

Supporting Information

Fully Printed μ -Needle Electrode Array from Conductive Polymer Ink for Bioelectronic Applications

*Sabine Zips,[†] Leroy Grob,[†] Philipp Rinklin,[†] Korkut Terkan,[†] Nouran Yehia Adly,[†] Lennart Jakob
Konstantin Weiß,[†] Dirk Mayer,[‡] and Bernhard Wolfrum^{*,†,‡}*

[†] Neuroelectronics - Munich School of Bioengineering, Department of Electrical and Computer Engineering, Technical University of Munich, Boltzmannstr. 11, 85748 Garching, Germany

[‡] Institute of Complex Systems, Bioelectronics (ICS-8), Forschungszentrum Jülich, 52425 Jülich, Germany

Corresponding Author

*E-mail: bernhard.wolfrum@tum.de

For measuring the conductivity of the PEDOT:PSS-MWCNT composite ink, electrodes with contact pads were aerosol-jet printed onto a Q83 substrate using an aerosol-jet printing system from Optomec (Albuquerque, USA; see Figure S1) integrated in an inkjet-printing system from Ceradrop (F-series, Limoges, France). The system generated the aerosol pneumatically using a pre-humidified nitrogen gas stream. The electrodes were fabricated with a writing speed of 1 mm s⁻¹, trace spacing of 25 µm, a push flow of 50 sccm (standard cubic centimeter per minute), and a focusing ration of 3 using a 250 µm nozzle. The temperature of the substrate holder was held at 58 °C. After printing, the solvents in the material were evaporated at 150 °C overnight. A potentiostat (VSP-300, BioLogic Science Instruments, Seyssinet-Pariset, France) was then used to apply a voltage ramp (0 V to 0.6 V with 5 mV s⁻¹) to the electrodes in a 4-point measurement setup and the current was recorded to assess the resistance R . The length l was measured optically (DM 2700 M, Leica, Wetzlar, Germany; Discovery.V20 SteREO, Zeiss, Oberkochen, Germany), the cross-sectional area A was measured with a laser scanning microscope (VK-X250, Keyence, Osaka, Japan) and evaluated with MultiFileAnalyzer (Keyence, Osaka, Japan). The conductivity σ was then calculated using the relation

$$\sigma = \frac{l}{A \cdot R}. \quad (\text{S1})$$

The measured average conductivity was 323±75 S m⁻¹(n = 5).

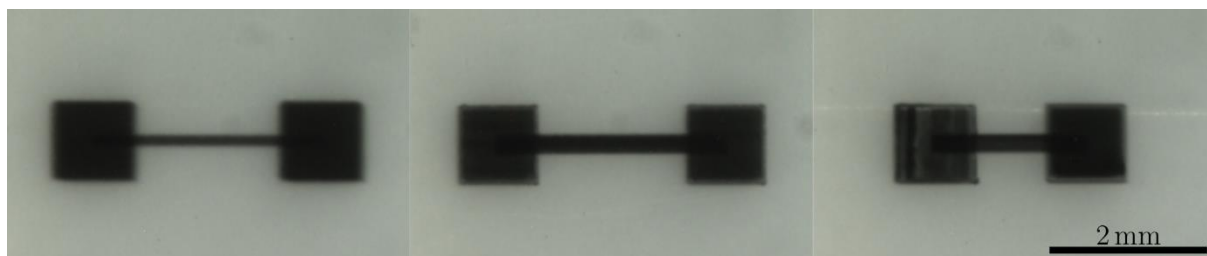


Figure S1. Aerosol-jet printed test structures for assessing the conductivity of the PEDOT:PSS-MWCNT composite ink.

A SEM image was taken from a passivated μ -needle microelectrode array (MEA) to show the three-dimensional structure of the electrode tips. The μ -needle MEA was first sputtered for 40 s with gold at 0.05 mbar argon gas pressure (MED 020, BAL-TEC, Balzers, Liechtenstein) and then characterized with SEM (JSM-6060LV, Jeol, Tokyo, Japan).

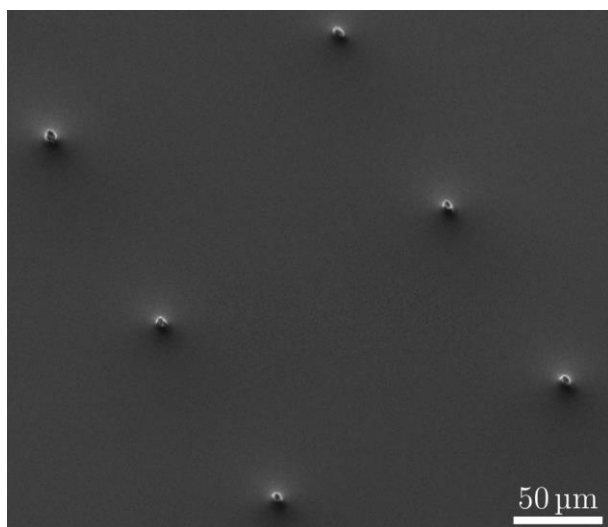


Figure S2. SEM image of a passivated μ -needle MEA.

The μ -needle MEAs were used to record signals from cardiomyocyte-like HL-1 cells. Time traces from three neighboring electrodes spaced $250\ \mu\text{m}$ apart are shown in Figure S3. The observed phase delay between the traces indicates a local recording of the cell signals at the individual electrodes.

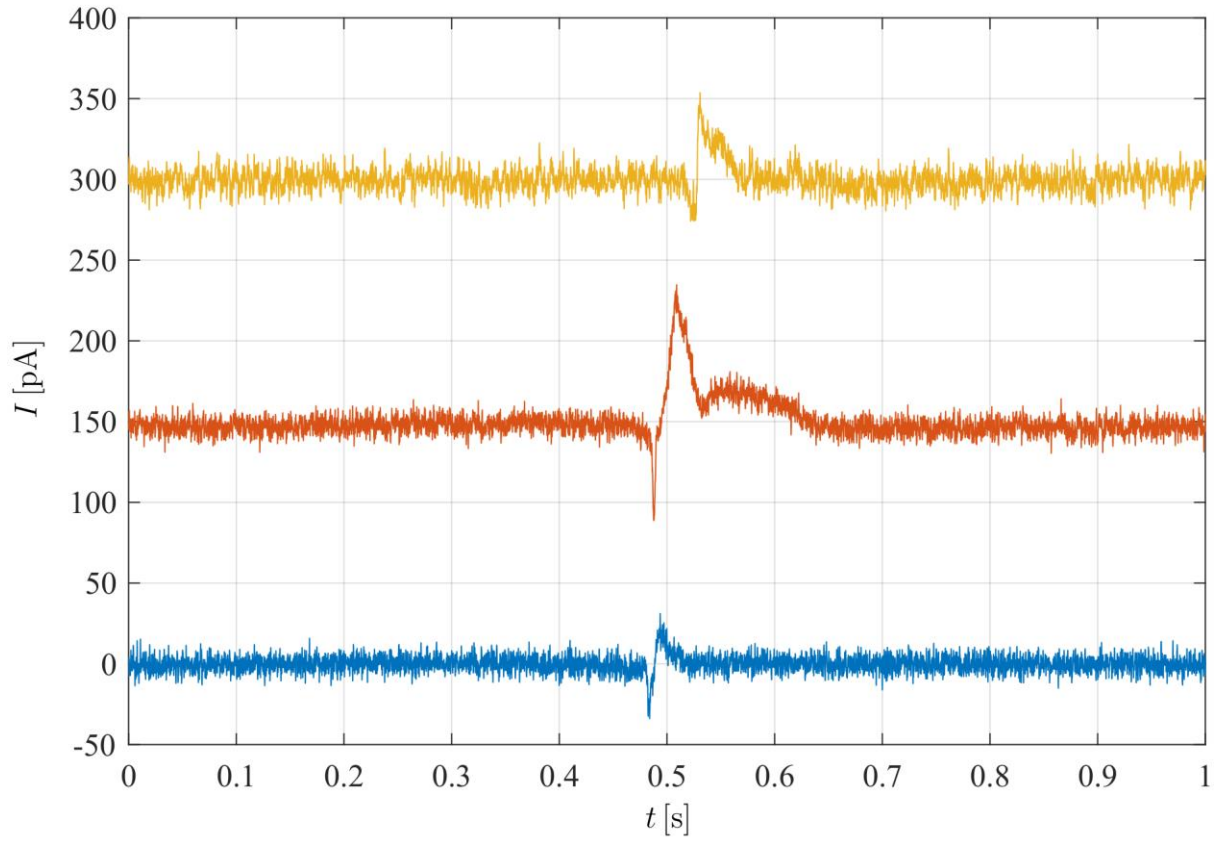


Figure S3. Recorded cell signals from three neighboring electrodes spaced $250\ \mu\text{m}$ apart. For presentation reasons, an arbitrary offset was added to the traces.