



**HAL**  
open science

## Carbon Nanofiber/PEDOT Based Macro-porous Composite For High Performance Multifunctional Neural Microelectrode

Venkata Suresh Vajrala, Valentin Saunier, Lionel Nowak, Emmanuel Flahaut, Christian Bergaud, Ali Maziz

► **To cite this version:**

Venkata Suresh Vajrala, Valentin Saunier, Lionel Nowak, Emmanuel Flahaut, Christian Bergaud, et al.. Carbon Nanofiber/PEDOT Based Macro-porous Composite For High Performance Multifunctional Neural Microelectrode. 240th ElectroChemical Society Meeting, Oct 2021, Orlando, United States. hal-03445109

**HAL Id: hal-03445109**

**<https://hal.science/hal-03445109v1>**

Submitted on 23 Nov 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Carbon Nanofiber/PEDOT Based Macro-porous Composite For High Performance Multifunctional Neural Microelectrode

Venkata Suresh Vajrala<sup>a</sup>, Valentin Saunier<sup>a</sup>, Lionel Nowak<sup>b</sup>, Emmanuel Flahaut<sup>c</sup>,  
Christian Bergaud<sup>a</sup> and Ali Maziz<sup>a</sup>

<sup>a</sup> Laboratory for Analysis and Architecture of Systems, CNRS, Toulouse, France

<sup>b</sup> Centre de Recherche Cerveau et Cognition (CerCo), CNRS, Toulouse, France

<sup>c</sup> CIRIMAT, Université de Toulouse, route de Narbonne, F-31062 Toulouse, France

Brain study methods mainly rely on neurochemical detection and electrophysiology, respectively to study the molecular dynamics [1] and electrical activity [2] in the brain cellular environment. Since the brain functioning relies on careful orchestration of both neurotransmitter and neuroelectric activities, coupled monitoring of them holds great promise in elucidating the brain functioning mechanisms and its related diseases e.g. Parkinson's, epilepsy, etc [3]. Most of the conventional implantable neural interfacing technologies are comprised of noble metals on silicon/ polymer substrates. They suffer from inferior electrical properties, mechanical tissue-electrode mismatch, incompatible surface area, and low signal-to-noise ratio [4]. To address the need, researchers around the world are developing innovative soft materials with multimodal functionalities, especially the organic flexible materials such as conductive polymers and carbon allotropes, to fuel the next-generation multimodal neural electrode devices [5].

Here in this work, we present a new macro-porous, conductive, and stable nanocomposite, made up of carbon nanofibers (CNFs) and PEDOT polymer, coated on a flexible neural microelectrode array (Fig. 1A-B). A fully controlled one-shot electrodeposition strategy was developed using chronopotentiometry technique, to coat flexible Au-microelectrode surfaces with macro-porous CNF/PEDOT nanocomposite. The oxidized CNFs were used as a dopant and infused within the conductive PEDOT, electrochemically, in such a way that their excellent electronic, mechanical, chemical properties, and resulting combined performances can be exploited to yield better quality neural recordings, electrical stimulation and neurotransmitter detection. At first, CNFs were oxidized to be dispersible in water (unlike raw CNFs) by vortex and sonication. Later, CNF/PEDOT composite was deposited on Au-electrodes galvanostatically, resulted in a 3D porous and fibrous network (Fig. 1B-D). Then, CNF/PEDOT deposits were characterized through electrochemical impedance spectroscopy (EIS) and pulse current injection. The composite microelectrodes showed low impedance,  $16 \pm 2 \text{ k}\Omega$  for a typical electrode area of  $1250 \mu\text{m}^2$ , at 1kHz (value corresponding to the neuron firing frequency) (Fig. 1E). Voltage transient responses were measured, at continuous 1ms-biphasic current pulses (cathodic first) in biologically relevant aCSF media, resulted in a charge-injection limit value of  $7.6 \pm 1.3 \text{ mC/cm}^2$  (Fig. F). Among all reported organic nanostructured composite materials that were deposited on flexible metallic substrates, CNF/PEDOT displayed superior electrical properties and charge injection capabilities [5]. Next, the capability of CNF/PEDOT composite electrode for *in-vitro* Dopamine (DA) sensing was evaluated by chronoamperometry, at 130mV vs SCE (oxidation potential of DA). The current responses submitted to DA injections resulted in linear regression (Fig. 1G,  $R^2 > 0.99$ ), with a high sensitivity of  $13.4 \text{ pA/nM}\cdot\mu\text{m}^2$ , compared to similar electrochemical sensors [6]. Overall, these electrodes displayed excellent electrical properties: low impedance ( $16 \pm 2 \text{ M}\Omega\cdot\mu\text{m}^2$  at 1 kHz) and high charge

injection capabilities ( $7.5 \pm 1.3 \text{ mC/cm}^2$ ) making them promising candidates for bidirectional electrophysiology, while being capable to detect neurotransmitters like dopamine. Finally, integrated upon flexible neural probes, these composite microelectrodes were tested *in-vivo* on mouse brain slices as recording and stimulating electrodes (Fig. 1H). They displayed excellent performances, being capable to record spontaneous activities of neurons (sharp wave-ripples and single unit action potentials) and allowed to stimulate electrically the brain slice tissues, to obtain safe and stable evoked potentials. The obtained results show a great prospect for CNF/PEDOT composites for developing next-generation microelectrodes for applications in neural therapies.

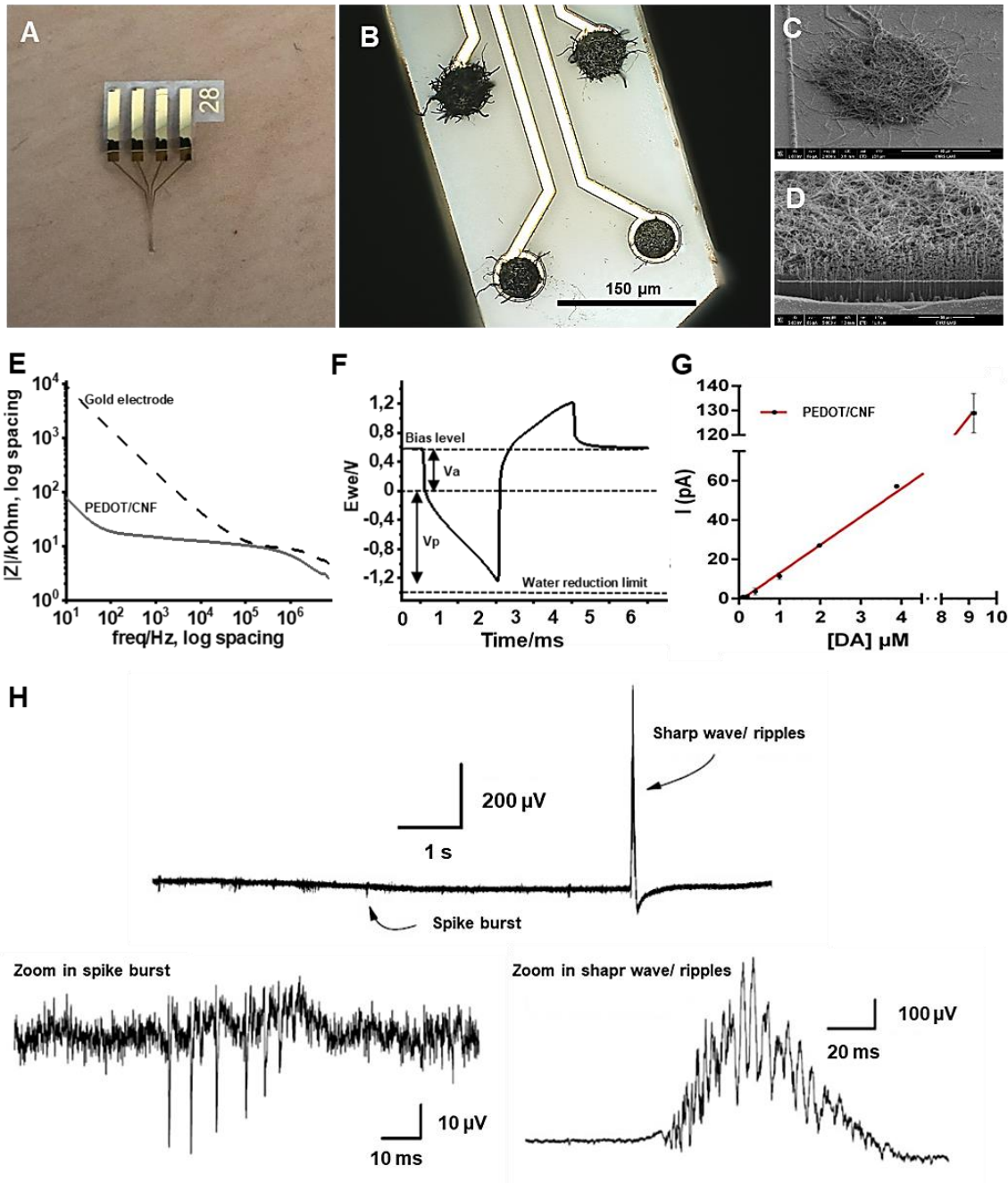


Figure 1. (A) Optical micrograph of flexible neural probe. (B) CNF/PEDOT deposition on 4 Au-microelectrodes of the implant. SEM images, (C) top view and (D) cross-sectional view of the composite electrode. (E) EIS measurement on modified

microelectrodes from 10 Hz to 7 MHz in aCSF at 0V Vs Ag/AgCl. (F) Voltage transient of a CNF/PEDOT microelectrode resulting from the injection of a biphasic current pulse (90  $\mu$ A with 1 ms pulse width). (G) Linear regression curve of CNF/PEDOT electrode current response at 130mV vs SCE to dopamine injections. (H) Electrophysiological recordings in the hippocampal region (CA1 and CA3) of a mouse brain slice, using flexible microelectrode array modified with CNF/PEDOT composite.

### Acknowledgments

Agence Nationale de la Recherche (ANR-15-CE19-0006 and ANR-19-CE19-0002-01) and French RENATECH network.

### References

1. Lama R.D., Karl Charlson, Arun Anantharam, Parastoo Hashemi, *Analytical Chemistry*, **84**(19): p 8096-101 (2012).
2. Normann R.A. and E. Fernandez, *Journal of Neural Engineering*, **13**(6): p 061003 (2016).
3. Ledo A., Cátia F. Lourenço, João Laranjinha, Greg A. Gerhard, and Rui M. Barbosa, *Analytical Chemistry*, **89**(22): p 12383-12390 (2017).
4. Enming Song, Jinghua Li, Sang Min Won, Wubin Bai, and John A. Rogers, *Nature Materials*, **16**, 590-603 (2020).
5. Zaid Aqrawea, Johanna Montgomeryb, Jadranka Travas-Sejdicc,d, Darren Svirskis, *Sensors and Actuators B*, **257**,753–765 (2018)
6. Jong-Min Moon, Neeta Thapliyal, Khalil Khadim Hussain, Rajendra N.Goyal, Yoon-Bo Shim, *Biosensors and Bioelectronics*, **102**, 540-552 (2018).