High-mobility, Low-power and Fast-switching Organic Field-effect Transistors with Ionic Liquids

Background

An important challenge in the study of organic field-effect transistors (OFETs) is to realize low-cost, high-mobility, low-power, and fast-switching devices. In this regard, there has been significant interest in developing a new kind of organic transistor with electric double layers (EDLs) of electrolytes (Fig. 1). Recently, it was shown that the EDLs of polymer electrolytes can gate organic transistors and that high-density carriers are injected indeed with the application of small gate voltages. However such devices show relatively large hysteresis, because the high viscosity of the polymer electrolyte prevents the devices from forming the EDLs immediately.

Objectives

To realize the high performance OFETs, this study aims to use ionic liquids (Fig. 2) as the electrolyte layer in the EDL-gated OFETs. An advantage of the ionic-liquid electrolyte is its rapid ionic diffusion and large capacitance. Rapid ionic diffusion of ionic liquids in the OFETs translates into quick-switching devices and the large capacitance into high density of induced charge with minimum gate voltages, meaning that sufficiently large ON current can be achieved even with the switching voltage less than 0.5 V.

Principal Results

We put an ionic liquid electrolyte on top of rubrene single crystals to make organic single crystal field-effect transistors, so that formation of the EDLs in the electrolyte could induce high-density carriers at the surface of the crystal and obtained the following results:

1) Low-power operation

We found that rather large current in the order of μA was generated with the application of less than 0.5 V for both gate voltage V_G and drain voltage V_D, demonstrating the very low-power operation of the organic transistors due to the high-density carrier accumulation at the ionic liquid/rubrene liquid-to-solid interfaces (Fig. 3). Same drain current could be generated with 2 orders of magnitude larger gate voltage in SiO_2 gated devices that are the most common gate dielectrics used for the OFETs.

2) High-mobility

The obtained mobility became as large as 1.0 - 1.2 cm^2 /Vs as a statics of several similarly prepared samples. These values were higher than those ever reported for EDL-gated OFETs and those required for organic flexible displays (0.1～0.5 cm^2/Vs).

3) Fast-switching operation

EDL capacitance of the IL was measured over the range from 0.1 Hz to 1 MHz (Fig. 4). The EDL capacitance of the IL became as large as 11 $\mu F/cm^2$ at 0.1 Hz and remained large even at 1 MHz, demonstrating the fast ionic diffusion in response to the voltage application. Therefore, the EDL-gated OFETs incorporating the IL allowed switching operation at such a high frequency, which none of the previously reported devices do.

Future Developments

It is planned to demonstrate that the use of ionic-liquid electrolytes in organic single- crystal FETs enables high-density carrier doping with minimum gate voltages without sacrificing the carrier mobility. Therefore, the ionic-liquid gating can be a promising technology to realize high-mobility, fast-switching and low-power organic transistors. Owing to varieties of ILs that have been synthesized so far, higher performances are likely to emerge by elaborate search for compounds incorporated in OFETs. Due to the capability of the high-density carrier doping, the present technique is also useful in more basic material sciences such as carrier-density driven phase transition in strongly correlated electron systems.

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Reference

S. Ono, S. Seki, R. Hirahara, Y. Tominari and J. Takeya "High-mobility, low-power, and fast-switching organic field-effect transistors with ionic liquids" Applied Physics Letter 92 (2008) 103313.

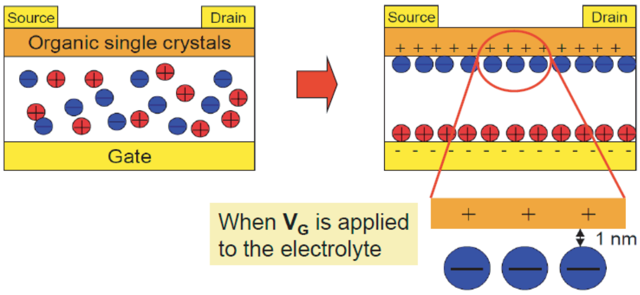

Fig.1 A schematic illustration of the single crystal field-effect transistor with ionic liquid electrolyte (left).

When the gate voltage V_G is applied to the electrolyte, the EDLs are formed after the ionic redistribution (right). Gate electric field is confined only to the EDLs with 1 nm.

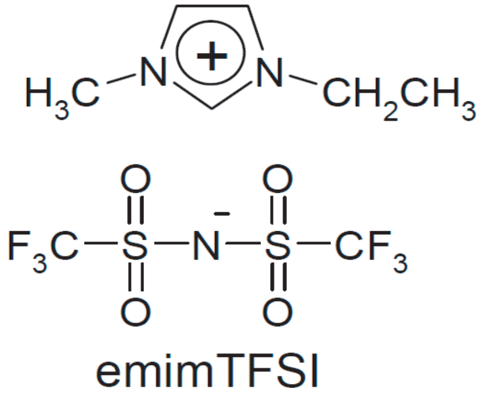

Fig.2 Chemical structure of the ionic liquid used in this device.

The ionic liquid used in this experiment is 1-ethyl-3methylimidazolium bis (trifluoromethanesulfonyl) imide (emimTFSI).

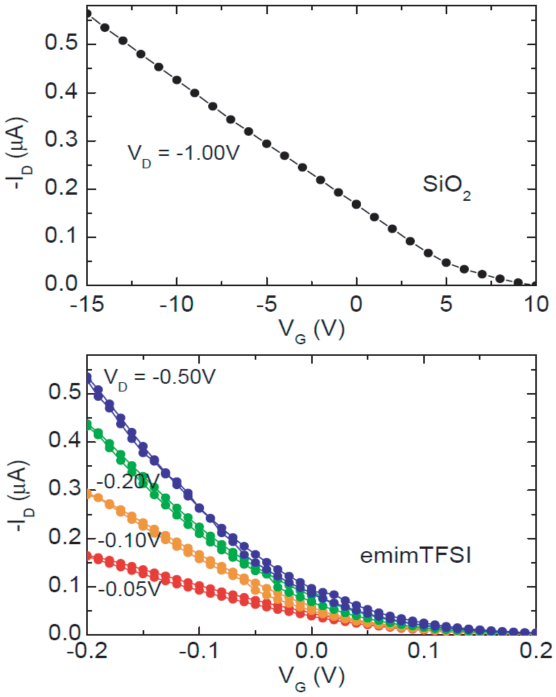

Fig.3 Transfer characteristics (drain current I_D as a function of gate voltage V_G) of the EDL-gated OFETs with ionic liquid (Bottom).

Same drain current in IL gated OFETs can be generated with 2 orders of magnitude larger gate voltage in SiO_2 gated devices (upper).

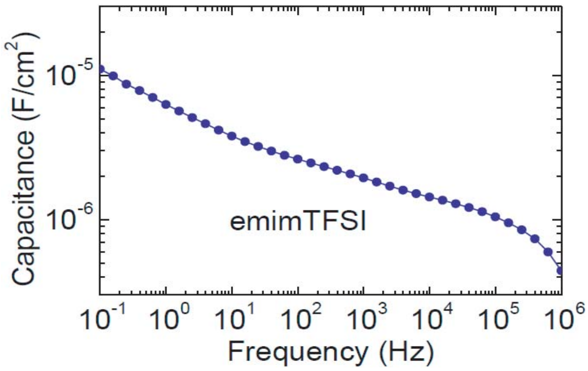

Fig.4 Capacitance of the ionic liquid as a function of frequency measured by the ac impedance technique.

The EDLs are formed even at the high frequency.

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