Conductive polymer coated 3D-nanostructured electrodes to enhance the stimulation and recording performances of neuronal activity

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Understanding the functioning of the brain and the mechanisms involved in neuronal networks is one of the biggest scientific challenges yet to overcome. Within this field, remarkable advances were made, thanks to the development of a new generation of *in-vitro* micro-electrode arrays, in which the sensing elements are miniaturized and 3D-structured. Such devices, called Nanostructured Electrode Arrays (NEAs), offer real benefits, as they possess a high spatial resolution and an important surface-to-volume ratio leading to a higher affinity with cells. This technology enables to stimulate and record the neuronal activity at the single cell level. However, the electrodes size reduction diminishes their effective area, which increases their impedance, leading to a loss in signal resolution. It also negatively affects the charge injection properties, a key parameter for stimulation processes.

Here, we demonstrate for the first time the ability to selectively deposit a nanolayer of poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS), a conductive polymer, on metal 3D nanoprobes through electrochemical deposition. These polymer-coated nanoelectrodes have been fully characterized, both electrochemically and morphologically, in order to establish a direct relationship between the synthesis conditions, the final morphology and the conductive features

First, nanowires-based NEAs were fabricated at wafer scale using a cost effective top-down approach, combining conventional lithography tools, plasma etching, sacrificial oxidation, metal deposition and chemical etching steps. All sensing electrodes are formed by 7 vertical platinum-silicide nanowires connected together. Each nanowire is 4µm high and has a diameter of 400nm. All the conductive access lines are insulated from the liquid media and only the nanowires are in contact with the solution. The nanoprobes were coated with PEDOT:PSS via electrochemical deposition. Different polymerization routes have been investigated, from galvanostatic to potentiodynamic, showing a large range of layer morphology. After optimizing the coating conditions, conformal and homogenous PEDOT:PSS layers, down to 75nm thin, were successfully deposited. Indeed, Scanning Electron Microscopy demonstrated that the nanowires were wrapped tightly by the polymer coating, keeping the high aspect ratio of the nanoprobes.

The recording properties of the probes were evaluated, by performing Electrochemical Impedance Spectroscopy measurements in a saline media. The impedance values (at 1kHz) of the coated nanoprobes decreased by 2 orders of magnitude compared to bare nano-electrodes. Cyclic voltammetry and voltage transients experiments have also been conducted, to estimate the charge injection capabilities of the polymer-coated NEAs. Results indicated an enhancement in delivering a higher charge at the 3D electrode-electrolyte interface. In fact, the charge storage capacity increased up to 10 times and the charge injection limit doubled compared to bare electrodes.

Thanks to their improved performances, PEDOT-coated 3D-nanostructured devices open new perspectives to stimulate and record the *in-vitro* neuronal activity with higher spatial and signal resolution.