovski, M. Bébarová, The microelectrode array technique - a crucial tool for studying excitable tissue disorders and drug testing: an update on recent advances, *Progress in Biophysics and Molecular Biology* (2025); doi: 10.1016/j.pbio-molbio.2025.07.005
- [2] A. Tanwar, H. Gandhi, D. Kushwaha, J. Bhattacharya, A review on microelectrode array fabrication techniques and their applications, *Materials Today Chemistry* (2022); doi: 10.1016/j.mtchem.2022.101153
- [3] J. Pas, C. Pitsalidis, D.A. Koutsouras, P.P. Quilichini, F. Santoro, B. Cui, L. Gallais, R.P. O'Connor, G.G. Malliaras, R.M. Owens, Neurospheres on patterned PEDOT:PSS microelectrode arrays enhance electrophysiology recordings, *Advanced Biosystems* **2**, 1700164 (2018); doi: 10.1002/adbi.2017001