

Control of Threshold Voltage in Electrolyte-Gated Organic Transistors by Cations

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Abstract

Electrolyte-gated organic transistors promise for low-power consumption electronics. To enhance the practicability of electrical circuit-based systems, the control of threshold voltage of the transistors is crucial. For achieving the goal of tuning threshold voltage, we herein report the correlation between electrolytes (*i.e.* tetraalkylammonium salts) and electric properties of organic transistors. Our proposed strategy could contribute to realize various systems utilizing electrolyte-based organic devices.

1. Introduction

Electrolyte-gated organic field-effect transistors (EG-OFETs) are some of the intriguing electrical devices in the field of organic electronics, because of their flexibility, robustness, printability, and low-power consumption [1]. These advantages allow for various applications such as e-textiles, radio frequency identification (RFID) tags, and biosensors. Since electrical-circuit properties notably rely on threshold voltage (V_{TH}) of each EG-OFET component in the system [2], tuning methods for V_{TH} should be established. However, reversible control methods of V_{TH} are still in their early stages. In that regard, we have focused on chemical-stimuli based manipulation of electric properties of the organic device. Herein, we demonstrate a systematic control of V_{TH} in the EG-OFET by the difference of chemical structures of cations in an electrolyte solution.

2. Device Fabrication

To investigate the V_{TH} controllability, we fabricated a side-gate structured EG-OFET. High polarizability of an electric double layer (EDL) in the EG-OFET enables the gate terminal of the device to be physically offset from the channel region, means that multi-stacked device structures are not required [3]. In other words, the fabrication process of the EG-OFET is much simpler than that of general solid-state type FETs. Thus, easy-to-fabricate integrated circuits can be realized by employing the planar device structure.

Gold electrodes (=source, drain, and gate) were firstly deposited on a glass substrate. Next, an amorphous fluorinated polymer (=Cytol) was spin-coated and patterned with an

oxygen reactive-ion etching for the formation of a hydrophobic bank layer on the substrate. Subsequently, a π -conjugated polymer (poly{2,5-bis(3-hexadecylthiophene-2-yl)thieno[3,2-*b*]thiophene}, PBTTT) thin-film was formed in the bank region. Importantly, the relationship between V_{TH} and chemical structures of cations was determined by utilizing a series of tetraalkylammonium bromide (TAABr) in 4-(2-hydroxyethyl)-1-piperazineethanesulfonic acid (HEPES) buffer (100 mM, pH 7.4). Electric measurements were performed by using a source meter or a LCR one.

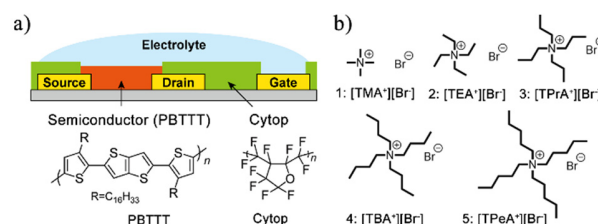


Fig. 1. (a) A schematic illustration of the EG-OFET. (b) Chemical structures of TAABr.

3. Results and Discussion

First, we investigated the basic electrical properties (=transfer and output characteristics) of the EG-OFET with TMABr. As a result, the fabricated device operated reproducibly without hysteresis behavior under low-applied voltage ($< |0.8|$ V) (Fig. 2).

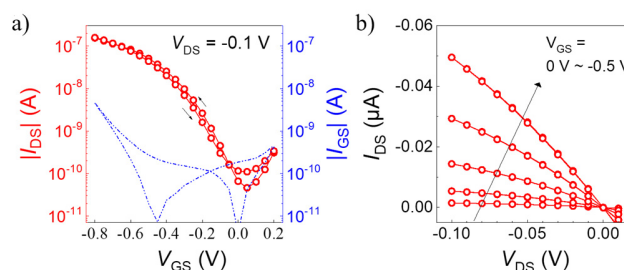


Fig. 2. (a) Transfer and gate-leakage characteristics and (b) output characteristics of the EG-OFET using the TMABr (10 mM) in the HEPES buffer (100 mM) at pH 7.4 at r.t.

To evaluate the V_{TH} controllability, we next examined cation dependency in the electrical properties. Here, we found that the distinct negative shift of transfer characteristics with increasing the alkyl chain length of the TAABr (Fig. 3a). Additionally, we observed the similar behavior with changing the molar ratio of two cations ($=TMA^+$ and $TPeA^+$) (Fig. 3b). The maximum V_{TH} change in Fig. 3b was estimated to be around 0.3 V. These results indicate that the EG-PFET can be systematically respond with altering electrolyte cations.

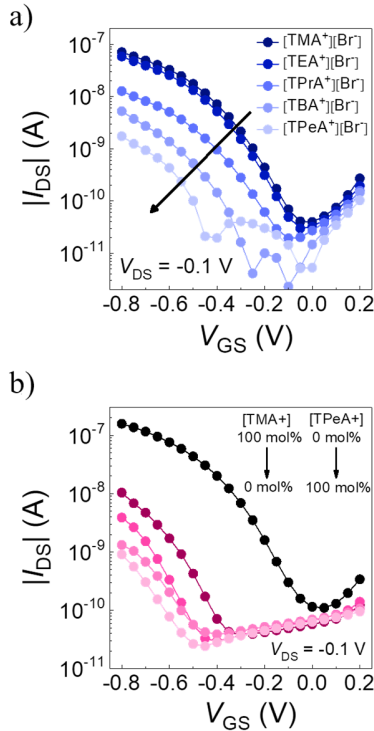


Fig 3. (a) Cation dependency of transfer characteristics of the EG-OFET. (b) Transfer characteristics of the EG-OFET upon changes of the molar ratio between TMA^+ and $TPeA^+$.

To make a deeper discussion of the cation dependency of the EG-OFET characteristics, we measured capacitance in each electrolyte solution. Fig. 4 exhibits V_{TH} as a function of capacitance of cations. As predicted, such electric property systematically depended on the molecular size of cations. This is because the thickness of the EDL is thinned by employing smaller cations [4]. Importantly, the obtained result clearly shows a proportional relation between capacitance and V_{TH} (a correlation coefficient: 0.97). Theoretically, V_{TH} of OFETs can be defined with a flat-band voltage (V_{FB}) at an electrolyte/gate interface. Moreover, V_{FB} can be expressed by the following equation:

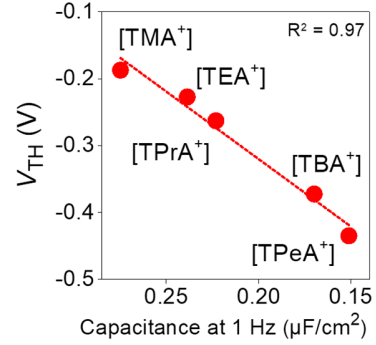


Fig. 4. Correlation between capacitance of electrolyte and V_{TH} . The linear line is the fitting.

$$V_{FB} = \frac{\phi_{MS}}{q} - \frac{Q_{if}}{C_i}, \quad (1)$$

where ϕ_{MS} is the difference between the work function of the gate and the ionic potential of the semiconductor, q is the elementary charge, Q_{if} is charge at the dielectric/semiconductor interface, and C_i is dielectric capacitance. In the case of EG-OFETs, the EDL consisted of cations could be formed at the gate terminal by applying the negative bias voltage [3]. Hence, the V_{TH} shift would be derived from changes in capacitance by altering cationic species.

4. Conclusion

The systematic control of V_{TH} in the EG-OFET has been successfully demonstrated by only changing applied cationic species. This approach could be utilized to achieve various electrical systems based on EG-OFETs. Notably, our proposed chemical-approach for controlling V_{TH} in the EG-OFET is much simpler than other conventional methods [2]. We believe that the obtained expertise is worthwhile for development of EG-OFET based logic circuits in the near future.

Acknowledgements

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