Carbon 152 (2019) 424–433

Contents lists available at ScienceDirect

Carbon

journal homepage: www.elsevier.com/locate/carbon

Micro graphite-patterned diamond sensors: Towards the simultaneous *in vitro* detection of molecular release and action potentials generation from excitable cells

Giulia Tomagra [a, 1], Pietro Aprà [b, c, 1], Alfio Battiato [c], Cecilia Collà Ruvolo [b], Alberto Pasquarelli [d], Andrea Marcantoni [a], Emilio Carbone [a], Valentina Carabelli [a], Paolo Olivero [b, c], Federico Picollo [b, c, *]

[a] Department of Drug and Science Technology and "NIS" Inter-departmental Centre, University of Torino, Corso Raffaello 30, 10125, Torino, Italy
[b] Department of Physics and "NIS" Inter-departmental Centre, University of Torino, Via Pietro Giuria 1, 10125, Torino, Italy
[c] Istituto Nazionale di Fisica Nucleare, Sezione di Torino, Via Pietro Giuria 1, 10125, Torino, Italy
[d] Institute of Electron Devices and Circuits, University of Ulm, 89069, Ulm, Germany

ARTICLE INFO

Article history:
Received 28 February 2019
Received in revised form
21 May 2019
Accepted 7 June 2019
Available online 14 June 2019

ABSTRACT

In neuroscience, a deep understanding of communication mechanisms at the cellular level is of paramount importance, since their dysfunction determines the onset of several diseases. The development of innovative sensors devoted to the investigation of both chemical and electrical signals it is therefore essential to improve the outcome of standard trials and to define novel methodologies. Here we report on the fabrication and the characterization of multi-functional micrographite patterned diamond multi-electrode arrays. These sensors are obtained by means of a three-dimensional patterning process of single-crystal diamond substrates by means of MeV ion-beam-based lithography, which allows the direct fabrication of graphitic micro-channels embedded within the bulk of the electrically insulating diamond matrix.

Proof-of-concept *in vitro* experiments on cultured neurons and cardiac tissue were performed, in which quantal secretory events were amperometrically recorded from dopaminergic neurons, while potentiometric measurements of action potential generation were collected from both hippocampal neuronal networks and intact sinoatrial nodes. These achievements represent the demonstration of the applicability of an all-carbon hybrid graphite/diamond device for the multi parametric detection of chemical and electrical signals, thus representing a fundamental step for the simultaneous *in vitro* measurement of the two types of signals from the same biological sample.

1. Introduction

The main mechanisms regulating the intra- and extra-cellular communication in neurons and neuroendocrine cells are based on two distinct phenomena: the neurotransmitter release and the action potential generation.

The former consists of the quantal release of bioactive molecules from secretory vesicles into the extracellular environment. This process is based on the fusion of presynaptic vesicles with the plasma membrane and, in the context of neurotransmission, the release occurs into the synaptic cleft by means of a calcium-triggered mechanism [1–3]. The latter depends by somatic action potential (AP) generation and its propagation through axon fibers to the presynaptic terminal where the variation of the membrane potential induces the opening of voltage-gated calcium channels and the onset of Ca^{2+}-dependent synaptic transmission. The AP generation and propagation is specific of all excitable cells and modulate other physiological function such as hormonal release and muscle contraction [4–6]. Dysfunctions involving these mechanisms determine the onset of several neuropsychiatric and neurological disorders such as Alzheimer, Parkinson and Huntington diseases.

* Corresponding author. Department of Physics and "NIS" inter-departmental centre, University of Torino, Via Pietro Giuria 1, 10125, Torino, Italy.
E-mail address: federico.picollo@unito.it (F. Picollo).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.carbon.2019.06.035
0008-6223/