Student Paper

Thermal Stress Induced Trap Generation in Solution-Deposited Organic Thin-Film Transistors

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Organic materials are viable candidates for flexible electronic applications given their facile processing and malleability to any substrate shape, size and type. We demonstrate that solution-deposited organic thin-film transistors (OTFTs) fabricated with a novel small molecule organic semiconductor, 2,8-difluoro-5,11-bis(triethylgermylethynyl) anthradithiophene, diF-TEG ADT, can exhibit charge carrier mobilities greater than 5 $cm^2V^{-1}s^{-1}$ upon tuning the fabrication parameters [1]. We evaluate the film morphology and electrical properties of devices fabricated on this material by drop-casting, spin-coating and spray-coating processing methods. The measured charge carrier mobilities in these films range from 5.4 $cm^2V^{-1}s^{-1}$ in drop-casted OTFTs, to 2.2 $cm^2V^{-1}s^{-1}$ in spray-coated samples and 3.7 $cm^2V^{-1}s^{-1}$ in spin-coated devices. These differences arise from defects originating at grain boundaries, as well as from different molecular orientations obtained as a result of tailoring the surface energy and chemistry.

A differential microstructure is observed in spin-coated devices, with large grains on and around contacts treated with fluorinated self-assembled monolayers, and small grains around these regions. This phenomenon is of relevance for devices based on this material, as it provides low-cost self-patterning. From the fundamental standpoint, the formation of two regions, in which the large grains attain a mobility as high as 3.7 $cm^2V^{-1}s^{-1}$, while the small grain regions do not exceed $5*10^{-4}$ $cm^2V^{-1}s^{-1}$ (Figure 1), offer a great platform for studies on the effect of grain size and grain boundary density on charge transport in organic semiconductors. Here we report on performance degradation in OTFTs due to generation of trap states as a result of different thermal expansion between the dielectric and organic semiconductor layers. We observe that the thermal expansion of the two regions of diF-TEG ADT films is significantly different, with a thermal expansion coefficient of 177 ppm/K for the film regions consisting of large grains and 90 ppm/K for the small grains region (Figure2). We show that the relative differences in thermal expansion between the dielectric and the organic film can produce stress-induced defects that act as trapping sites for the injected charges. In diF-TEG ADT, for example, the trap density at the semiconductor/SiO_2 dielectric (thermal expansion coefficient 4.1 ppm/K, [2]) interface increases by 22% between room-temperature and 150K for the large grain devices, and by 5 times for the small grain devices, where the difference in thermal behavior is significantly larger. We compare these results with the case of other organic semiconductors, characterized by different thermal expansion coefficients (pentacene, 78 ppm/K and rubrene, 28 ppm/K).

References

[1] Y. Mei, M. A. Loth, M. Payne, W. Zhang, J. Smith, C. S. Day, S. R. Parkin, M. Heeney, I. McCulloch, T. D. Anthopoulos, J. E. Anthony, O. D. Jurchescu, "High Mobility Field-Effect Transistors with Versatile Processing from a Small-Molecule Organic Semiconductor," *Adv. Mater.*, vol. 25, No.31, pp. 4352-4357, 2013.

[2] G. W. McLellan and E. B. Shand, *Glass Engineering Handbook, 3rd ed.* McGraw-Hill, New York, pp. 214–215, 1984.

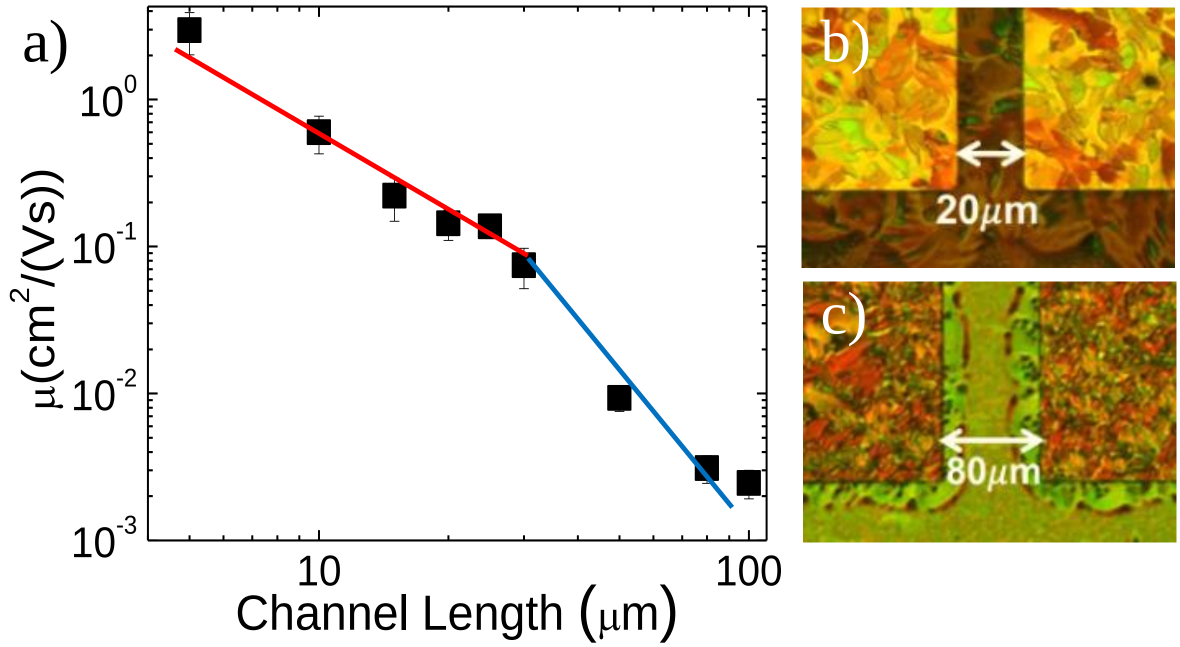

Fig. 1 Spin-coated diF-TEG ADT transistors. a) Evolution of the mobility with channel length. b) Optical micrograph of a short channel device (L = 20 µm). c) Optical micrograph of a long channel device (L = 80 µm) showing the differential microstructure.

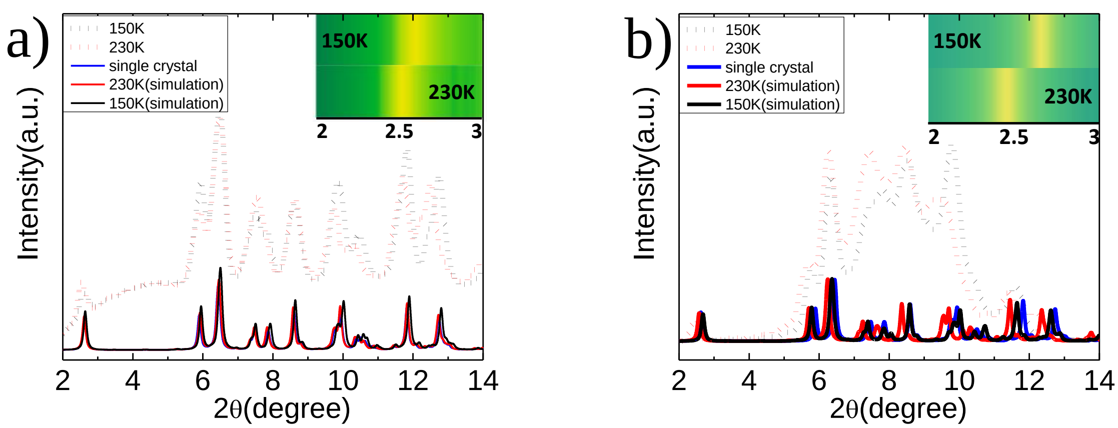

Fig. 2 θ-2θ XRD results on diF-TEG ADT films, showing the differential temperature-induced structure changes in a) large grains and b) small grains.