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Infrared Electo-Optic Response and Novel Mobility Measurement of Soluble Organic Semiconductors in Thin Film Transistors

Emily G. Bittle and Joseph W. Brill

Department of Physics and Astronomy, University of Kentucky, USA, e.g.bittle@uky.edu

Previously we have demonstrated a novel technique to measure charge mobility in small molecule organic semiconductors, such as 6,13 bis(triisopropylsilylethynyl)-pentacene (TIPS Pn), incorporated in thin film transistors (TFTs) using a position dependent electro-optic measurement of the infrared absorption of holes injected by the gate field [1], illustrated in Figure 1. By using the infrared response, the mobility can be measured without knowledge of capacitance or induced charge. This technique is realized by focusing infrared light at the center of the TFT channel and measuring the change in reflection while applying a square wave with variable frequency to the sample gate. The mobility is calculated by fitting the frequency dependence of the electro-optic signal to the solution of a non-linear differential equation describing the flow of charge in a bottom contact thin-film transistor [2]; the characteristic frequency at which the signal cuts off is

$$\omega_0 \approx 6\mu V_g / L^2,$$

where L is the channel length and V_g is the gate voltage.

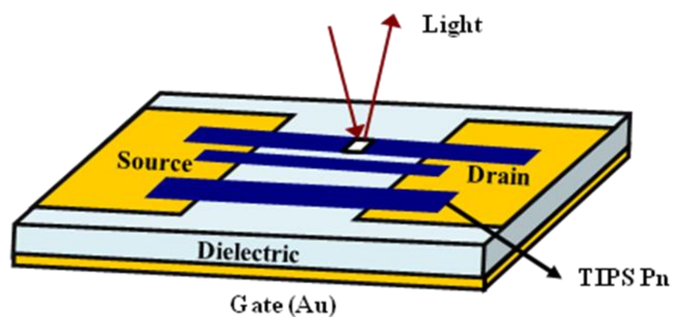

Figure 1 Cartoon of a TFT with TIPS Pn as the active material. Also shown is the approximate size of the infrared light measurement area.

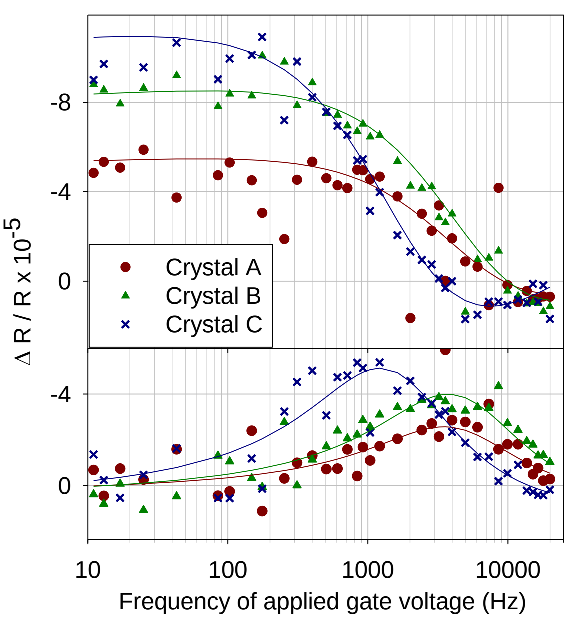

Figure 2 The infrared response measured as a function of the frequency of the gate voltage. The y-axis shows the change in reflectance of the transistor, $\Delta R = R_{on} - R_{off}$, normalized to the total reflectance both in-phase (top-panel) and in quadrature (bottom panel) with the applied voltage. Measured mobilities are 0.13, 0.12 and 0.07 for crystals A, B, and C, respectively.

For small induced charges, the electro-optic response is primarily due to absorption in the charged layer. To take advantage of the buried metal layer effect, which maximizes infrared absorption through the conducting layer for a dielectric ~ ¼ wavelength thick, TFTs tested were prepared using thick dielectrics on highly reflective surfaces (gold or aluminum) which double as the gate contact.

For such thick (~ 1 micron) dielectrics, the charge induced by the gate voltage is small (< 1% of molecules on the interface with the dielectric are charged) and the electro-optic response is due to absorption in the charged layer. Using this charge induced infrared signal, we measure the local mobility within the transistor, and are able to identify weaker or stronger conduction pathways within the transistor. Figure 2 shows a comparison in signal as a function of gate voltage frequency for three crystals on one transistor with a polymer dielectric. Differences in the frequency dependence are mainly due to differences in the effective length of the crystals, but there are also (factor of two) differences in mobilities of the crystals, indicative of varying numbers of trapping sites or the presence of grain boundaries. Inorganic dielectrics, with higher k (dielectric constant), prepared by atomic layer deposition show increased signal and interesting deviations from modeled behavior at high frequencies, perhaps due to poor lamination at the contacts.

References

[1] E. G. Bittle, J. W. Brill, and J. E. Anthony, "Electro-optic measurement of carrier mobility in an organic thin-film transistor," *Appl. Phys. Lett.*, vol. 97, p. 013302, 2010.

[2] E. G. Bittle, J. W. Brill, and J. P. Straley, "Dynamics of charge flow in the channel of a thin-film field-effect transistor," *J. Appl. Phys.*, vol. 112, p. 094507, 2012.