Final report for BIOORGANICS

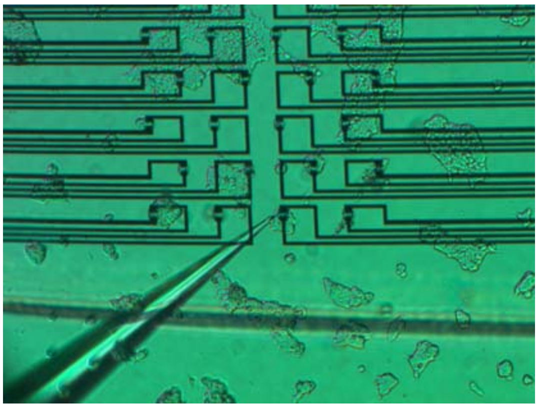
The coupling of electronics with living tissue holds the key to a variety of important life-enhancing technologies. One example is bioelectronic implants that record neural signals and/or electrically stimulate neurons. These devices offer unique opportunities to understand and treat conditions such as hearing and vision loss, epilepsy, brain degenerative diseases, and spinal cord injury. The potential benefit to humanity is enormous: According to the World Health Organization, 278 million people have moderate to profound hearing loss in both ears (2005 estimate), and more than 161 million people are visually impaired (2002 estimate). These numbers are on the rise due to a growing global population and longer life expectancies. A second example is sensor arrays that utilize living cells as the biorecognition element. These devices offer tremendous value in new drug development and in “canary in a coal mine” detectors protecting human and animal health and the environment. **Key to these technologies is a fundamental understanding of electrical communication at the interface between electronic materials and living cells.** Improved understanding of this interface will translate to implants that are more stable and dissipate less power, and sensors that offer better sensitivity and lower detection limit, addressing unmet and pressing needs in the field. The project BIOORGANICS addressed this challenge head-on: It developed a fundamental understanding of the communication between conducting polymer devices and living cells.

When electrically active cells (mostly neurons and muscle cells) are excited, ionic currents flow through their membranes. In the recording mode, multi-electrode arrays (MEA) act as sensors that transduce these ionic currents to electronic ones that can be subsequently amplified and read-out. The opposite happens when using MEAs to stimulate cells: A voltage pulse on a MEA electrode triggers the voltage-gated ion channels on the membranes of the excitable cells, causing the cell to depolarize and generate an action potential (neurons) or a twitch (muscle cells). This experiment is not unlike the one performed by Galvani in the 18th century, in which electrical stimulation made the detached leg of a frog move. The past two decades have witnessed a great deal of development in the application of silicon microelectronics to the interface with cells. The integration of microelectronics with neurons in particular has received a great deal of attention as a vehicle for massively parallel recording and stimulation.

The emergence of organic electronics – a technology that relies on carbon-based electronic materials to deliver devices with unique properties – represents one of the most dramatic developments of the past two decades. A rapidly emerging new direction in the field involves the interface with biology. The “soft” nature of organics offers better mechanical compatibility with tissue than traditional electronic materials, while their natural compatibility with mechanically flexible substrates suits the non-planar form factors often required for implants. More importantly, their ability to conduct ions in addition to electrons and holes opens up a new communication channel with biology.

The project BIOORGANICS explored the fundamentals of communication at the interface between conducting polymers and living cells. Specifically, this project examined the merits of organic electrochemical transistors (OECTs) as the “input” devices from the cellular world. OECTs are devices that translate ionic fluxes from electrically active cells into electrical signals in the transistor channel. The fellow established an understanding of the mechanism behind recording the electrical activity of cells with OECTs and used this knowledge to design OECTs that record action potentials in an efficient and ion-sensitive manner.

OECTs with micron-scale channels were fabricated and living cells expressing ion channels were cultured on them. A pipette electrode (see photo below) was used to excite a cell and record the changes in the transistor current. The coupling between the cell current and the transistor current was quantified through a numerical model, and optimized by tuning the device parameters. It was verified that the transistors were sensitive to the ionic current that flows out of the cells.



This work marks the first time an organic transistor was used to interface with single cells. As such, it explored the fundamental limits of organic electronics as interface devices with life sciences. It paves the road for the development of new neural interface devices.

The project led to four publications in peer-reviewed journals, two of which have an impact factor > 10. Two more are submitted, while a final one is being written. Between the fellow and the supervisor, 38 invited talks were given at international conferences or universities, including a plenary talk at the 2012 E-MRS meeting.

The fellow participated in outreach to the general public, during the annual festival of science (fête de la science), the open day of the Gardanne campus of the Ecole des Mines. These events hosted over a thousand visitors and included many experimental demonstrations for children of primary schools and their parents. An exhibit on bioelectronics was displayed that included commercial and our own implants, as well as a presentation of some of our findings from BIOORGANICS.

An electrophysiology instrumentation company called MICROVITAE (an SME) is interested in this device, though the results are still too early-stage for commercialization. Our laboratory is a recipient of a PhD student grant from MICROVITAE to further develop conducting polymer devices for neural interfacing.