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Electric field distribution in organic field effect transistor evaluated by microscopic second harmonic generation

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1.INTRODUCTION

Recently, there has been an increase in the research interest in organic semiconductors along with the successful preparation of film with high mobility. As well as the research for practical use, the importance of the basic research such as mechanism and physics of OFET is being recognized to improve the device performance. In actual, device physics of OFET is not so clear in comparison with that of inorganic FET, e.g. semiconductor FET device physics, at this stage.

It is known that the dominant carriers in pentacene FET are holes injected from the source electrode [1,2], not accumulated charges from bulk pentacene. Under the establishment of thermal equilibrium as in the inorganic devices, carrier distribution is determined by the potential in the devices. Poisson's equation describes the potential charge relation in semiconductor. These imply that the information about potential distribution is the key issue to discuss the device operation of the Si devices. However it is reasonable to consider that the thermal equilibrium is not established over the whole devices in the OFET. In spite of the situation that the thermal equilibrium is established or not, the equation expressing current density in the material $J=en\mu E$ is always valid. Thus, to get the field distribution directly rather than the potential distribution is more fundamental way to discuss the device operation in OFET.

In our previous paper, we proposed a novel technique to monitor the channel formation process in OFET by the macroscopic SHG measurement [3]. Roughly speaking, change in the field distribution due to the injected charge decreases an effective intensity of the SHG signal. These previous results tell implicitly us that the SHG method can be used to evaluate the field distribution in the OFET channel. In this presentation, we extended the system to acquire the SHG signal from micro-spot. This extension enables us to evaluate the electric field distribution in the FET channel directly.

2. EXPERIMENT

Samples used here were top-contact pentacene FETs. Before deposition of pentacene, highly doped-Si substrates covered with SiO_2 layer of 500 nm thickness were immersed in toluene solution of octadecyltrichlorosilane (OTS) to improve the on/off ratio. Approximately 100 nm thick pentacene layer was deposited on the SiO_2 surface, and source and drain electrodes were deposited on the pentacene surface. Channel length and width were 50 μm and 2 mm, respectively. Figure 1 shows the optical setup for the microscopic SHG measurement. The light source was an optical parametric oscillator (OPO) and wavelength was fixed at 1120 nm where the SHG peak induced by DC electric field located [4]. Fundamental light was focused on the channel region of the OFET using an long working distance objective lens, and the spot size of laser is approximately 20 μm. In this

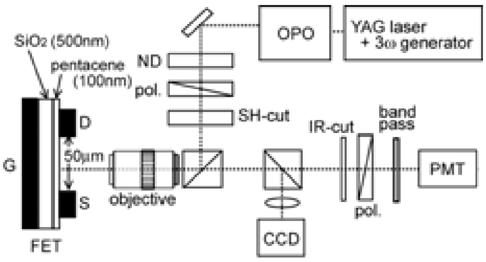

Fig. 1 : Setup for the SHG measurement.

configuration, polarization direction of the light was chosen in that the direction corresponds to the channel direction.

3. RESULTS AND DISCUSSIONS

Figure 2(a) shows the SHG intensity profile in the FET channel. In this measurement, region from 20 μm to 70 μm corresponds to the channel. Open and filled circles represent the SHG intensity at each spot position at off and on state of the FET, respectively. At off state, remarkable SHG signal was observed at drain side as shown in the figure. After turning on the FET, i.e., applying Vg, strong SHG signal observed at the drain edge clearly decrease. SHG intensity at drain side is extremely large compared with that of source side. Such enhancement of the SHG signal at drain side is reasonably understood taking into account the electric field distribution in the channel. SHG intensity profile can be considered as a convolution of the beam pattern of the laser and the actual electric field distribution According to the finite element calculation, field concentration is expected at the drain side due to the specific electrodes configuration. Fig.2(b) shows the estimated SHG profile taking into account the field distribution. In this figure, open circles represent the observed SHG intensity for off state. As shown in the figure, theoretical estimation well reproduces the experimental result, indicating that field distribution in off state can be regarded as the Laplace field. This implies that the insulating nature of the OFET channel at off state, i.e., low carrier density in the devices at off state. The low carrier density is an intrinsic nature of the organic

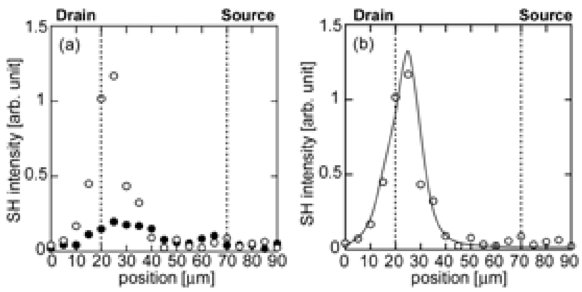

Fig. 2 : (a)SHG intensity profile in the FET channel. Filled and open circles corresponds to the off and on state of the FET. (b) estimated SHG profile.

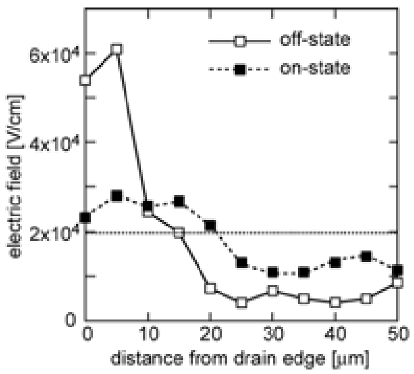

Fig. 3 : Evaluated electric field distribution in the FET channel from SHG intensity profile.

materials and the SHG measurements also support this character of the OFET.

To get the electric field distribution from the SHG profile is just a deconvolution problem. Here, δ-function distribution is approximately used as the intensity profile of the laser to evaluate the electric field distribution. Figure 3 shows the evaluated electric field distribution in the pentacene FET channel. Interestingly, electric field distribution changes its profile smooth at on state. Taking into consideration only Laplace field formation, the concentration of the electric field occurs source edge at on state. The inconsistency reminds us the operation mechanism of the OFET. After turning on the FET, carriers are injected from electrode and accumulated at the channel, and these carriers change the electric field distribution. Thus, change in the field distribution due to the injected charge is the most reasonable explanation for the observed SHG profile at on state. Anyhow, the SHG microscopy becomes a powerful tool for the direct observation of the electric field distribution in the devices. Potentiality of this method is also discussed in the presentation.

References

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