Chapter 25
Field Effect Transistor Sensing Devices Employing Lipid Layers

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Abstract Field-Effect Transistors comprising layers of lipids have been developed and characterized from the electrical point of view. Lipid layers-OTFT are proposed as novel devices for perspective application in the detection of analytes from aqueous samples.

25.1 Introduction

Electronic transduction of bio-recognition events can provide new perspectives for the development of Organic Thin Film Transistor (OTFT) devices. Solid state sensors, such as resistors or transistors, potentially offer the advantage of allowing an "on-line" monitoring of the critical process parameters. OTFTs can be operated as potentially multi-parameter responsive systems, also in a sensing circuits

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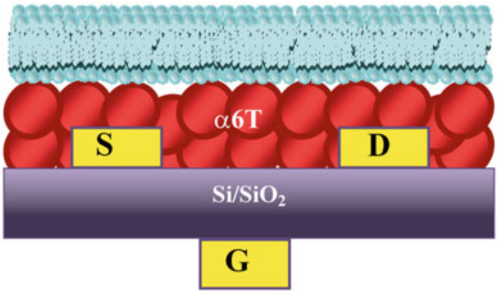

Fig. 25.1 Schematic representation of a lipid layers OTFT

configuration [1]. The smart use of a field-effect device for sensing applications appeared useful also to produce sensors with high repeatability [2]. Exposure of the organic active layer to an analyte leads to charge trapping which prevents the full base line recovery. OTFT sensors exhibited extremely good response repeatability, and their relative sensor response was in the range from 5 to 15%, for 10–100 ppm analyte concentrations, while measurements were carried out at room temperature and in regular laboratory atmosphere [3, 4]. Besides the field-induced response enhancement, also a field-induced sensitivity enhancement has been very recently demonstrated [5]. The OTFT sensitivity can be increased by orders of magnitude and the "turn-on" of the sensitivity occurs in the accumulation mode regime beyond the threshold voltage. This field-induced sensitivity enhancement lead to chiral differential detection, in the vapour phase, at unprecedented low concentrations, i.e. at the low ppm level: three order of magnitude lower than state-of-the-art values [6, 7].

25.2 Device Structure and Electrical Characterization

In the present study, a totally innovative OTFT device has been realized, by fully integrating in the electronic device a lipid layers structure specifically appointed for bio-sensing applications allowing processing in liquid samples.

In particular, a bottom gate, bottom contact OTFT device, whose structure is reported in Fig. 25.1, was fabricated using a SiO_2/n-doped Si substrate. The silicon substrate with a gold pad acts as the gate contact (G) while the silicon dioxide is the gate dielectric. The dielectric surface was covered by a α6T thin-film deposited by thermal evaporation at a low pressure of 5×10^{-7} Torr, with the substrate kept at room temperature. The final thickness of the organic semiconductor film was of 50 nm. To realize the lipid layers, 10 μl of the liposome solution were deposited by drop casting technique, directly over the organic semiconductor active layer. The solution was left to evaporate in nitrogen atmosphere over night.

Previous example of such a device configuration was carried out by X. Zhou and P.L. McEuen at the Cornell University. In this case, a supported lipid bilayer was realized on single-walled carbon nanotubes transistors and the device was used to detect the specific binding of proteins to membrane-embedded targets [8].

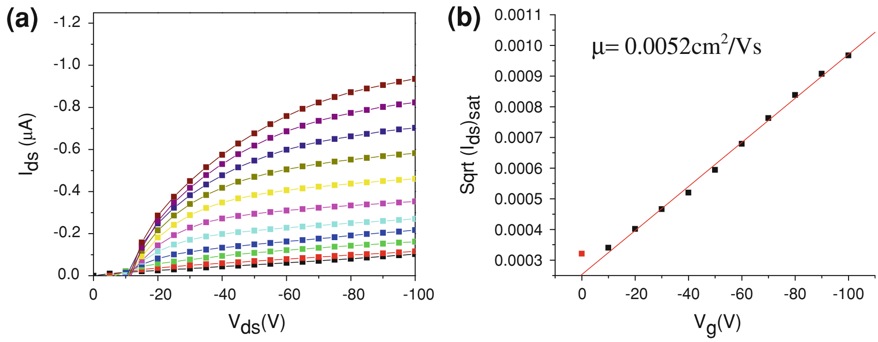

Fig. 25.2 **a** $I_{ds}-V_{ds}$ curves for the lipid layers OTFT; **b** square root of I_{ds} vs. V_g plot of the lipid layers OTFT for the electrical parameter extraction

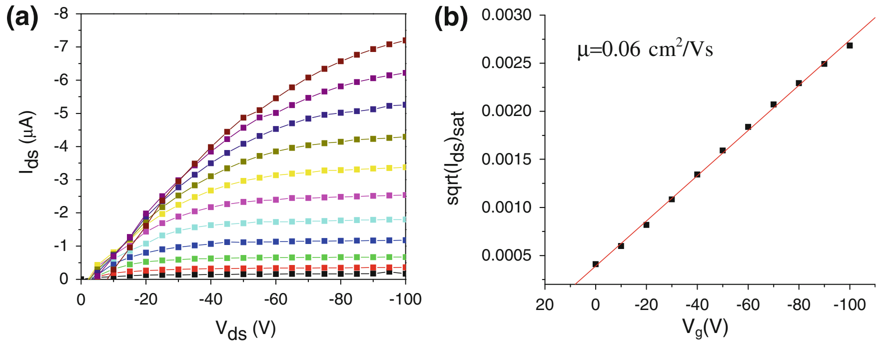

Fig. 25.3 **a** $I_{ds}-V_{ds}$ curves for the α-6T based OTFT; **b** square root of I_{ds} vs. V_g plot of for the α-6T based OTFT for the electrical parameter extraction

In the present study, we focussed on the electrical performances of the transistor and their dependence upon the presence of lipid layers.

In Fig. 25.2a, the source-drain current (I_{ds}) of the lipid layers OTFT is reported as a function of the source-drain bias (V_{ds}) for different gate biases (V_g). The field-effect mobility (μ) is graphically extracted from the relevant square root of I_{ds} vs. V_g plot (Fig. 25.2b) resulting in $\mu = 0.0052$ cm^2/Vs.

In Fig. 25.3, the I_d-V_{ds} characteristics of an OTFT whose active layer consists only in an α6T organic semiconductor is reported. The extracted electrical parameters result in a field effect mobility of 0.06 cm^2/Vs.

The comparison of the electrical performance of these two differently structured OTFT shows a slight decrease of the electrical performances in the case of the lipid layers-OTFT device. This behavior was explained considering that the lipid layers interacting with the organic semiconductor, affect the short-range molecular order of its polycrystalline structure. This can influence the grain boundary potential barrier height, reflecting directly onto the transistor channel transport. It is important to outline that this is quite a moderate effect that strongly encourages further development of the study and particularly the investigation of sensing applications in aqueous media.

In particular, the immobilization of a protein into lipid layers represents an innovative approach that is going to be soon investigated. This will be also applied to ad hoc modified antibodies although such bio-molecules will be also immobilised directly over the device active surface using more standard approaches. In this respect a properly deposited phospholipid bi-layer, including proteins such as photosynthetic reaction centres and antibodies, will confer specificity. In fact this protein (RC) has been already successfully used as a recognition element in optical biosensor for herbicides detection, achieving detection limits of 0.1 mM [9].

25.3 Conclusions

A totally innovative device, based on an OTFT comprising a properly deposited lipid layer is presented. In order to understand if the lipid layers can affect the electrical performance of the device, a comparison with the electrical performances of a bottom gate-bottom contact α6T based OTFT was performed. Sensing and bio-sensing applications in aqueous media are envisaged, as well.

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