Devices

Cambridge Univ.: On insulators for organic FETs

H. Sandberg

Investigation at the interface between insulator and semiconductor layers

In several papers published by **H. Sirringhaus** et al. the interface between the insulator and semiconductor layers in organic FETs are investigated. The first paper [1] concentrates on the polaron localization in this interface, and following review articles [2], [3] touches also upon the same results from slightly different angles. The motivation for the work is to clarify the influence of the gate dielectric - semiconductor interface on device performance. While it is clear that localized polaron states are where charge carriers reside, and the origin of energetic disorder is fairly well understood, there is no clear picture of how an interface in the proximity influences the polaron states and the polaron relaxation in this interface.

To investigate this issue further, several insulators were applied in an FET using high performance semicrystalline conjugated polymer PBTTT as the semiconductor. The insulators represent a range of dielectric constants: polystyrene (PS, ε = 2.6), a cyclized perfluoro polymer (CYTOP™, ε = 2.1), poly(methyl methacrylate) (PMMA, ε = 3.5), and poly(vinyl phenol) (PVP, ε = 6.5). The charge-modulation spectroscopy (CMS) technique is applied to measure the induced absorptions of the charges that carry the transistor current upon modulation of the gate voltage. The charge induced absorption peaks in the CMS spectrum are related to the transitions in the energy levels according to well established models.

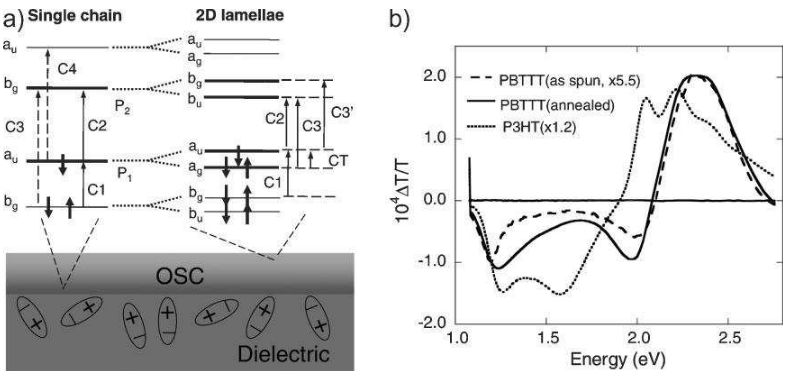

Figure 1: a) Model for the energy levels and related optical transitions of polarons on a single chain (top left) and polarons delocalized over two cofacial chains (top right), and the schematic diagram for the distribution of polaron species in the organic semiconductor (OSC) with the presence of the disordered dipoles near the dielectric surface. b) CMS spectra of P3HT and PBTTT devices (PMMA as the gate dielectric). The measurements were performed at 37 Hz, with gate bias at (-20+-2) V. The CMS signals of p3HT and pristine PBTTT devices were magnified for clarity.
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By operating the devices in accumulated and depletion mode, charges at the interface and in the bulk of the semiconductor film are probed respectively, since the accumulation of charges takes place in a very thin layer at the interface. Based on the CMS spectra, the authors from **Cambridge University** show that the dipolar disorder in the high-k dielectrics causes polaron localization at the interface. The CMS measurements provide direct spectroscopic evidence for gate-dielectric-induced localization of the electronic states of polaronic charges at the interface. However, for a crystalline semiconductor (as used here, PBTTT) the charge carrier mobility at room temperature is not much affected by the polaron localization, nor by the energetic disorder caused by the dielectric. To investigate the reason why the mobility is not more strongly affected by the energetic disorder induced by the gate dielectric, the temperature dependence of the field-effect mobility for PMMA and PS was measured, showing that the density of states (DOS) in PBTTT is in fact broadened when in contact with PMMA. The DOS broadening is studied as a function of distance from the interface, and the conclusion is that from a practical point of view in semicrystalline polymers with lamellar ordering, higher-k gate dielectrics can be used without device performance suffering from degradation of field-effect mobility. The thin layer of alkyl chains beside the conjugated lamella of the ordered semiconductor is sufficient to mask off the DOS broadening significantly.

As a general conclusion it is noted that the mobility reducing effects are very short range and are usually masked off by other effects such as intermixing between the layers. The review articles also referenced touch upon the same topic and discuss the matter somewhat more broadly in a much larger context. The papers offer hints on how to optimize the insulator-semiconductor material pair in organic electronics. Due to the short range of this interaction a very thin spacer layer may remove the effects that lower field effect mobility, such as self assembled monolayers or well controlled side chains on the polymers.

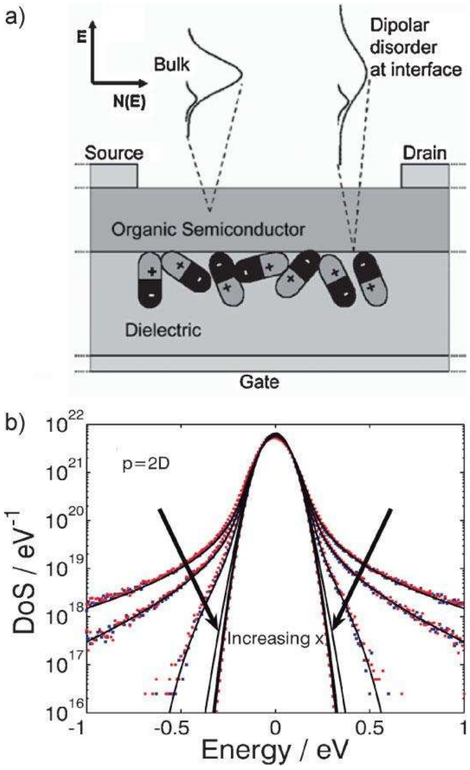

Figure 2: (a) Schematic diagram of the effect of disordered polar groups on the energetic disorder at the active interface. (b) Calculated DOS broadening due to static dipolar disorder in a dielectric with dipole moment of 2 Debye (D) with increasing distance into the semiconductor. Each line corresponds to a different distances x of the location in the organic semiconductor from the dielectric interface varying from x=0Å (broad DOS right at interface) up to x=5Å (bulk-like DOS). The dashed line indicates the unbroadened Gaussian DOS in the bulk with a characteristic width of 60 meV. The dots are a result of numerical simulation including either just the nearest dipole (n=1, blue squares) or the nearest ten dipoles (n=10, red circles).
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[1] "Polaron Localization at Interfaces in High-Mobility Microcrystalline Conjugated Polymers"; N. Zhao, Y.Y. Noh, J.F. Chang, M. Heeney, I. McCulloch, H. Sirringhaus : Advanced Materials **21**, 3759 (2009).
[2] "Materials and Applications for Solution-Processed Organic Field-Effect Transistors"; H. Sirringhaus : Proceedings of the IEEE **97**, 1570 (2009).
[3] "Reliability of Organic Field-Effect Transistors"; H. Sirringhaus: Advanced Materials **21**, 3859 (2009).