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PEDOT: PSS gated field-effect transistor for ion sensing applications

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Summary:

This paper introduces a new approach utilizing poly(3,4-ethylenedioxythiophene): poly(styrene sulfonate) (PEDOT: PSS) as the gate electrode of an ion-sensitive field-effect transistor (ISFET) in a configuration similar to a metal oxide semiconductor field-effect transistor (MOSFET) for ion sensing applications. The transistor exhibited the capability to operate effectively in both dry and aqueous environments. In the latter case, the aqueous solution is in direct contact with the PEDOT:PSS while the gate voltage is applied to the PEDOT:PSS gate. Experimental results demonstrated significant sensitivity to the conductivity of the solution and stable performance of the device over many cycles.

Keywords: ISFET, PEDOT:PSS, Ion sensor, Biochemical sensing

Background and Motivation

Ion-sensitive field-effect transistors (ISFETs) are well-established sensors that have been used to detect ions, pH value or biomolecules, through the gate oxide surface potential changes [1]. To be used as an ion-sensitive sensor, the gate oxide of the ISFET must be functionalized with an ion-sensitive layer that is in direct contact with the electrolyte. Furthermore, the ISFET requires a reference electrode to provide a known, stable potential to the electrolyte during the measurements, which brings challenges when compact encapsulations are needed in practical applications. PEDOT: PSS is a widely used conductive polymer in the field of bioelectronics because of its high conductivity, biocompatibility and processability [2]. The applications of PEDOT:PSS as an organic electrochemical transistor (OECT) channel material and the electrode coating material indicate its ability as an ionic-to-electronic transducer [3,4]. This work introduces an approach that allows for ion detection without a reference electrode by reconfiguring an ISFET into a MOSFET configuration, utilizing PEDOT:PSS as the gate electrode material. We present the fabrication methods and key characteristics of these transistors, specifically their stability and response to solution conductivity.

Materials and Methods

The p-type enhancement ISFET was fabricated using standard microfabrication techniques on a 4-inch wafer scale as described previously [5]. 4x4 arrays of ISFET were fabricated on an n-type silicon substrate. The conducting line was highly implanted with boron to decrease the serial resistance and passivated with 200 nm thermal-grown SiO_2. A high-quality 8 nm thermal-grown SiO_2 gate insulator was used for the ISFET operation. An Au ring microelectrode was fabricated around the gate of the ISFET while the contact line of the ring electrode was passivated with 300 nm PECVD SiO_2.

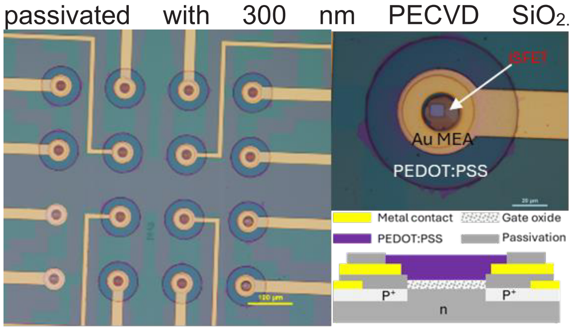

Fig. 1 Left: light microscope images of a 4x4 array of PEDOT:PSS gated FET. Right: optical image of a device in the arrays and a schematic representation of the cross-section view of the device

Aqueous PEDOT:PSS dispersion was modified by ethylene glycol (EG) to enhance the conductivity, and (3-glycidyloxypropyl) trimethoxysilane (GOPS) was used as a crosslinker to enhance the stability of PEDOT: PSS film in electrolyte. The deposition of PEDOT: PSS on the gate of the ISFET was accomplished using laser lithography, followed by spin-coating of the mixture solution and a subsequent lift-off process in acetone and isopropanol to remove the unwanted PEDOT: PSS. [4]. Figure 1 shows the top view of a 4x4 array ISFET-MEA coated with PEDOT: PSS along with its cross-sectional view. Electrical measurements were performed using a Keithley 4200-SCS semiconductor analyzer. The transfer characteristics of the transistors were investigated in air and under NaCl solutions with varying concentrations.

Results

Figure 2 illustrates the transfer characteristics of the transistor measured in air and with a liquid (DI water) in contact with PEDOT: PSS. Under dry conditions, the transistor operates similarly to a MOSFET device. However, when DI water was introduced to the chip surface, there was a significant change in the threshold voltage as well as in the transconductance of the transistor.

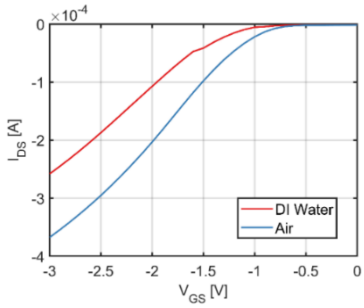

Fig. 2 Transfer characteristics of the transistor in air and aqueous environments, with V_{DS} = -1V.

Figure 3a shows the transfer characteristics of the devices measured in NaCl solutions with concentrations of 1 mM, 10 mM, and 100 mM, corresponding to the conductivities of these solutions at 96.2 µS/cm, 918.7 µS/cm, and 8937.9 µS/cm, respectively. A clear shift in the threshold voltage was observed. As the concentration of NaCl increases, the absolute value of the threshold voltage decreases. The shift in threshold voltage was extracted from the transfer characteristic curves, as shown in Figure 3b. A linear dependence was observed between the change in threshold voltage and the logarithm of the NaCl concentration, or conductivity. The shift in threshold voltage yielded a sensitivity of approximately 90.7 mV/decade.

The durability tests on the transistor in an electrolyte solution showed reliable transfer characteristics with a shift of the threshold voltage of around 2 mV after 350 measurements.

The proposed system can be used as a reliable ion-sensitive sensor compared to our previous work using OECT [4], demonstrating potential for miniaturization by excluding the reference electrode. Further experiments are being conducted to evaluate the system with different ions and enhance the selectivity of the sensor.

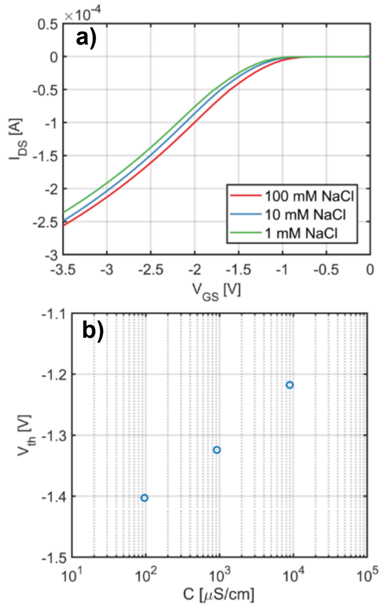

Fig. 3 (a)Transistor's responses to different NaCl solution concentrations, V_{DS} = -1V. (b)Threshold voltages shift according to the corresponding solution conductivity

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