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Charge modulated reflectance measurement for probing carrier distribution in the pentacene field effect transistor

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1. INTRODUCTION

Organic electronic devices, such as thin film transistors (TFTs) and light emitting diodes (LEDs), have attracted a lot of research interests along with the development of high-performance materials. Recent trend in the research on organic devices is focused on the fabrication of the practical ones based on easy and low-cost process [1]. However, understanding of the operation mechanism in the OFET is still insufficient. The importance of fundamental research is being recognized to improve the performance of organic devices. Since current flowing in the materials is expressed as $J=en\mu E$, evaluation of each parameters, i.e., carrier density (en), mobility (μ) and electric field (E), is of great importance to discuss the device operation from a fundamental point of view. Nevertheless, these contribution cannot be discriminated by the simple electrical measurements.

Recently, we developed a procedure for evaluating electric field distribution in organic thin-film transistors (OTFT) on the basis of the electric field induced SHG (EFISHG) measurement[2,3]. Using this method, the electric field distribution in OFET could be evaluated with high spatial resolution. Organic device operation is dominated by the injected carriers, because intrinsic carrier density in organic materials is low. Such injected carriers change the optical response of the materials. For instance, formation of the anionic or cationic state of molecule due to carrier injection reduces the original optical absorption of the neutral molecule. In the π-conjugated polymers, it is known that polaron absorption is induced by the injected carriers. Accordingly, charge modulation spectroscopy (CMS) has been developed to observe the carrier behavior in the organic devices.

In this presentation, microscopic charge modulated reflectance spectroscopy was conducted to study the injected carrier distribution (n) in pentacene FET. Signal distribution along channel is clearly good agreement with the carrier distribution calculated on the basis of a simple carrier transport model. In combination with the EFISHG mentioned above, each parameters in $J=en\mu E$ is discriminately evaluated.

2. EXPERIMENT

Samples used here were top-contact pentacene FET (channel length was 80 μm). Thickness of the insulating layer (SiO_2) and pentacene were 500 nm and 25 nm, respectively. Before the pentacene deposition, 100 nm thick poly(methyl methacrylate) (PMMA) layer was spin-coated. Conductive channel in the OFET is known to be formed within quite thin region close to a pentacene/insulator interface. Thus, the thinner pentacene layer is suitable for observing signal modulation effectively, because modulation of the optical signal due to

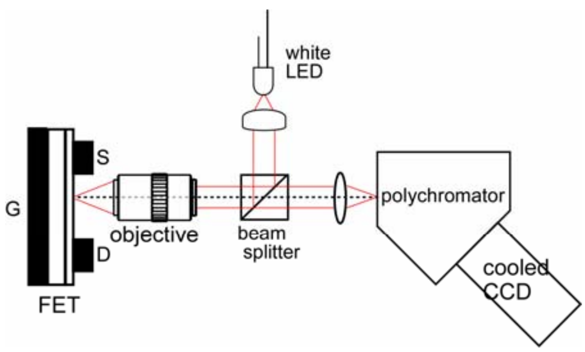

Fig.1 Optical setup for the microscopic CMS measurement and FET structure.

carrier injection is dominated in the conductive channel. Figure 1 illustrates the optical setup for the present experiments. White light-emitting diode (LED) was used as a light source. As shown in the figure, impinging white light was uniformly illuminated across the FET channel with epi-illumination. Spot size was approximately 10 μm. External voltages were applied using source meters (Keithley: 2400) to observe the charge modulation of the optical signal. All measurements were performed in laboratory ambient atmosphere.

3. RESULTS AND DISCUSSIONS

Figure 2 shows the charge modulated microscopic reflectance spectrum measured at the center of the channel. The reflectance spectrum (not modulated spectrum) of actual device deviates greatly from the typical absorption spectrum of a pentacene film due to the multiple reflection in the device. Nevertheless, the eflectance spectrum could be well reproduced on a basis of the multi-layer optical analysis taking into consideration the optical constant of all composed layers. Modulated spectrum was measured under the negative gate condition and was corrected with respect to the off-state (V_{gs}=V_{ds}=0 V) one, namely, signal modulation accompanied with voltage application is demonstrated. As shown, signal modulation was clearly observed under the negative gate application. Holes are injected and accumulated at the interface in the negative gate condition. On the other hand, no modulation was observed (dashed line in Fig. 2) under the positive gate application, indicating the use of Au top-electrodes and measurement in ambient atmosphere suppressed the n-type operation. This implies that reflectance modulation is due to the charge injection.

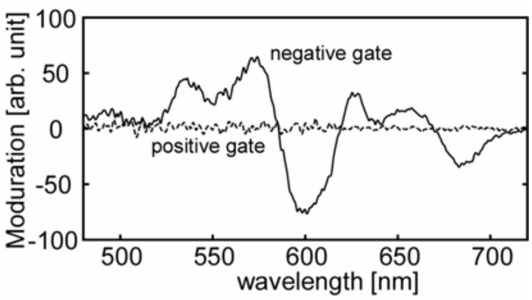

Fig.2 Charge modulated microscopic reflectance spectrum in the pentace FET under the negative and positive gate.

Since peak intensity at around 600 nm linearly increases with the negative gate voltage, mapping signal modulation at around 600 nm enables us to discuss the carrier density distribution in the channel. Figure 3 shows modulated signal intensity at a spot position of drain edge, center of channel and source edge, together with carrier distribution obtained on a basis of a transmission line theory (dashed line in Fig. 3) [4]. In the figure, signal modulations at 600 nm are plotted, and signal was measured in the on-state of FET (V_g = V_d = -100 V). As shown in the figure, signal intensity close to drain electrode decreased compared with the source electrode. In the on state, drain field drifts the holes accumulated in the channel in the direction from source to drain electrode. This results in the lower carrier density in the FET channel near the drain electrode. Accordingly, microscopic CMS measurement successfully evaluated the carrier distribution in the devices.

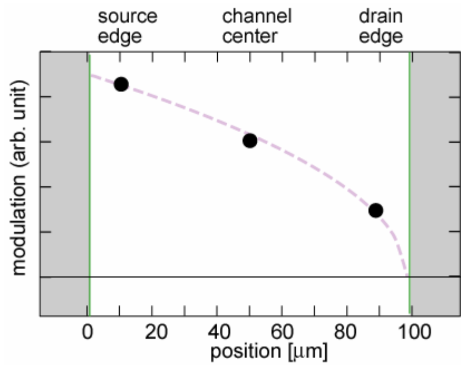

Fig.3 Charge modulated microscopic reflectance spectrum at source edge, center of channel and drain edge.

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