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Effect of carrier trap on the electron transport in pentacene FET observed by the time-resolved microscopic SHG measurement

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1. INTRODUCTION

Electronic devices using organic materials have attracted a lot of research interests. Organic electroluminescent (EL) devices are now commercially available, and organic field effect transistor (OFET) is the next target for the practical use [1]. However, understanding of the operation mechanism in the OFET is still insufficient. For Si and other inorganic semiconductors, intentionally doping precisely determines the type of majority carrier and carrier density in the semiconductors, and thus the device properties can be fully controlled. In contrast, adequate control of the device characteristics is not an easy task in organic devices owing to the ambiguities of metal-organic and organic-insulator interface. For the OFETs, device operation is ruled by the injection, accumulation and transport processes of carrier. Appropriate evaluation and control of these processes are of great importance to understand the device operation.

On the basis of electric field induced SHG, we have developed a procedure for evaluating electric field distribution in the organic devices [2,3] and a time-resolved measurement for visualizing a carrier motion in organic thin film transistors [4]. Since carrier is the source of the electric field, carrier motion can be traced by following the time-evolution of the electric field distribution in the devices. Direct observation of carrier enables us to evaluate intrinsic carrier mobility in the devices. On the one hand, contact between electrode and organic materials can be also discussed by monitoring the electric field formed near the interface. Thus, the TRM-SHG measurement becomes a powerful tool to evaluate the injection, accumulation and transport processes individually.

In this presentation, electron injection from gold electrode into pentacene was investigated by the TRM-SHG imaging. Smooth injection and transport of holes is verified for pentacene FET with Au electrode. In contrast, TRM-SHG results clearly indicated the presence of electron injection from the high-work function metal into electrode, though after injection, electron motion was stopped in the channel and cannot contribute to the conduction. Such a difference is attributed to a higher trapped carrier density in the channel of OFET. Theoretical calculation based on the multiple trapping and releasing model successfully reproduced such a carrier dynamics in these devices.

2. EXPERIMENT

Samples used here were top-contact pentacene FET (channel length was 50 mm). Thickness of the insulating layer (SiO2) and pentacene were 500 nm and 100 nm, respectively. Before the pentacene deposition, 100 nm thick of poly(methyl methacrylate) (PMMA) layer was spin-coated. In the experiment, OFET was operated by application of the pulse voltage. Pulse voltage was applied to the source electrode, and drain and gate electrodes were connected to ground. 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

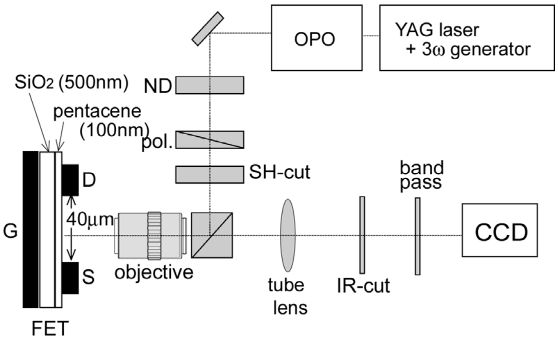

Fig.1 Optical setup for the SHG imaging measurement and the FET structure.

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 (see Fig. 1).

3. RESULTS AND DISCUSSIONS

Figure 2 represents the SHG images from OFET channel captured with different delay times. To take these images positive pulses were applied to the source electrode. Here, source electrode is defined as an electrode from which carriers are injected by the applied voltage pulse. As shown, SHG peak moves rapidly from the source to the drain electrode with an increase of delay time. For hole injection, the injected holes from the source electrode spread immediately in the FET channel. After carrier injection, carriers adequately accumulate in the channel. Sufficiently accumulated charges in the channel form the space charge field that cancels out the source field so that no SHG signal generates from the edge of the source electrode.

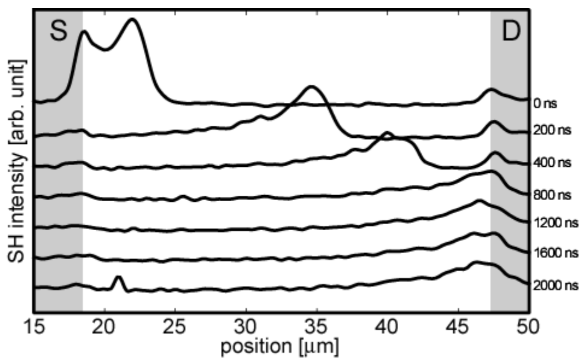

Fig.2 Change in the SH intensity distribution for hole injection.

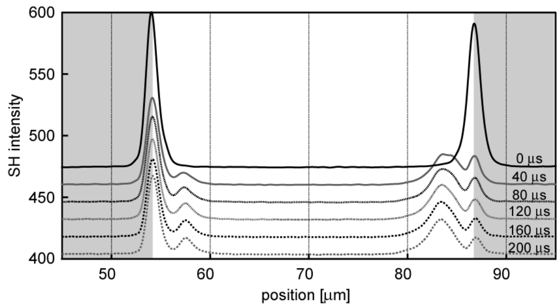

Fig.3 Change in the SH intensity distribution for electron injection.

Fig. 3 represents SHG images from OFET channel with different delay times under the negative pulse application. It was found that the emission band of the SHG slightly moved from source electrode as shown in figure. This result indicates that electron injection was actually allowed from the Au electrode to pentacene film. Interestingly, after the electron injection, motion of the emission band of the SHG stopped immediately near electrode (typically few μm from the edge of electrodes). These results imply that injected electrons were trapped near the electrode in the FET channel. To quantitatively support this physical explanation, we modeled the carrier transport in the OFET as a multiple-trapping and releasing (MTR) process under the presence of the traps. As a result, the peak in the channel with high carrier density moves far slower than that in the channel with low carrier density. The main characteristics of these electric field profiles agree well with the experimental observations. In the presentation, quantitative parameter such as amount of trapped carrier will be also discussed.

References

[1] H. E. Katz, Chem. Mater., **16** (2004) 4748.
[2] T. Manaka, E. Lim, R. Tamura, D. Yamada, and M.Iwamoto, Appl. Phys. Lett., **89** (2006) 072113.
[3] T. Manaka, M. Nakao, D. Yamada, E. Lim, and M. Iwamoto, Opt. Express, **15** (2007) 15964.
[4] T. Manaka, E. Lim, R. Tamura, and M.Iwamoto, Nature Photon., **1** (2007) 581.