# Trap-controlled transient carrier transport in organic field effect transistors studied by time-resolved optical second harmonic generation

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### **1. INTRODUCTION**

With a development of high-performance organic semiconductor materials, the electronic devices based on organic materials, such as field effect transistors (FETs) have attracted a lot of research interests. The important applications of the organic FET (OFET) are a driving transistor of organic electroluminescence display and the printed organic radio frequency identification tags. In such applications, OFETs are operated under a transient state, rather than a simple steady state. However, understanding of the device operation of OFET in the transient state is not satisfactory. Carrier transport in a transient state is also strongly affected by the trap of carrier in the channel. To understand and control the trapping states in the transient states is significant for the practical applications.

In the OFETs, device operation is dominated by the injection, accumulation and transport processes of carrier. Among these, transport process is ruled by not only organic semiconductor layer but also insulating layer. However, an adequate control of the carrier transport is not an easy task owing to ambiguities of the carrier trapping at the organic-insulator interface. To control the transport process, an appropriate evaluation of the transport process is also important. Recently, we developed a time-resolved microscopic optical second-harmonic generation (TRM-SHG) technique for visualizing carrier motion in the OFET [1]. Using this technique, we found that transient hole transport in the pentacene **OFETs** with poly(methylmethacrylate) (PMMA) insulator is dominated by carrier trapping [2]. In this presentation, a character of carrier trap in the transient states is studied on the basis of the transient TRM-SHG experiment. The gate-voltage dependence on the transient mobility of the OFETs is discussed on the basis of the TRM-SHG experiment, where the gate voltage is used to pre-fill the trapping sites with holes that are injected from the source and drain electrodes. Pre-filling of trap sites promotes the transient carrier transport, resulting in the increase of the effective mobility.

#### 2. EXPERIMENT

Samples used here were top-contact pentacene FET with SiO<sub>2</sub> and poly(methyl methacrylate) (PMMA) gate insulator. The OFET was operated by application of the pulse voltage to appropriate electrodes. A time delay between pulse applied to the OFET and Q-switch trigger of pulsed laser was changed to perform the time-resolved measurement. For the SHG measurement, the light source was an optical parametric oscillator (OPO) and wavelength was fixed at 1120 nm. Fundamental light was focused on the channel region of the OFET using a microscope objective lens. SHG images from OFET channel were captured with a high-sensitive cooled CCD camera.



Figure 1 Schematic diagram of "pre-filling" experiment. The negative Vg is applied for 20 µs before injecting carriers by positive source pulse.

## 3. RESULTS AND DISCUSSIONS

It was found that the transient hole transport in pentacene FET is significantly different between the devices with the  $SiO_2$  and PMMA insulator. As shown in Fig. 2, the SHG profile has sharp peaks at the front edge of the fields for the device with the PMMA insulator. On the contrary, the profiles are relatively broad and we did not see obvious sharp peaks in the device with the  $SiO_2$  insulator. Moreover, the peak in the PMMA based device moves far slower than that in the  $SiO_2$  one. Such a difference is attributed to a difference in a trapped carrier density in the channel of OFET.



Figure 2 Transient carrier motion in the pentacene FET channel with different insulator.

In order to further clarify the effect of traps on transient carrier transport in the OFETs with PMMA gate-insulator, we carried out the pre-filling experiments. Figure 1 schematic diagram of the voltage pulse application in the pre-filling experiments. Negative gate pulse was applied to the devices before the source pulse. After applying the gate pulse, holes injected from the source and drain electodes partly fill the trap sites (pre-filling effect). Thus, vacant trap sites effectively decrease after applying the prefilling gate pulse.

It is found that the transient carrier transport



Figure 3 Pre-filling voltage dependence of the transient carrier mobility of pentacene FET with PMMA gate insulator.

was strongly dependent on trap-filling condition, pre-filling voltage. Figure 3 shows e.g., pre-filling voltage dependence of the transient carrier mobility of pentacene FET with PMMA gate insulator. To take these data, gate pulse was applied to prefill the traps for 20 µs before applying the source pulse (see Fig. 1). The effective carrier mobility increases with the increase of the pre-filling voltage. These results clearly showed that the effective carrier mobility increases with decrease of the vacant hole trap density, and finally reaches a maximum when all trap sites are filled. From this voltage, effective density of trap states is estimated as  $1.25 \times 10^{12}$  /cm<sup>2</sup> at room temperature. This corresponds to the situation that one trap site shared by approximately 300 is pentacene molecules. In the presentation, temperature dependence of the trap effect will be discussed within the framework of a simple model.

#### References

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