Physics of Microstructured Bioelectronic Devices

Project Description:

In recent years, organic semiconductors were introduced as multifunctional materials for bioelectronic interfaces enabeling a novel generation of diagnostic and therapeutic biomedical devices.[1] Organic semiconductors show stable chemical properties even when operated in acqueous electrolytes and are non-toxic and biocompatible for cell-cultures and more complex biological organisms.[2] With such propeties organic semiconductors enable to exploit fundametal semiconductor phenomena such as field effect, carrier concentration control by doping and optoelectronic charge carrier generation at the direct interface with biological cells. However, the biological environment imposes new constraints that are unknown in traditional silicon based semiocnductor physics and require novel approaches to understand charge accumulation and transport. Example effects are the high dielectric constant and the ionic conductivity of the surounding acqueous electrolyte or the presence of electron transfer reactions from the semiconducting channel to molecules in the electrolyte solution.[3] Experimetal and theoretical approaches that address these effects are currently under investigation and central to this research project. They will provide a crucial contribution to realize the open promisses of organic bioelectronics.

A first effect to address in the project are organic electrochemical transistors (OECTs). In such devices ionic charges contained in an electrolyte exert a field effect on an organic semiconducting channel. Depending on the semiconductor, the ionic charges can migrate into the semiconducting channel, thereby extending the traditional 2D interface of field effect to 3D.[4] In this way channel gating becomes a volumetric effect and the consequences on device properties are manifold. The project starts with microstructured OECTs fabricated in our laboratory and has the objective to inquire on ionic transport properties in such devices.[5] As a method, atomic force microscopy experiments in water will be exploited. Objective is to measure small height changes on the channel surface of the transistor due to ion uptake. Analysis of such height changes will allow to understand the local electrochemical potential and charge density in the transistor channel. As a final outcome the experiments will produce a new characterization method that provides information on contact resistsance and local charge carrier density in water gated transistor structures.

A second physical effect to address in the project regards the optoelectronic properties of organic semiconductors immersed in acqeous electrolytes.[6] For such purposes our laboratory investigates organic semiconductor p/n junctions with a planar heterojunction.[7] Exciton separation at the junction generates a strong dipole that induces ionic displacement currents in the electrolyte. Several questions and application ideas are related to this basic physical effect. First, spectroscopic investigations are necessary to untangle the relevant timescales of the physico-chemical processes involved in the generation of ionic currents. Light modulated spectroscopy combined with impedance spectroscopy will be used to investigate the timescales of ionic transport and charge generation. Scanning probe microscopies will be used to understand the impact of the local semiconductor morphology. A new experimental setup will be developed to achieve local photocurrent maping at the semiconductor electrolyte intefaces. Such an experiment could provide new means to monitor the dielectric properties of biological cells.

Activity Plan

Month 1-2:

Fabricate microstructured organic electrochemical transistors. The channel geometry has to be below 50 x 50 um^2.

Characterize electrical transistor properties (carrier mobility, capacitance, timescale, density of states).

Calibrate the working procedure of AFM experiments in acqueous electrolytes

Month 3-4:

Investigate fabricated OECTs with modulated electrochemical force microscopy

Month 5-6:

Analyze data and write article.

Month 7-8:

Investigate photovoltage and photocurrents in pn-planar heterojunction structures fabricated with molecules H2Pc and PTCDI.

Month 9-10:

Investigate structures with IMPS and photocurrent microscopy techniques

Perform optoelectronic experiments on devices with cells cultured on top surface

Month 11-12:

Analyze data and write article.

References

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