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Characterization of CVD Heavily B-Doped Diamond Thin Films for Multi Electrode Array Biosensors

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Nanocrystalline diamond is an excellent material for the fabrication of Multi Electrode Arrays used to monitor the activity of biological cells and tissues. Yet, the overall performances in terms of background noise, electrochemical activity and transparency for fluorescence detection, are difficult to optimize. The aim of this study is to obtain an orientative guide on how to reach a good compromise between the competing properties. For this purpose, several samples of diamond films were produced under a variety of synthesis conditions, to be employed in the fabrication of amperometric Multi Electrode Arrays. After the fabrication, the samples were characterized from a structural, electrical, electrochemical and optical point of view in order to find possible correlations with the parameters adopted in their production.

1. Introduction

Boron-doped diamond (BDD) Multi Electrode Arrays (MEAs) are planar sensors that allow the non-invasive measurement of the secretory and bioelectrical activity of in vitro cell cultures, with high temporal and spatial resolution.[1] It is possible to investigate the cellular activity by measuring the action potential thanks to the capacitive coupling between the cellular membrane and the sensing electrode (potentiometry),[2–5] or the redox current due to the oxidation of neurotransmitters released during exocytotic events (amperometry).[6] Furthermore, MEAs fabricated on transparent substrates allow simultaneous fluorescence and bioelectrical investigations, for example monitoring by fluorescence microscopy the intracellular calcium oscillations, which cannot be detected by electrical methods.[7,8]

The dominant noise source in measurements with microelectrodes is the thermal noise originating at the electrode electrolyte interface.[12] However, the optimization of the signal-to-noise ratio for potentiometry and amperometry goes in two different directions. In the first case, an electrode is connected to a high-impedance voltage amplifier, which measures an open circuit potential and therefore, the relevant noise parameter is the total voltage power spectral density. Under optimal conditions, this is dominated by (and proportional to) the electrochemical impedance of the electrode. Consequently, low-noise potentiometric electrodes, independently from the chosen technology, are designed for large capacity and low resistance. In most cases, this goal is achieved by providing a 3D-structure of the electrode active surface, for example by roughening, using fractal or porous materials.[9,10] Other authors used scaffolds of nanowires, overgrown with a biocompatible material to enhance cell viability.[3,11] Unfortunately, all these strategies spoil the electrodes transparency so that simultaneous fluorescence measurements like confocal imaging or TIRF (total internal reflection fluorescence) are no longer possible due to the need of an inverted microscope.

In the case of amperometry, the electrode is short-circuited to the virtual ground of a transimpedance amplifier and the current is measured. In this case, the relevant noise parameter is the total current power spectral density, which in turn is proportional to the real part of the admittance of the electrode.[12] Since the electrode admittance is dominated by its constant phase element (CPE), the current standard deviation results in good approximation proportional to the square root of the area of the working electrode.[12] In other words, the noise in an amperometric measurement is proportional to the electrode capacity and can be improved by reducing the electrode area, but this improvement is possible until the amplifier noise becomes dominating.[13] This result is convenient for fluorescent measurements because a smooth planar surface combines lower capacity and lower light scattering and absorption, that is lower noise and better transmissivity.

If we now consider the outstanding chemical resistance and biocompatibility of diamond, which can outcompete most other

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