Probing electric field distribution of P3HT in ITO/PI/P3HT/Au by using EFISHG measurement

Ryo Miyazawa, Dai Taguchi, Takaaki Manaka, Mitsumasa Iwamoto

Department of Physical Electronics, Tokyo Institute of Technology
2-12-1 O-okayama, Meguro-ku, Tokyo 152-8552, Japan
Phone: +81-3-5734-2191 E-mail: iwamoto@pe.titech.ac.jp

1. Introduction
In recent years, organic electronics have demonstrated great potential in various applications [1]. Taking advantage of the use of easy and low-cost preparation method, many organic devices have been proposed. Among them are organic field effect transistors (OFETs), and much effort has been made to efficiently derive OFETs, by the use of novel organic conducting materials [2], by the modification of gate insulator surface, by the use of top-contact device structure, and so forth. Understanding carrier motions in organic materials is fundamental issue in physics and in electronics and electronic engineering. However, further understanding is necessary for practical applications. In our group, we have developed a method for direct evaluating the static and transient electric field in the organic materials, respectively, by electric-field-induced second harmonic generation (EFI-SHG) and time-resolved microscopic SHG (TRM-SHG) measurements [3,4]. These direct measurements enable us to distinguish carrier transport process and injection process easier than indirect measurement such as time-of-flight (TOF). We have observed carrier behavior in poly(3-hexylthiophene) (P3HT) of Au/P3HT/Polyimide/ITO by using SHG measurements. The results showed that photoillumination strongly affected the MIS devices operation. Previously, we revealed that electrons generated by photo-illumination were trapped in the PI layer. However, the devices operations under illumination are still not clear. In this paper, we observed internal electric field distributions in the P3HT layer by using EFI-SHG measurements for investigation of MIS devices operation under photo-illumination.

2. Experiment
Figure 1 shows the schematic diagram of the MIS structure. Au and indium tin oxide (ITO) were used as semi-transparent electrodes. The Au electrode was 20 nm in thickness. Polyimide (160 ± 20 nm thickness) was yielded by thermally imidized polyamic acid derived from cyclobutane 1,4-dianhydride and 2,2-bis(4-aminophenoxyphenyl)propane(CBDA-BAPP) (PI). PI was a good insulator, and leakage current across MIS diodes was less than 0.013 A/m² at ±30 V. The P3HT layer (300 nm in thickness) was deposited using a spin coating method. Figure 2 portrays the experimental setup for EFI-SHG measurement. The light source was Nd:YAG laser coupled with optical parametric oscillator. The p-polarized light (1060 nm) impinged on the sample from ITO or Au side at the angle of 45°, and transmitted light through monochromator (530 nm) was detected by using a photomultiplier tube, where the voltage dependence of the SHG signal from P3HT (not Polyimide, Au and ITO) was intensively observed at 530 nm [5]. The intensity of SHG signal I_{SHG} is proportional to \| \chi^{(3)}(0) E_{(0)} E_{(x)} \|^2. Here, E_{(0)} is the internal static electric field in P3HT and E_{(x)} is the electric field intensity of incident laser. \chi^{(3)} is the third-order susceptibility tensor dependent on the light wavelength and is determined by intrinsic material property. Therefore, the I_{SHG} from P3HT layer is detected selectively even when P3HT layer is located inside the multiple layer system. Impedance measurements were also conducted using an impedance analyzer (Solatron, Model 1286). The applied AC amplitude and frequency were 0.1 V and 1 kHz, respectively. All measurements were conducted in N₂ atmosphere.

3. Results and discussion
Figure 3 shows the C-V characteristics in dark and under illumination. Under illumination, large hysteresis was observed, indicating that electrons generated by photo-illumination were trapped in the PI layer [6,7]. Increasing of minimum capacitance was observed [8]. This phenomenon can be explained by using a model illustrated in...
Fig. 4. Under photo-illumination, photo-carriers were separated by internal electric field in the P3HT layer, and separated electrons moved to the PI layer and were trapped in its layer. Electron trapping decreased internal electric field in the P3HT layer, accompanying with decreasing the depletion layer. The trapping continued until electric field at P3HT/PI interface decreased to a low value which was inadequate to separate the photo-carrier in the P3HT layer.

4. Conclusions
We investigated the C-V characteristics under photo-illumination and studied the electric field distribution in the P3HT layer by using EFM-SHG measurement. The C-V characteristics showed that minimum capacitance increased under photo-illumination. The EFM-SHG measurements showed that electric field at Au/P3HT interface decreased to zero after photo-illumination, while electric field at P3HT/PI interface decreased, but not zero. We also showed that the proposed mode illustrated in Fig.4 account for the results of C-V and EFM-SHG measurements.

Acknowledgements
A part of this work was supported by the Grants-in-Aid for Scientific Research, JSPS (Numbers 20656052 and 19206034).

References