Probing and Control of Surface Polarization Phenomena in Molecular Films for Organic Electronics

Mitsumasa Iwamoto

Department of Physical Electronics, Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro-ku, Tokyo152-8552, Japan
iwamoto@pe.titech.ac.jp

Abstract : Orientational ordering of polar molecules and excess charges at the interface are main origins of surface polarization. For organic electronics, probing and control of these two surface polarization phenomena are key issues. In this presentation, I report a novel electrical measurement that can directly probe orientational dipolar motion in surface monolayers by Maxwell-displacement-current, and also report a novel optical technique that allows carrier motions in organic materials by measuring the optical second harmonic signals activated by the electric field. Then I discuss how the control of dipolar motions and carrier motions are linked to organic electronics applications such as organic field effect transistors.

Key Words : Surface Polarization, MDC, EFISHG, OFET

1. Introduction

Organic materials have attracted much attention in electronics. Successful preparation of films with high mobility and high electrical conductivity has motivated us to study organic devices such as organic field effect transistors (OFETs) [1]. Similarly, successful preparation of organic mono-molecular films such as self-assembly films, Langmuir-Blodgett films, etc. has motivated us to study electronic devices operating at molecular level [2]. In these devices, understanding of nano-interfacial electrostatic phenomena, i.e. surface polarization phenomena, is of great importance [1,2]. Orientational ordering of polar molecules, displacement of electrons at the metal-film interface, and accumulation of carriers at the interface are origins of surface polarization phenomena [3]. Thus the establishment of theory and experiments related to these phenomena is important. Paying attention to the orientational alignment of polar molecules, the author has been developing a Maxwell -displacement-current (MDC) measuring technique coupled with optical second harmonic generation (SHG) measurement [4]. Furthermore to study the dipolar energy effect on the two-dimensional domain shapes, Brewster angle microscope (BAM) technique has been added [5]. Note that, using these techniques, a set of orientational order parameters for analyzing surface dipolar structures are completely obtained. Interestingly, theoretical and experimental studies revealed that domain shapes must be quantumized [6-8]. This finding gives us a hint for future organic electronics.

On the other hand, paying attention to nano-electrostatic phenomena due to excess charges, the author has been employing a Kelvin-probe surface potential measurement as well as optical SHG measurement, and could demonstrate the space charge effect on the organic device operation such as single-electron-tunneling phenomena [9,10]. Our recent study reveals that SHG well probes the electrostatic phenomena including carrier injection, trapping, and transport in OFET [11-16].

In this presentation, I will summarize nano-interfacial electrostatic phenomena of organic films. Then as an example, I will demonstrate carrier motions in OFETs probed by SHG measurement.

2. Surface polarization due to dipolar molecules

Using orientational order parameters S_n (n = 1, 2, and 3) specified by the Legendre polynomials, P_n (cos') (n = 1, 2, and 3) with tilt angle, surface polarization induced by dipolar polarization is described [2]. Among them, non-zero S_1 and S_3 specify the unique surface polarization such as spontaneous and non-linear polarization. MDC and SHG probe the spontaneous polarization and non-linear polarization, respectively, and we can determine order parameters S_1 and S_3 using these measurements [4]. Linear surface polarization is also induced and it is linked to S2, and it can be probed by the reflected light from the polarized surface layers, where BAM can be used [5]. The unique property of monomolecular films lie in that it has both crystal-like and liquid crystal-like properties. As such, a variety of textures appear in dipolar monolayers, where dipolar energy stored in surface layers make a significant contribution. I have succeeded in deriving a shape equation that can determine the texture. Interestingly, the solutions of the shape equation clearly predict the presence of quantumized shapes such as circle, and torus [6-8]. This finding gives us a hint for utilizing organic materials in electronics. Furthermore, we can utilize electronic phenomena originating from non-zero S1 as a memory effect at molecular level [2,17]

3. Surface polarization due to excess charges

According to the Maxwell's electromagnetic field theory, charge Q_s is accumulated at the interface between two dielectric materials with different relaxation times when current flows across the interface. This is the Maxwell-Wagner (MW) effect, and provides us a chance to utilize Q_s in organic devices. In OFETs, accumulated charge Q_s at the interface is conveyed along the interface by an external field parallel to the inter face. In other words, surface polarization phenomena accounts for the OFET characteristics [11,12].

Electric field distribution in OFETs changes due to the carrier injection, possibly because carriers are excessive ones for OFETs. Electric field induced SHG (EFISHG) probes this field effectively [13,14], and thus can explore the static electric field [15,16] and dynamical carrier motions in FETs. Figure 1 shows an example of macroscopic SHG experiment employed for pentacene FETs. As we can see in the figures, SH is enhanced depending on the application gate and drain voltages. In greater detail, SH is enhanced depending on the accumulated charges that are expected from the MW effect. This findings is important in that not only we can probe surface polarization in organic deices by means of SHG, but also we can control of SH enhancement by accumulated charges using an FET structure. Furthermore we can probe motion of carriers injected from electrodes when we use microscopic SHG measurement, because the electric field induced by mobile carriers is probed. In this way, the

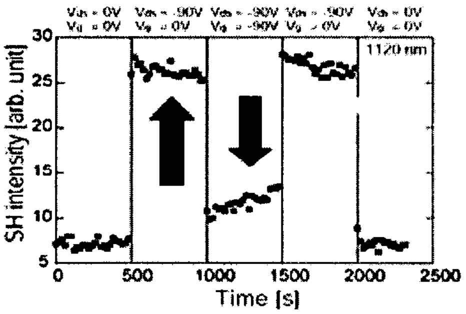

Fig. 1 Generation of SH from pentacene FET

macro- and microscopic SHG lead to a new way to electronics, in particular, in the field where combination of organic electronics and opto-electronics is required.

4. Conclusion

Surface polarization phenomena due to orientational ordering of polar dipoles and accumulation of excess charges are briefly reviewed. We then show that understanding of surface polarization phenomena is essential in the field of organic electronics.

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