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Effects of Poly(3-hexylthiophene) Concentration on Performance of Extended-Gate Field-Effect Transistor for Silver Ion Detection

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Abstract

The characteristics of selective silver ion sensors are developed by extended-gate field-effect transistor (EGFET) are reported. In comparison with various concentrations of P3HT, the 70 mg/ml P3HT exhibits an excellent sensitivity of 68.15 mV/decade and a linearity of 0.969 in the silver ion range of 10^{-1} M to 10^{-7} M. We believe that broad orientation distribution of crystalline domains, which caused more interaction between Ag+ and conjugated polymer backbone, and lead 70 mg/ml P3HT films in Ag^+-EGFET have high sensitivity.

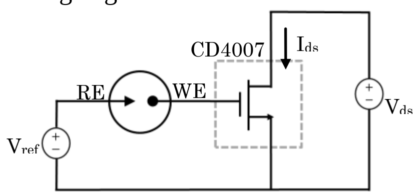
1. Introduction

In 1983, J. V. D. Spiegel et al [1] investigated extended gate field effect transistor (EGFET). The characteristic of EGFET structure is chemical sensitive area isolated from MOSFET, and this makes the device has many advantages, including simplicity of packing and passivation. In 2000, the research of J. C. Chou. et al [2] is different from Van Der Spiegel et al, which designed silicon oxide (SiO_2) sensing membrane to connect with gate of commercial MOSFET CD4007 UB, realized that great linearity and sensitivity of pH sensor. Recently, numerous researchers attempted to extend EGFET application for ion sensor and biosensor by using several sensing membrane integrated with biological and chemical modification, such as tin dioxide [3], carbon nanotube[4], ZnO nanostructure[5] and gallium nitride [6].

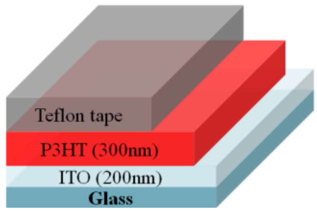
Conducting polymer (CP) has been widely applied for organic thin film transistor (OTFT), solar cell, chemical sensor and biological sensor because of desirable properties [7]. The chemical bond and electrical conductivity made the CP more multifunctional than traditional semiconductor, for example J. W. Jenong et al [8] developed gas sensor based on poly(3-hexylthiophene) (P3HT) transistors by P3HT acting NH_3 gas receptor and signal transformer. Recently, M. Vazquez et al [9] investigated the poly(3-octylthiophene) (POT) applied for silver ion selective electrodes (Ag^+-ISEs) that indicated Ag^+ interacts with sulfur atom and double bonds in POT and other polythiophenes. According to above investigations, we integrated P3HT thin films into EGFET as silver ion sensed membrane, and had developed extended gate field effect transistor for selective silver ion sensors (Ag^+-EGFET) successfully. Furthermore, effects of various P3HT concentrations on surface morphology and crystalline structure correlative to performance of EGFET applied for silver ion are investigated.

2. Results and Discussion

The diagram of extended-gate field-effect transistor (EGFET) is shown in Fig. 1(a). Extended-gate FET structure includes two parts: One of parts is electrochemical cell, also called sensitive part, where includes working electrode (WE) and reference electrode (RE), the other is commercial n type metal-oxide-semiconductor field-effect-transistor (n-MOSFET; CD4007). The gate of n-MOSFET connects to working electrode as extended-gate. The structure of electrochemical cell is shown in Fig. 1(b). The reference electrode was Ag/AgCl (sat. NaCl). The ITO glass substrates, purchased from Luminescence Technology Corp, Taiwan, which sheet resistance is 5 Ω/sq. Poly(3-hexylthiophene) (P3HT), obtained from Luminescence Technology Corp, blended with 1,2-dichlorobenzene (DCB) to obtain various concentrations of P3HT solutions range from 30 mg/ml to 70 mg/ml. Teflon tape was used for package and defined 3 mm diameter sense area. X-ray determining method was recorded using Rotating Anode X-ray Generator (D/MAX 2500, Rigaku) with a low grazing angle incidence.



(a)



(b)

Fig. 1 (a) Extended-gate field-effect transistor (EGFET) structure includes electrochemical cell and commercial MOSFET. Using working electrode (WE) as extended-gate, and it is connecting to gate of n-MOSFET. V_{ref} stands for reference electrode voltage, which is applied to the reference electrode (RE), Ag/AgCl (Sat. NaCl). V_{ds} and I_{ds} stand for voltage and drain-source current respectively. (b)Schematic of working electrode is ITO(200nm)/P3HT(~300nm). The working electrode is packaged by Teflon tape, and defined sensing area is 3mm diameter.

The drain-source current (I_{ds}) versus refernce electrode voltage (V_{ref}) curves of extended-gate field-effect transistor for selective silver ion sensors (Ag^+-EGFET) based on 70 mg/ml P3HT thin film were measured in various $AgNO_3$ concentrations ranging from 10^{-1} M to 10^{-7} M, shown in Fig. 2. It can be observed that I_{ds} decreased as $AgNO_3$ concentrations increased, and lead the threshold voltage (V_{th}) is changed. In Fig. 3, threshold voltage were extracted from curves of $(I_{DS})^{1/2}$ versus V_{ref} for each $AgNO_3$ concentration, and we could observe that V_{th} decreased when the $AgNO_3$ concentrations increased. For FET devices, V_{th} is an important parameter, which is defined the gate voltage at minimum to turn "on" transistor, and it could be dependent on the interface between gate and channel. Therefore, Ag^+ concentration increased caused more Ag^+ on the P3HT surface and gate electrode become more positive bias and lead to V_{th} decreased. Furthermore, changing the concentrations of P3HT fabrication from 30 mg/ml to 70 mg/ml, the 70 mg/ml has excellent linearity and a high sensitivity of 68.15 mV/decd in silver ion range 10^{-1} M-10^{-7} M.

Besides, X-ray diffraction (XRD) profiles of various concentrations P3HT films were measured, shown in Fig. 4. It indicated that 70 mg/ml P3HT films had broad orientation distribution of crystalline domains. Therefore, we believe that broad orientation distribution of crystalline domains, which caused more interaction between Ag^+ and conjugated polymer backbone, and lead 70 mg/ml P3HT films in Ag^+-EGFET have high sensitivities.

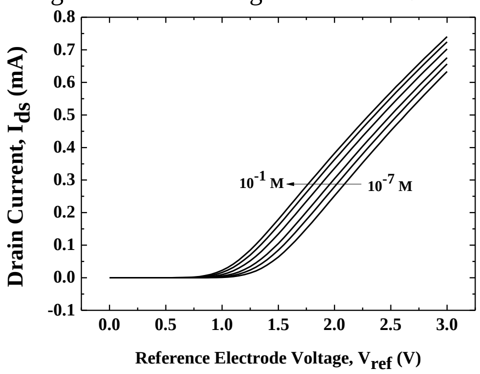


Fig. 2 I_{ds}-V_{ref} curves for Ag^+-EGFET sensor with70 mg/ml P3HT thin film.

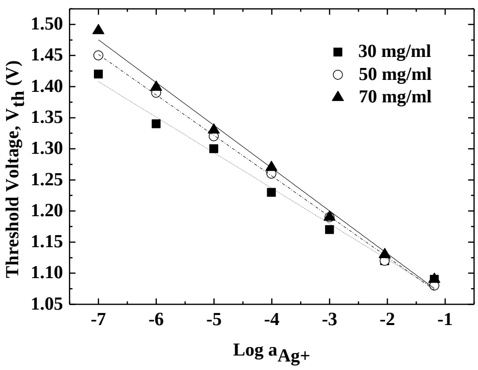


Fig. 3 Threshold voltages of Ag^+-EGFET sensor with 30 mg/ml, 50 mg/ml and 70mg/ml P3HT thin films in various Ag^+ activities.

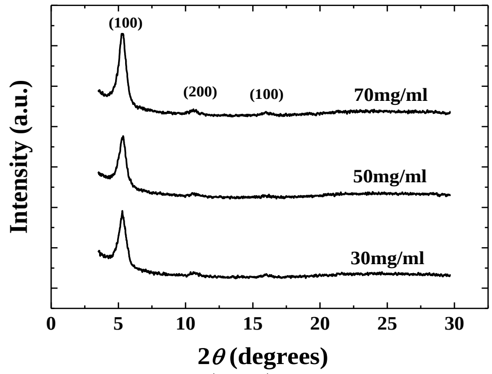


Fig. 4 X-ray diffraction (XRD) profiles of various concentrations P3HT films.

3. Conclusion

The extended-gate field-effect transistor for selective silver ion sensors (Ag^+-EGFET) based on poly(3-hexylthiophene) (P3HT) has been developed successfully. Changing the concentrations of P3HT fabrication from 30 mg/ml to 70 mg/ml, the 70 mg/ml has excellent linearity and a high sensitivity of 68.15 mV/decd in silver ion range of 10^{-1} M-10^{-7} M. As results shown, the 70 mg/ml P3HT film has rough surface morphology and broad orientation distribution of crystalline domains, which caused more interaction between Ag^+ and conjugated polymer backbone, and make Ag^+-EGFET has high sensitivity.

Acknowledgements

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