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Visualization of charge activities at the semiconductor/insulator interface of OFET during operation by SFG spectroscopy

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【Abstract】 In our work, being aimed at clarifying the mechanism of charge transport in organic field-effect transistors (OFET) during operation and furthermore designing new OFET with higher performances, interfaces of OFET are studied by sum-frequency generation (SFG) spectroscopy. The effect of drain voltage on SFG spectra of OFET is obtained. A bias distribution of SFG intensities at 3000 cm^{-1} between source and drain electrodes caused by charge transport is obtained. Charge activities at the semiconductor/insulator interface of OFET during operation are preliminary mapped by SFG spectroscopy.

【序】 OFET have developed a lot since 30 years ago for their industrial applications such as displays and mechanical sensors[1]. Studying interfaces of OFET where charge transport occur is a motivating topic for good device performance[2]. Although theoretical simulation can be used to elucidate charge transfer at interfaces of OFET[3], it is problematic to experimentally observe it for lacking of a highly surface-selective analytical method. Second harmonic generation (SHG) and SFG, as inherently surface-selective methods[4], have been utilized into studying interfaces of OFET since 2006 while electric-field was induced[5-10]. Among these work, visualization of charge accumulation in OFET is rarely intriguing because it provides a two-dimensional XY-map and thus a complete image of charge activities in the conducting channel of OFET[7, 9]. However, charge transport at interfaces of OFET that essentially determines the device performance has not been visualized. In this work, by using SFG spectroscopy with stepping motors installed, we obtained the effect of drain voltage on SFG spectra of OFET, a bias distribution of SFG intensities at 3000 cm^{-1} from source to drain electrodes, and a 4.0×4.0 mm XY-map of charge activities at the semiconductor/insulator interface of OFET during operation.

【方法 (実験・理論)】 A top-contact bottom-gate OFET was constructed with two gold electrodes of 30 nm thick, a 50-nm-thick layer of 2,7-dioctyl[1]benzothieno[3,2-b]benzothiophene (C8-BTBT), and a silicon substrate with a 200-nm-thick layer of SiO_2 coated above as the gate dielectric. The length/width for a channel is 1000/1000 µm. An SFG spectrometer is consisted of a picosecond laser (Ekspla, PL2231-50) of 50 Hz repetition rate, a harmonic unit (Ekspla, SFGH500-2H), and an optical parametric generation unit (Ekspla, PG501-DFG1P). The output energies of lasers were controlled at the minimum conditions to avoid sample damage. The polarizations were set in PPP during measurements. The incident angles for visible and infrared beams were 65° and 55°, respectively. The SFG spectra were measured at the channel center. A precision source/measure unit (Keysight, B2902A) was induced to the SFG spectrometer to apply gate and drain voltages into OFET. The scanning steps were 0.1 mm for the distribution of SFG intensities and 0.2 mm for the XY-map. The plane of visible, infrared and SFG beams is parallel to that of source and drain in the SFG spectra measurements but perpendicular in the distribution of SFG intensities and the XY-map measurements. The resolutions in X and Y directions are 0.2 mm and 0.1 mm, respectively.

【結果・考察】Whereas the effect of applying a V_g of −30 V on the SFG spectra caused by charge accumulation was discussed elsewhere[9], that of applying a V_{ds} of −50 V on SFG spectra in alkyl chain region of C8-BTBT in OFET is obtained in Fig. 1. The SFG spectra shape does not change as a V_{ds} of −50 V is applied, showing that there is no obvious change for the orientation of the CH_3 group of C8-BTBT at the interfaces during operation. However, the SFG background intensity decreases while a V_{ds} of −50 V compared to that of only applying a V_g of −30 V, because charges accumulated at the channel center transport away, resulting in a correspondingly decreased electric field.

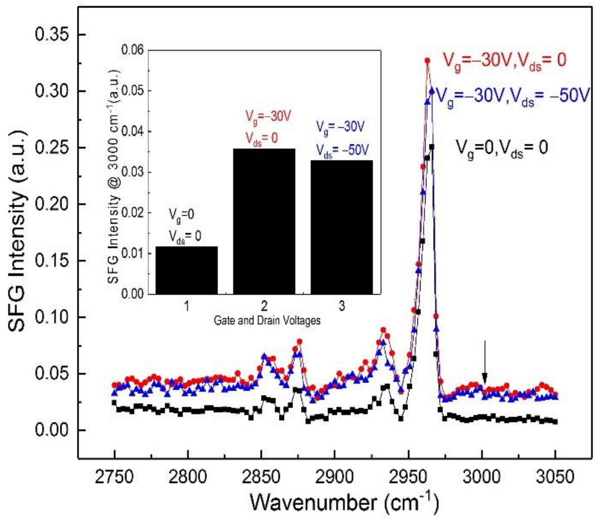

Fig. 1. The effect of applying a V_{ds} of −50 V on SFG spectra of OFET in the alkyl chain region

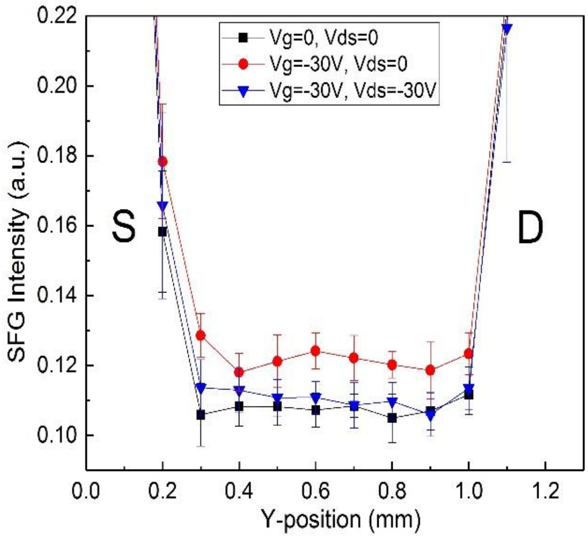

Fig. 2. A distribution of SFG intensities at 3000 cm^{-1} from source to drain electrodes while applying different V_g and V_{ds}

A distribution of SFG intensities at 3000 cm^{-1} (see the arrow in Fig. 1) from source to drain electrodes while applying different V_g and V_{ds} is obtained. As shown in Fig. 2., applying a V_g of −30 V and V_{ds} of −30 V into OFET, the SFG background intensity decreases entirely all over the channel, compared with that in a state of charge accumulation when only a V_g of −30 V is being applied. Additionally, a nonuniform distribution of SFG intensities is also observed between source and drain electrodes, which is caused by a bias distribution of charges in the channel between these two electrodes while a V_{ds} of −30 V is being applied.

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