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Observation of Electric Field in Tetracene Field-Effect Transistor Using Optical Second Harmonic Generation

Yuki Ohshima, Hideki Satou, Hideki Kohn, Takaaki Manaka, and Mitsumasa Iwamoto*

Department of Physical Electronics, Graduate School of Science and Engineering, Tokyo Institute of Technology,
2-12-1 O-okayama, Meguro-ku, Tokyo, 152-8552, Japan
*E-mail: iwamoto@pe.titech.ac.jp

1. Introduction

Organic electronic devices, such as organic field-effect transistors (OFETs) and organic light-emitting diodes (OLEDs), have called our attention since the discovery of high-mobility organic materials. In these devices, injected charges make a main contribution to the electric conduction. For example, holes and electrons injected from two different electrodes recombine in an emission layer in OLEDs [1,2]. The injected charges form a space charge field and this complicates our understanding of the device operation, especially, of organic electroluminescent (OEL) device, e.g., OLED operation, where both carrier behaviors of electrons and holes must be considered at the same time. For fully understanding device operation, such as carrier transport in active layer of organic devices, information on the electric field distribution is needed.

OLEDs have a two-electrode system, i.e., metal-insulator-metal (MIM) structure. However, it is difficult to probe the electric field profile in that system owing to the sandwich structure. On the other hand, a three-electrode system device such as OFET with a planar structure (see Fig.1(a)) enables us to probe the electric field distribution in the active layer because of a wide spacing between source (S) and drain (D) electrodes. Furthermore, gate electrode is available to regulate injected carriers motion. For using such three-electrode system, the enhancement of OEL has been reported under device operation [3]. This motivated us to study the electric field profile during OEL in electroluminescent materials, tetracene, etc., using a FET structure. Our final interest lies in the observation of carrier behavior during OEL by detecting the space charge field, and we are also paying attention to AC voltage in our study.

In our previous study, using tetracene FET by applying DC bias field superposed with AC electric field [4], we argued that a space charge field formed by injected charges made a significant contribution to the carrier injection leading to the OEL [5]. However, we could not directly show the presence of the space charge field formed at the DC biasing condition. We have been developing a method using electric field induced optical second harmonic generation (EFI-SHG) for probing the electric field formed in organic materials, and could show the electric field distribution as we as carrier propagation in pentacene FETs. In the present study, we use this technique to show the space charge field formation in the tetracene FETs. However this is not so simple, because there is a possibility that incident laser enhances photoluminescence (PL) from tetracene owing to the two photon absorption process. For probing the electric field using EFI-SHG signals, we have to separate it from PL.

EFI-SHG is generated as a signal with a double-angular frequency of the incident laser light from the tetracene in the presence of electric field. On the other hand, PL is generated at the wavelength of about 540m, without depending on the wavelength of incident laser light. This provides us an opportunity to distinguish the two signals. In the present study, we evidently demonstrate that the EFI-SHG could probe the electric field formation in the tetracene FETs.

2. Experiment

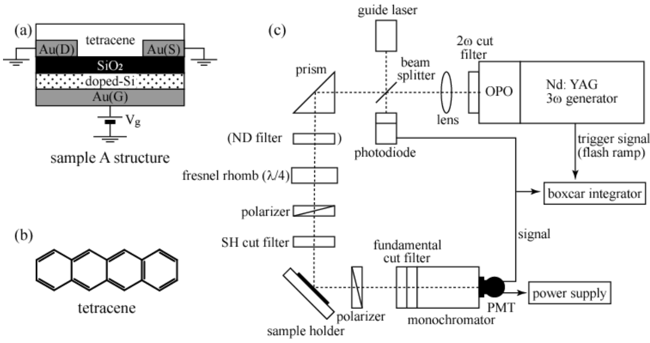

Fig. 1 Experimental Setup for SHG spectrum

We prepared two kinds of tetracene FET, A; bottom-contact type OFET with interdigital Au source and drain electrodes, where the channel length and width are 50μm and 11cm, respectively (Fig. 1(a)), B; top-contact type OFET with Ag source and drain electrodes, where channel length and width are 30μm and 3mm. Tetracene and electrodes were evaporated in a vacuum less than 4×10^{-6} Torr. The thicknesses of tetracene and source-drain electrodes were adjusted to 200nm and 100nm, respectively using a quartz crystal microbalance (QCM).

Figure 1(c) shows the experimental setup for SHG spectrum measurement. Using YAG (Yttrium Aluminum Garnet) laser used with THG (Third Harmonic Generation) crystal and OPO (Optical Parametric Oscillator), incident laser was prepared at variable wavelengths. SHG was detected by photomultiplier tube (PMT) with boxcar integrator at incident laser wavelength in the region from 800nm to 1100nm. The detected light was selected from 400nm to 550nm by monochromator, where Vg at Fig.1(a) were 100V and 0V. Note that in this condition, only Laplace field formation was confirmed [6], i.e., no carrier was injected.

We also carried out the SHG image observation by using a CCD image sensor as a detector, by removing the monochromator and PMT. The incident laser wavelength was chosen as 860nm, and the generated SHG image, corresponding to the electric field distribution, was recorded. Note that, in this experiment, we focus on the electric field formed at 0 sec, after applying electric field. The SHG images at Vg = 150 V and 0 V were compared.

3. Results and Discussions

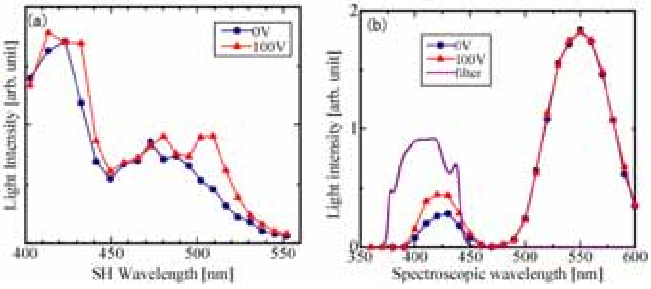

Fig. 2　SHG spectra from tetracene FET

Figure 2(a) shows the SHG spectrum with (triangle) and without (circle) Vg. The wavelength is displayed as detected light wavelength (half of the incident wavelength). We could easily observe the spectrum peak induced by external electric field around the wavelength of 430nm and 510nm. These are candidates of EFI-SHG, but it is possible that a two-photon photoluminescence (TPPL) is observed. To distinguish SHG and TPPL, using the incident light with a wavelength of 860nm and we measure the enhanced signals in the region from 350nm to 600nm by monochromator (see Fig. 2(b)). The peak at 430nm is the half wavelength of incident light and changes with external electric field, i.e., EFI-SHG, while the peak at 540nm does not show the external electric field dependence and corresponds well to the intrinsic photoluminescence wavelength [7], i.e., TPPL process. The solid line indicates the transmission spectrum of interference filter to select the EFI-SHG in SHG image experiment.

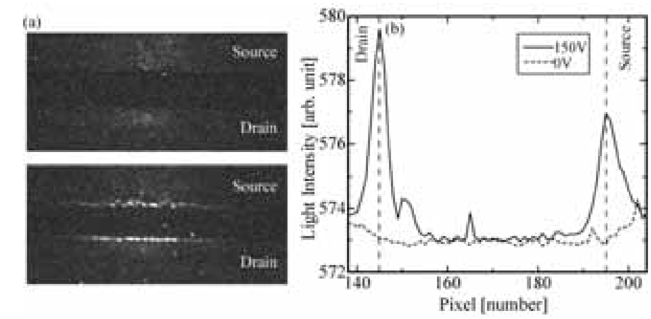

Fig. 3　SHG image in the channel region

Figure 3(a) shows the SHG signal image in the channel region of tetracene FET. SHG was observed from the edge of the source and drain electrodes at Vg=150V. Figure 3(b) shows the vertical cross section of the Fig.3(a). An evident difference of the signal between Vg=150V and Vg=0V, indicates that the signal was induced by electric field. In addition, this electric field is the parallel to the tetracene thin film. From these results, we could evidently confirm the presence of electric field around the sour and drain electrodes, and concluded that EFI-SHG is available for detecting space charge field formed in tetracene FET caused by space charge field.

4. Conclusion

We observed electric field in tetracene FET without carrier injection, i.e., Laplace field. The observed light was free from TPPL using optical interference filter. The experimental method used here could be available to observe the electric field in the tetracene under EL.

Acknowledgement

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