INKJET PRINTED FET FOR BIOSENSING APPLICATIONS

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ABSTRACT

The developed bio-field effect transistor (BioFET) consists in nano-silver ink printed source and drain electrodes, a polymeric organic semiconductor, dielectric layer based on methyl methacrylate (MMA) and finally the reference electrode of silver-silver chloride ink. The thickness of the dielectric layer was optimized and characterized by Scanning Electron Microscopy (SEM) and by electrical measurements to characterize the dielectric breakdown and the semiconductor dielectric interface. The electrical characterization was also performed using different electrolytic solutions. Finally some preliminary results about the FET functionalization onto dielectric layer so as to obtain a BioFET are shown.

KEYWORDS: Inkjet, organic transistor, biosensor, BioFET, EISFET, surface functionalization, protein.

INTRODUCTION

The development of Organic Thin Film Transistors (OTFTs) has opened an interesting research field in biosensing applications by replacing the gate by an electrolyte and a reference electrode [1]. By functionalizing this field effect transistor (FET) with biological materials, a BioFET is obtained. The main advantage of this FET based biosensor is the possibility to get an all-integrated, portable and low cost system, compatible with the "single-use sensor" concept. In addition, these devices generally are fabricated by photolithography methods that require expensive masks and cleaning room facilities. To overcome these issues an inkjet based FET for biosensing applications is proposed.

BioFETs to be used as biomedical devices require specific interactions between biological molecules used as receptors and the analyte contained in the sample fluid. Up to date the fabrication of such biosensors has involved the assembly of many parts making them expensive and non-reproducible. Recently, the production of BioFETs has moved to fabrication and production processes with high throughput and integration level. Indeed traditional silicon-based semiconductor electronics tend to be replaced by organic, hybrid and flexible printed electronic methodologies. Between examples of biosensors fabricated with these new technologies are the development of electrochemical biosensor based on gold electrodes by inkjet printing onto polyimide (PI) substrate, for detection of a cancer biomarker such as interleukin-6 (IL-6) in serum [2]. Organic field effect transistors are also used for glucose detection. A simple poly(3,4.ethylene dioxythiophene)/poly(styrene sulfonic acid) based transistor was used for glucose detection through a mechanism that involves sensing of hydrogen peroxide [3].

Regarding the deposition of organic materials [4] several technologies such as inkjet-printing, screen-printing, micro contact-printing, gravure and flexography beside lithography's such as scanning probe, photo and e-beam and laser printing are already known. Between these various deposition technologies, inkjet printing has become one of the most promising techniques capable of manufacturing devices by using small volumes of ink, in a rapid and additive procedure, achieving high pattern precision and resolution with greater reproducibility. This method doesn't require any mask which makes it easier and cheaper in comparison to other ones [5].

The purpose of this work is to develop a simple, low cost and miniaturized BioFET to determine biomarkers (i.e. for Alzheimer, cancer etc.) based on the use of specific antibodies immobilized onto the transducer surface of a field effect transistor. The quick and sensible detection of biomarkers in a point-of-care application will allow an early diagnosis achieving prompt treatments of patients.

PRINCIPLE OF BIOFET OPERATION

BioFET is based on the electrolyte–insulator–semiconductor field-effect transistor (EISFET) that provides means of electrical detecting of biomolecular interactions by the capacitive coupling between interacting species and the organic semiconductor. A simplified scheme of the BioFET is shown in Figure 1. It consists of a conventional FET structure that includes source, drain and gate. However, in the BioFET, the gate contact is replaced by an electrolytic solution, an antibody-protein conjugate and a reference electrode. The amount of accumulated charge on the dielectric gate in the BioFET can result in an increase (or decrease) of the Source-Drain current. This would create variations in the transistor responses (I-V curves) that are proportional to the amount of the introduced charge. If the change of the electrical charge is related to the interaction between biological molecules, then it can be used to monitor this process quite effectively and with very high sensitivity.

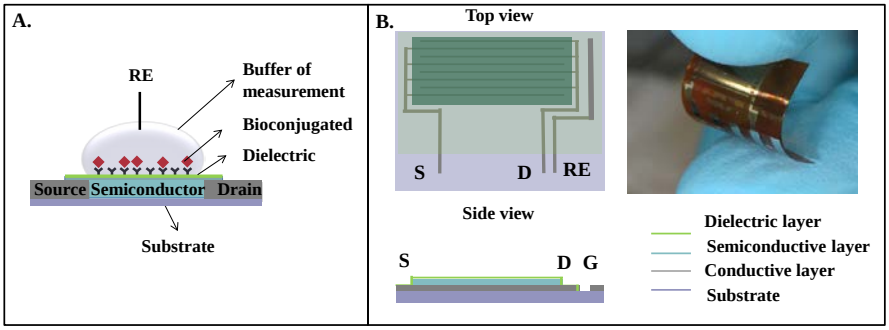

Figure 1. **Scheme of BioFET components (A), and top and side views (B) representing each layer of the BioFET including a picture of the flexible printed device.**

RESULTS AND DISCUSSIONS

Homemade BioFETs were fabricated by using an R&D inkjet printing machine (Dimatix DMP2831) which especially printed the silver contacts and the semiconductive layer (OSC layer), Figure 2B. The dielectric layer was obtained by an optimized deposition of methyl methacrylate (MMA) using spin coating process (Figure 2A). I-V results were obtained for different number of layers as well as their thickness, in order to select the properly thickness to decrease the current leakages (Figure 2C and 2D).

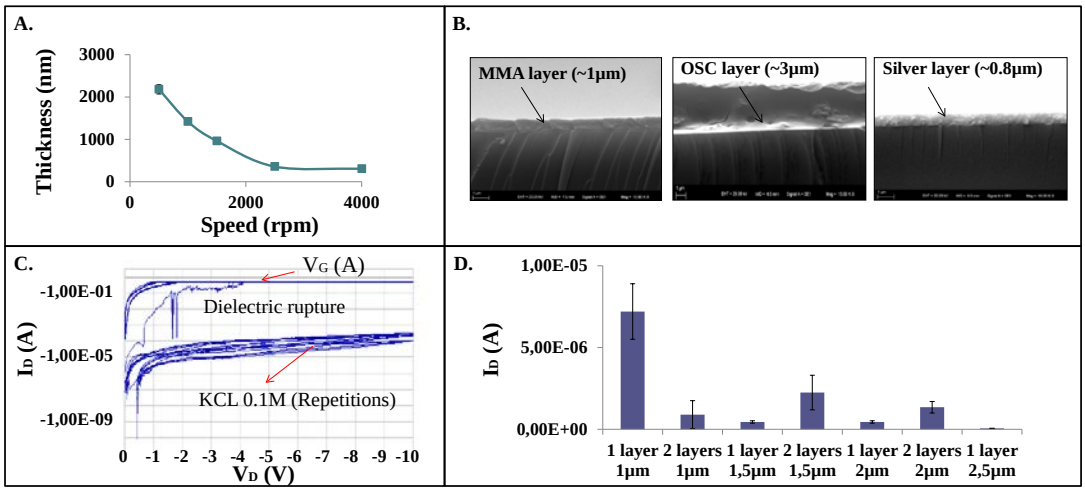

Figure 2. Dielectric layer studies that include thickness optimization (A), SEM images of the various layers are also shown (B), dielectric rupture studies (C), and study of current at different dielectric thickness (D).

MMA functionalization allowing the immobilization of proteins onto gate surface was performed. It consists in plasma oxidation of the MMA layer followed by an incubation using 3-aminopropyltriethoxysilane (APTES). Different concentrations of amino-groups were compared and characterized by colorimetric method for quantification of amine groups by using acid orange II dye (Figure 3A). 1% of APTES was chosen as a suitable concentration that does not affect the physical properties of the material, obtaining an adhesion of 0.18 µM.cm^2 amine groups. Fluorescence characterization of the bovine serum albumin (BSA) labeled with a fluorophore (ALEXA 555) by using epifluorescence microscope confirmed the selective adhesion of the analyte onto the device (Figure 3B). Atomic Force Microscopy (AFM) study was also performed. AFM images (Figure 3C) show a clear phase change and roughness increase after APTES and BSA immobilization.

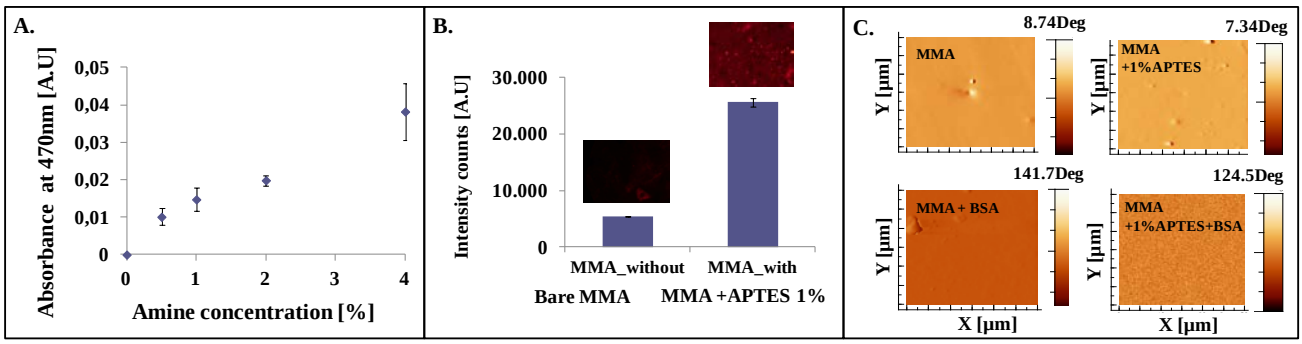

Figure 3. MMA layer functionalization. Absorbance studies at different APTES percentages, equivalent to 0, 0.13, 0.18, 0.24, and 0.41 µM/cm^2 (A), Fluorescence images (B), and Phase-atomic force microscopy (AFM) images (C).

To evaluate the detection of the immobilized protein BSA [1µg/mL], two kinds of capacitive structures were fabricated. The structures are based on buffer electrolyte PBS / MMA dielectric functionalized / semiconductor with and without BSA protein onto the dielectric surface. The capacitance-voltage (C-V) measurements were performed at 1kHz frequency at room temperature. This technique allows to know the response of surface states, surface accumulation and layer thickness beside others [6]. Figure 4A shows the C-V characteristics of electrolyte-insulator-semiconductor for the case of (a) structure functionalized and (b) structure functionalized with immobilized protein BSA. The capacitance depends on bias voltage and have three regions of accumulation-depletion-inversion indicating the modulation of the carriers. The capacitance remains constant under forward bias, although above the threshold gradually increases to reach the maximum peak value and then decreases with a higher bias. This phenomena is explained by short-circuited parallel capacitance and it is based on the model RC circuit. As shown in Figure 4A a significant difference of peak heights of capacitance for (a) and (b) is observed. The capacitance ranges from 100nF to 280nF with low variability for different devices shown in Figure 4B. Confocal and interferometry images are shown in Figure 4C with (a) functionalization and (b) with immobilized protein structures. Surface of immobilized protein shows a higher roughness comparatively to the functionalized. The high scale values compared to AFM images (1x1 μm^2) is due to large area (600x400 μm^2) taken by the confocal.

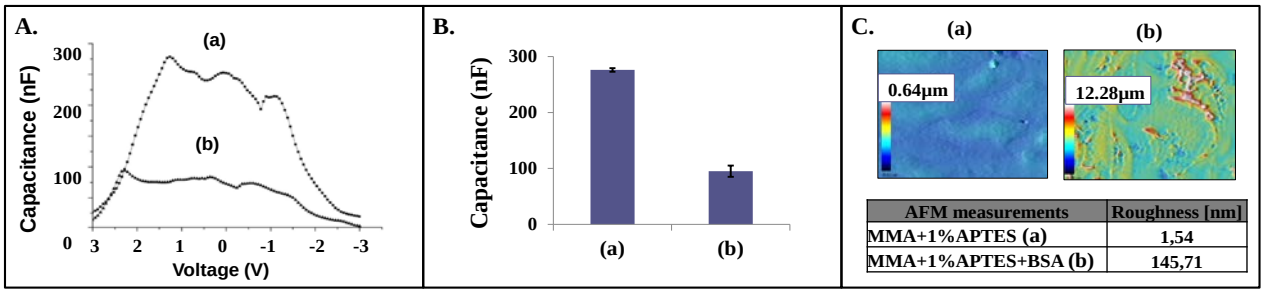

Figure 4. Capacitance-voltage with electrolyte (PBS) onto dielectric-semiconductive-conductive structure functionalized with APTES 1% (a) and functionalized with immobilized protein BSA [1µg/mL](b); Characteristic curves (A), repeatability with different devices (B), and confocal images with functionalization and with immobilized protein (C).

CONCLUSIONS

An all integrated and functional BioFET by using organic materials mostly deposited by inkjet technology and spin-coating was designed and fabricated. Characterizations of the deposited layers by using SEM and profilometry were performed. Dielectric rupture evaluation at different thicknesses (one and two layers of MMA dielectric layer) was also performed. MMA surface functionalization (with interest for future biological applications) study through colorometric assay to determine the quantity of amine groups onto FET surface, fluorescence measurements and AFM images to confirm the selective adhesion of proteins onto BioFET surface were also carried out. Detection of the immobilized protein BSA was performed by means of C-V measurement. Moreover, we present the repeatability with different devices. Finally, confocal and interferometry images was undertaken to assess the roughness of functionalized and immobilized protein structures.

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