Graphtivity: Graphene-based optoelectrochemical sensor for the simultaneous monitoring of the electrical and chemical activity of single cells

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Abstract

Improved understanding of molecular principles of neuronal communication allows new insights into neurodegenerative diseases and possibly to new therapeutic targets. However, there is a lack of tools able to monitor simultaneously electrical and chemicals signals of single cells. Therefore, we propose the development of a novel graphene-enhanced sensor allowing simultaneous monitoring of these two signals with single cell resolution both in cell cultures and organotypic tissue slices. The sensor will be based on surface plasmon resonance imaging (SPRi) and its ability to provide excellent spatial resolution also to electrochemical measurements. More importantly, by integrating graphene both the sensitivity of SPR detection and the current densities of the electrochemical measurement will be enhanced with concomitantly improved biocompatibility. In addition to generating new knowledge about the interplay of electrical and chemical signals of living cells, the development of the anticipated sensors will be an important step towards novel prostheses based on the bidirectional communication with living cells.

The core of the sensor will be a "cell chip" carrying disk microelectrodes, to which cells adhere, surrounded by cell-free ring microelectrodes. Once cells have adhered to the disk microelectrodes, the ring microelectrodes (bare or modified with enzymes) are polarized to a potential that allows oxidation or reduction of signalling molecules secreted by the cells. Subsequently, high-resolution SPR images of the "cell chip" are recorded at high frame rates (~10000 fps) while a physical or chemical stimulus is applied to the cells. SPR images of cell-covered disk microelectrodes are modulated by changes in the extracellular field potential of the cells (which enables us to monitor e.g. the propagation of action potentials). SPR images of the ring microelectrodes will be altered by changes in local current densities invoked by variations in the local concentrations of signaling molecules and will be used to observe chemical signals from the cells.

Neuronal cells change their extracellular field potential within the low millivolts range and release only tiny amounts of signaling molecules. Therefore, the sensitivity of SPRi has to be improved in order to be able to record electrical and chemical signals from cells simultaneously. Graphene has already been proved to enhance the sensitivity of both SPR and electrochemical detection. Hence, graphene and its derivatives will be applied for signal amplification.

Our optoelectrochemical approach to measure extracellular field potentials with sub-micrometer resolution will excel voltage sensitive dyes and electrically interrogated microelectrode arrays. In addition, it will provide unprecedented spatial resolution and interference elimination to the electrochemical monitoring of chemical signals from cells.

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