CHARACTERIZATION OF NANOSTRUCTURED ELECTRODES FOR NEURAL IMPLANT

O. Bibari, F. Sauter-Starace, P. Mailley, J. Dijon, E. Rouvière,
G. Charvet, S. Boisseau, C. Arnoult, P. Caillat and A.L. Benabid
CEA Grenoble, 17 Rue des Martyrs 38054 Grenoble,France
olivier.bibari@cea.fr

In recent years, researchers have been working on a way to interface living cells, such as neurons, to an electronic chain of acquisition to create a brain computer interface (BCI) system. Significant success has been reported using multi-electrode arrays implanted in motor cortex of paraplegic patient [1] to control a computer mouse or in a monkey's cortex [2] to move a mechanical arm. But all these devises have a limited efficiency for chronicle application due to the development of a fibrous shell around the implant, which degraded its electrical performances.
Carbon nanotubes structured surface seems to be a good candidate to make future biocompatible and biostable electrodes [3]. Indeed, numerous nanomaterials exhibit great affinity with biological samples [4], which could be link to the mimetism between the topology of nanomaterials and biological tissues. Furthermore, carbon nanotubes electrodes (CNT-Es) hold remarkable electrical properties coupled with a great surface area, which tends to a reduction of the electrode output impedance and an increase of its capacitance. Consequently, CNT-Es improve the stimulation capability and increases signal/noise ratio by limiting the thermal noise proportional to the interfacial impedance.
In this paper we expose our results on the integration of such system based on original nanotubes functionalization, electrochemical characterization related to electrical model, in-vitro biocompatibility testing and stimulation-sensing performance evaluation using a specific electronic system of measurement developed through the NEUROCOM project [5].

- Electrode fabrication

To produce CNT-Es, we first fabricate silicon based TiN microelectrodes of different diameter (50µm, 100µm, 150µm) on which we deposited by a lift-off process 5 nm of NiFe (80:20) catalyst layer. Finally, carbon nanotubes were synthesized on chip by CVD process at 570°C under acetylene atmosphere [6].

- Surface treatment and characterization

Carbon nanotubes surface treatment is a fundamental issue to overcome their hydrophobic property. Indeed, neurons growth requires hydrophilic surfaces and electrolyte has to go through pores to take advantage of the maximum surface area. Different treatments have been characterized such as, oxygen plasma, liquid phase oxidation in acidic or basic solution using XPS, surface energy measurement and impedance spectroscopy. Electrodes treated by AC-bias between -0.2V and +1.2 V in Brown solution (NaOH 1M in DI water: Ethanol; 1:1) show best results. We were able to measure by cyclic voltamperometry a capacitance of 1.3 mF/cm^2, which is 100 times the one of untreated electrodes. We also used impedance spectroscopy technique to characterized interfacial impedance between CNT-Es and a phosphate buffer solution (PBS) and develop an electrical model of the interface based on ladder representation and correlated with electrode porosity checked by BET.

- In vitro biocompatibility

We assessed the biocompatible properties of CNT-Es on NG108 neuron-like cells. For this study, we also investigated the influence of adhesion promoting layers such as poly-L-lysine coating. To visualize the NG108 cells we revealed by fluorescence with Tuj1 fluorescent dye and observed that cell tend to grow preferentially on CNT-Es. This result has been constantly observed independently to the use of a cell poly-L-Lysine coating.

- Electrical characterization and spike measurement

We first evaluated electrical noise of CNT-Es immerged in PBS and connected to NEUROCOM bench. 50µm diameter CNT-Es treated with brown solution were tested and show noise amplitude of 13µV pic to pic, which is remarkable considering that the electrical noise of NEUROCOM system by itself is 10µV.

Conclusion and Outlook

These first results are very promising. Indeed our carbon nanotubes have been shown to promote cell growth. Moreover, they improve our chip design by increasing signal to noise ratio which makes them compatible with applications of spike recording. To complete this study and confirm our results, CNT-Es are now being tested on their ability to record and stimulate the electrophysiological activity of cortical neural cells from embryonic mice. and these outcomes will be presented in future communication.

References:

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Figures :

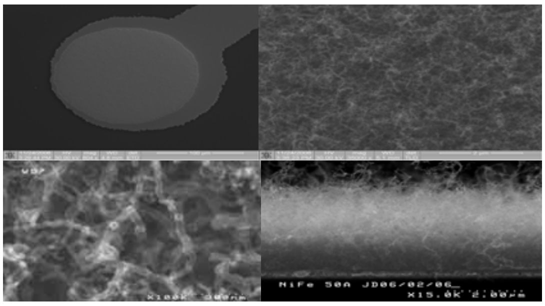

Figure 1: SEM of carbon nanotubes electrode on TiN, 150µm

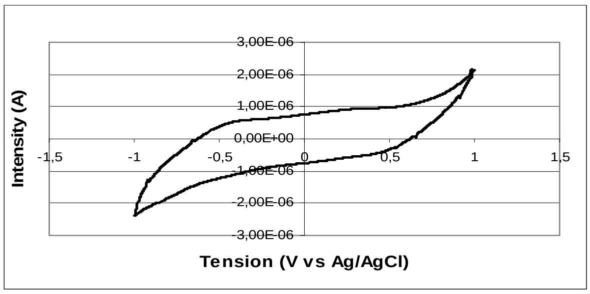

Figure 2: Voltamogram in PBS of TiN electrode, 150µm, v=100 mV/s

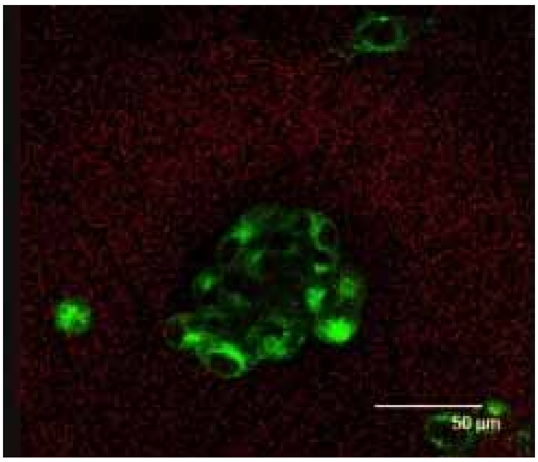

Figure 3: NG108 culture on CNT-E, 50µm, treated with Brown solution. UV picture of NG108 cells under fluorescence excitation.