Water-gated OFETs for pesticide detection

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Abstract

In this study, bottom-contact water-gated OFETs were fabricated. The effects of channel width and length ratio on electrical characteristics of the semiconducting layers were investigated. It was found that increasing channel width and length ratio improved the electrical performance of the water-gated OFETs. However, at short-channel lengths, the OFETs no longer saturate due to space charge limiting current effect. Changes in transistor characteristics when diluted pesticides were added to the water dielectrics were discussed.

Keywords: Organic Transistors, Field-effect Transistors, Semiconductor polymer

Introduction

A transistor is an electronic switch working like a water valve controlling water flow where the transistor controls current flows from source and drain. Current is controlled by magnitude of electric field applied at a gate contact known as 'gate bias'[1]. The most common type of transistor is field-effect transistor (FET) that relies on an electric field to control the conductivity of a channel of one type of charge carriers in a semiconductor material. Organic field effect transistors (OFETs) are widely utilized in alternative disposable electronic devices. These devices provide fabrication simplicity, low-cost, fast, and adequate sensitivity. Water-gated OFETs have been reported to operate under low-voltage with low-energy consumption and applied to DNA sensor [2].

In this study, Bottom-contact water-gated OFETs were fabricated. After characterization of the OFETs, an optimum suitable condition was taken to test the performance of sensor application.

Materials and Methods

Drain and source electrode materials were deposited by thermal evaporation of chromium and gold, respectively, on glass substrates. Interdigitated pattern masks of which channel width and length (W/L) ratios were varied were used for thermal evaporation of drain and source electrodes. These masks were fabricated in our laboratory by contact printing. Poly(3-hexylthiophene) (P3HT) semiconducting layers were, then, spin-coated using 1, 2 dichlorobenzene as a solvent on drain and source electrode. Deionized water droplets were applied as a dielectric layer for the devices. Gold gate electrode was dipped in deionized water on the top of device, see Figure 1. Pesticide Paraoxon was used to modify dielectric layer properties. 0, 10, 100, and 1000 ppm of Paraoxon was varied to deionized water droplets dielectric layer.

Semiconductor analyzer (Keithley 2612) was used to characterize the OFETs. The range of V_{DS} sweeps from 0.1 V to -0.7 V to force the current to flow to drain and V_{GS} starts from 0.1 V to -0.5 V with steps of 0.1 V. As V_{GS} decreases by 0.1 V, the device goes through inversion, depletion, and finally accumulation. The authors used this setup to illustrate all modes.

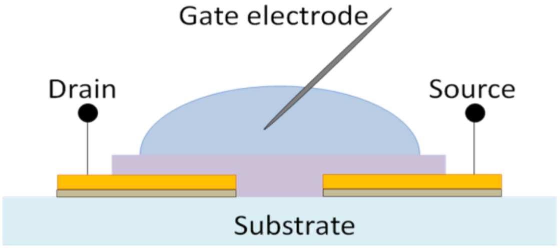


Figure 1. A water-gated OFETs

Results and Discussion

Figure 2 shows output characteristics of our water-gated OFETs. P3HT is a p-type semiconductor. The OFETs usually operate in the accumulation mode, whereas typical FET can be operated in the inversion and accumulation mode. Negative drain to source voltage (V_{ds}) and gate to source voltage (V_{gs}) are applied to accumulate holes at the P3HT/ deionized water interface and between source and drain electrodes, respectively. Increasing of negative V_{ds} and V_{gs} resulted in more hole accumulation so drain to source current (I_d) was increased. At the positive and low negative V_{gs} condition, I_d does not saturate. These current-voltage characteristics were obtained due to space charge limiting current effect [3-4]. Table 1 lists condition codes and W/L ratios in this study.

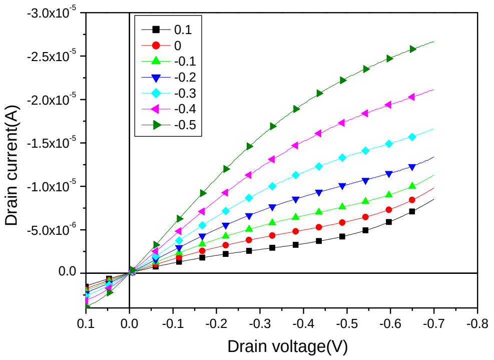


Figure 2. Current-voltage characteristics of channel width and length ratio of 2060 (10p-10-100 condition in Table 1) for water-gated OFETs.

Interdigitated drain and source electrodes were varied on number of pairs, channel widths and channel lengths. The current-voltage characteristics of FET in linear and saturation region are dependent on current channel width and length, according to equations (1) and (2), respectively.

$$I_d = \frac{\mu C_i W V_d}{L}\left[\left(V_g - V_t\right) - \frac{V_d}{2}\right] \qquad (1)$$

$$I_d = \frac{\mu C_i W}{2L}\left(V_{gs} - V_T\right)^2 \qquad (2)$$

Table 1 and figure 3 show I_d at applied V_{gs} and V_{ds} of -0.5 V and -0.6 V, respectively. Preliminary results of I_d calculated from equation (2) shows that maximum Id is obtained at W/L ratio of 2120. This W/L ratio was, then, taken to test performance of sensors as shown in figure 4.

Table 1: Condition code (number of pair- width of each electrode- channel length), channel width and length ratio (W/L ratio), drain to source current at V_{gs} and V_{ds} of -0.5 V and -0.6 V, respectively, and drain to source current standard deviation for our water-gated OFETs.

Condition	**W/L ratio**	**I_d(uA)**	**SD**
10p-5000-200	540	-8.33	0.52
10p-5000-150	713	-6.79	3.17
10p-5000-100	1060	-4.22	0.17
10p-10000-200	1040	-12.25	4.54
10p-10000-150	1380	-13.44	0.62
10p-10000-100	2060	-23.44	2.22
20p-5000-200	1080	-13.26	1.54
20p-5000-150	1426	-3.76	1.06
20p-5000-100	2120	-6.40	1.91
20p-10000-200	2080	-32.09	4.28
20p-10000-150	2760	-18.81	5.39
20p-10000-100	4120	-15.50	9.82

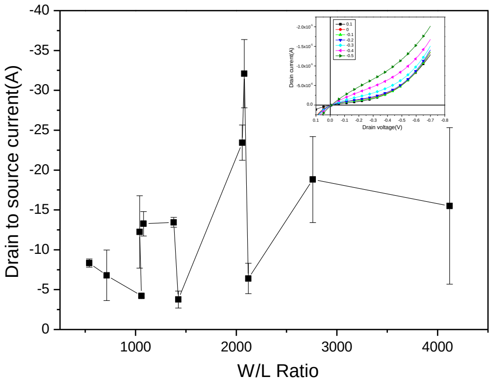
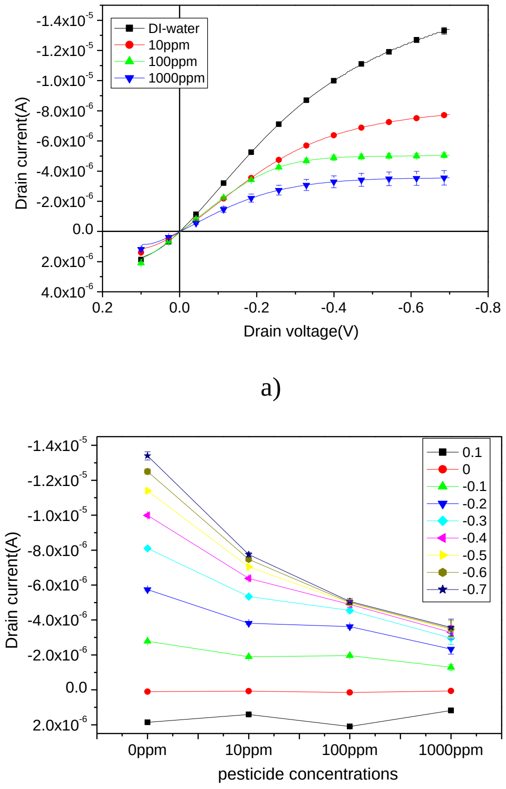


Figure 3. Saturation Drain to source current, I_{dsat}, at V_{gs} and V_{ds} of -0.5 V and -0.6 V, respectively, versus channel width and length ratio for fabricated water-gated OFETs. Inset shows current-voltage characteristics of channel width and length ratio of 2760 (20p-10-150 condition) for water-gated OFETs.

Figure 4 a) shows current-voltage characteristics at V_{gs} and V_{ds} of -0.5 V and 0.1 to -0.7 V respectively for 0, 10, 100, and 1000 ppm of Paraoxon concentration in deionized water droplet dielectrics. Increasing Paraoxon concentration in deionized water resulted in decreasing drain current. Drain current decrease is likely due to hydolysis of paraoxon. The hydolysis of paraoxon as shown in figure 5 has only two neutral ions so they do not react with gate electrode. Hydolysis of paraoxon ions block the electric field and lead to a reduction of the hole accumulation between drain and source electrodes. The direct determination of paraoxon by the enzyme organophosphorus hydrolase (OPH) was presented by M.J. Schoning et al [6]. The enzyme OPH hydrolyses organophosphorus compounds catalytically, thus releasing H^+ ions.



a)

b)

Figure 4. a) Current-voltage characteristics at V_{gs} and V_{ds} of -0.5 V and 0.1 to -0.7 V, respectively, for 0, 10, 100, and 1000 ppm of Paraoxon concentration in deionized water droplets dielectrics and b) Drain current as a function of pesticide concentrations at V_{gs} and V_{ds} of -0.5 V and 0.1 to -0.7 V, respectively.

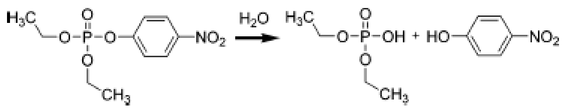


Figure 5. Hydrolysis of paraoxon[5].

Conclusions

Water-gated OFETs worked as transistors for all 10 pair condition. However, for all 20p condition, a water-gated OFETs do not have saturation I_d trend for current-voltage characteristics due to space charge limiting current effect. In sensor application, drain current decreasing was resulted from increasing Paraoxon concentration in deionized water. Because hydolysis of paraoxon ion was blocking an electric field that lead to the accumulation of hole between drain and source electrode reducing.

Acknowledgments

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