

CONTROL OF ROUGHNESS AT INTERFACES AND THE IMPACT ON CHARGE MOBILITY IN ALL-POLYMER FIELD-EFFECT TRANSISTORS

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Using conjugated polymers as the active materials in electronic and optoelectronic devices opens up the possibility of fabricating all-polymer devices using solution processing technologies. The fabrication of good quality field-effect transistors (FETs) is crucial to a number of polymer-based devices, such as active matrix displays and integrated circuits. Central to FET operation is the dielectric/semiconductor interface. Here we look at the interface between a polymer gate dielectric and a conjugated polymer, using neutron reflectivity. By using a mixed solvent (toluene/cyclohexane) to deposit the conjugated polymer directly on top of the polymer dielectric we are able to fabricate bilayer FET architectures with systematically controlled interfacial roughness, and study the impact on transistor performance.

The use of conjugated organic materials as the semiconducting component, within electronic devices is an increasingly important technology. Conjugated polymers combine the promise of products with desirable properties such as flexibility, with the processing advantages of solution-based production methods (large areas at low cost). The nature of the interfaces between semiconducting polymers and other materials is of vital importance in the performance of several organic devices. This study focuses on FETs, where the interface between the polymer dielectric and the semiconducting polymer is of crucial importance, as it is adjacent to this interface that current flows within the device.

In this work we focus on a bottom gate, top contact architecture, with poly(9,9-dioctylfluorene-*alt*-bithiophene) (F8T2) as the semiconducting layer and poly(methylmethacrylate) (PMMA) as the gate dielectric (see figure 1). By dissolving the F8T2 in a miscible mixture of a good solvent (toluene) and a poor solvent (cyclohexane) for PMMA in various volume ratios, and directly spin-coating onto the PMMA layer, it is possible to control the structure of the buried F8T2/PMMA interface. By varying the ratio of the two solvents in this mixture we are able to systematically control interfacial roughness over a broad range and correlate this directly with charge mobility. FETs were also fabricated following the same procedures, but with the addition of a 300nm SiO₂ on top of the silicon substrate.

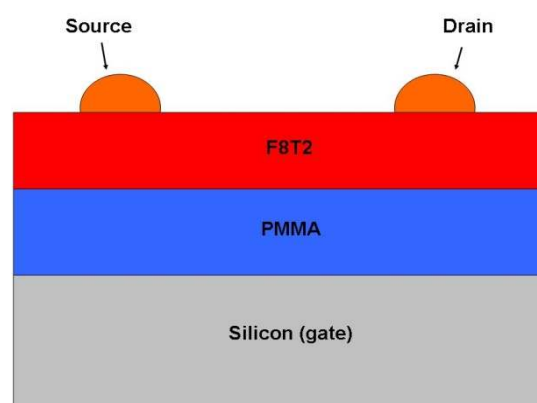
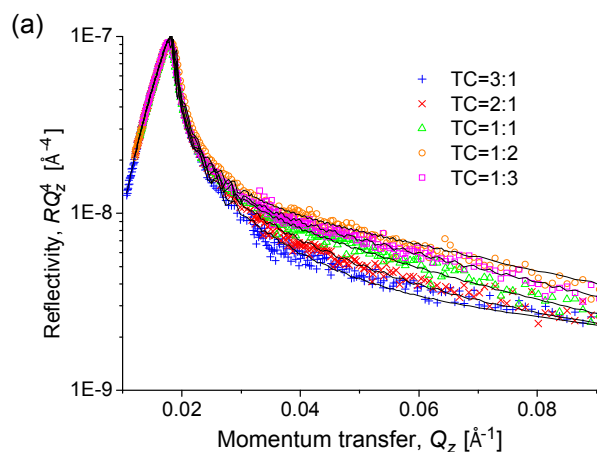


Figure 1. Schematic diagram of a bottom gate, top contact FET, showing the source, drain and gate electrodes.

Our goal in this study was to make polymer-polymer bilayers with controlled interfacial roughness. However, only specific combinations of PMMA molecular weight and solvent ratio can produce well-controlled bilayer structures. If the toluene content is too high, or the PMMA molecular weight too low, dissolution of the PMMA film by the solvent used for the deposition of the F8T2 is too rapid, and a complex laterally structured morphology is obtained. For PMMA with molecular weight $M_w=313,500$ g/mol we are able to produce bilayers for toluene:cyclohexane (T:C) solvent ratios ranging from 4:1 to 1:3, and it is these bilayers that we shall discuss here.



(b)

Figure 2. Reflectivity data (Reflectivity $\times Q_z^4$) for F8T2/PMMA/silicon bilayers at various solvent ratios. Solid lines represent bilayer fits with the surface and interfacial profiles modelled as error functions.

Specular neutron reflectivity measurements were performed on several bilayers at the reflectometers EROS (LLB) and CRISP (ISIS.). The reflectivity curves for five different bilayers with T:C ratios 3:1, 2:1, 1:1, 1:2, and 1:3 are shown in figure 2. It is clear that the reflectivity systematically reduces as the toluene content rises. The root-mean-square roughnesses extracted from the fits in figure 2 decrease from approximately 3.3 nm to around 1.5 nm as the T:C ratio changes from 3:1 to 1:3. It is therefore clear that we are able to systematically control the interfacial roughness at this dielectric/semiconductor interface using solvent quality as a control parameter.

Working devices were then made from these bilayers. Figure 3 shows the field-effect mobility extracted from the F8T2/PMMA FETs and from a set of control FETs. The controls were made from the same mixed solvents but used SiO₂ alone as the gate dielectric. The data from the F8T2/SiO₂ FETs allow a measurement of mobility as a function of the solvent quality, independent of the interface roughness, which remains constant at less than 5 Å. Figure 3 shows a clear correlation between the mobility and the T:C ratio for the F8T2/SiO₂ transistors, with higher charge mobility for toluene-rich solvent. We believe that this is because by using a good solvent the polymer

chains are more extended in the film leading to more homogeneous electronic structure across the film, more uniform interchain packing and improved mobilities. However, in the context of the present study which is focussed on the effects of interface roughness the detailed dependence of conformation/packing of the polymer chains within the solid films on solvent ratio has not yet been investigated.

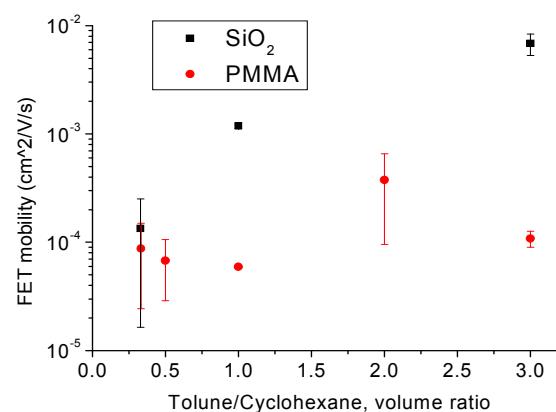


Figure 3. Field-effect mobility measurements for F8T2/SiO₂ and F8T2/PMMA FETs.

Typical mobilities in the F8T2/PMMA FETs are significantly lower than those in the F8T2/SiO₂ FETs, reflecting the significantly higher interface roughness at the F8T2/PMMA interfaces compared to that of F8T2/SiO₂. However, in contrast to the F8T2/SiO₂ FETs, the mobility of the F8T2/PMMA devices in figure 3 shows relatively little dependence on solvent ratio. Therefore it appears that, to a first approximation, the effect of increasing roughness is to reduce mobility, and that this effect is sufficiently strong to cancel out the dependence of F8T2 charge mobility on conformation/packing. It therefore appears that in this particular system the two effects counteract each other and lead to a mobility which is not significantly dependent on solvent quality.

References:

S. S. Chang et al. *Soft Matter*, 2008, **4**, 2220-2224.

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