Conjugated Polymers for Neural Interfaces

Prospects, possibilities and future challenges

MARIA ASPLUND

Academic Dissertation which, with due permission of the KTH Royal Institute of Technology, is submitted for public defence for the degree of Doctor in Technology on Friday the 30th January 2009, at 1:00 p.m. in Sal 3-221, Alfred Nobels Allé 10, Huddinge.
Abstract

Within the field of neuroprosthetics the possibility to use implanted electrodes for communication with the nervous system is explored. Much effort is put into the material aspects of the electrode implant to increase charge injection capacity, suppress foreign body response and build micro sized electrode arrays allowing close contact with neurons. Conducting polymers, in particular poly(3,4-ethylene dioxythiophene) (PEDOT), have been suggested as materials highly interesting for such neural communication electrodes. The possibility to tailor the material both mechanically and biochemically to suit specific applications, is a substantial benefit with polymers when compared to metals. PEDOT also have hybrid charge transfer properties, including both electronic and ionic conduction, which allow for highly efficient charge injection.

Part of this thesis describes a method of tailoring PEDOT through exchanging the counter ion used in electropolymerisation process. Commonly used surfactants can thereby be excluded and instead, different biomolecules can be incorporated into the polymer. The electrochemical characteristics of the polymer film depend on the ion. PEDOT electropolymerised with heparin was here determined to have the most advantageous properties. In vitro methods were applied to confirm non-cytotoxicity of the formed PEDOT:biomolecular composites. In addition, biocompatibility was affirmed for PEDOT:heparin by evaluation of inflammatory response and neuron density when implanted in rodent cortex.

One advantage with PEDOT often stated, is its high stability compared to other conducting polymers. A battery of tests simulating the biological environment was therefore applied to investigate this stability, and especially the influence of the incorporated heparin. These tests showed that there was a decline in the electroactivity of PEDOT over time. This also applied in phosphate buffered saline at body temperature and in the absence of other stressors. The time course of degradation also differed depending on whether the counter ion was the surfactant polystyrene sulphonate or heparin, with a slightly better stability for the former.

One possibility with PEDOT, often overlooked for biological applications, is the use of its semi conducting properties in order to include logic functions in the implant. This thesis presents the concept of using PEDOT electrochemical transistors to construct textile electrode arrays with in-built multiplexing. Using the electrolyte mediated interaction between adjacent PEDOT coated fibres to switch the polymer coat between conducting and non conducting states, then transistor function can be included in the conducting textile. Analogue circuit simulations based on experimentally found transistor
characteristics proved the feasibility of these textile arrays. Developments of better polymer coatings, electrolytes and encapsulation techniques for this technology, were also identified to be essential steps in order to make these devices truly useful.

In summary, this work shows the potential of PEDOT to improve neural interfaces in several ways. Some weaknesses of the polymer and the polymer electronics are presented and this, together with the epidemiological data, should point in the direction for future studies within this field.

**Key Words**

neuroprosthetics, conjugated polymers, conducting polymers, PEDOT, functional electrical stimulation, neural electrodes