Abstract

Dielectric materials for low operating voltage organic thin-film transistors

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Over the past few decades, interest in organic materials for electronic applications has been steadily increasing due to their distinct advantages for inexpensive, large area processing. While vast attention has been paid to organic materials as the active semiconductor layer, modest consideration has been given to the gate-dielectric material. Some of the earlier reports have shown great improvements in device performance using polymer blends as the dielectric materials[1]. Furthermore, low operating voltage devices have been realized with thin dielectric layers consisting of cross-linked networks of polymers in an alkylsilane matrix[2]. In our research, we show alternative materials and methods for cross-linking polymer layers integrated into organic thin-film transistors and continuing work toward low operating voltage devices.

Various strategies are investigated to achieve a cross-linked polymer dielectric layer. In the most general scheme, poly(vinylphenol) is mixed with a variety of cross-linking agents and additives and spin-coated onto either silicon or plastic substrates. The layers and then cured to promote cross-linking and remove any additional solvent. To ensure cross-linking with the polymer and not the formation of an interdigitated network, the cross-linking agents chosen for this study do not reaction with each other. After post bake, the degree of cross-linking is determined using Fourier transform infrared spectroscopy. Pinhole-free, cross-linked polymer layers can be achieved with a thickness as low as 12 nm, as determined by atomic force microscopy and ellipsometry. The capacitance of these films is as high as 320 nF/cm^2 with minimal leakage current. Films on the order of 20 nm or greater exhibit a leakage current of less than 10^{-7} A/cm^2.

The utility of the cross-linked dielectric layer is evaluated using many common organic semiconductors, such as pentacene, perfluorinated copper phthalocyanine, and alkyl-substituted fluorene-thiophene oligomers. To gauge the electronic performance, top-contact devices are fabricated with thermally evaporated films with gold electrodes patterned through a shadow mask. The performance of the devices is referenced to those fabricated on OTS treated silicon oxide substrates. Devices fabricated with thin polymer dielectric layers demonstrate ideal electric characteristics for operating voltages below 1V for the semiconductor materials tested. Figure 1 shows the output and transfer characteristics for 5,5'-bis-(7-dodecyl-9H-fluoren-2-yl)-[2,2']bithiophenyl (**DDFTTF**) (**a,b**) and perfluorinated copper Phthalocyanine (**FCuPc**) (**c,d**).

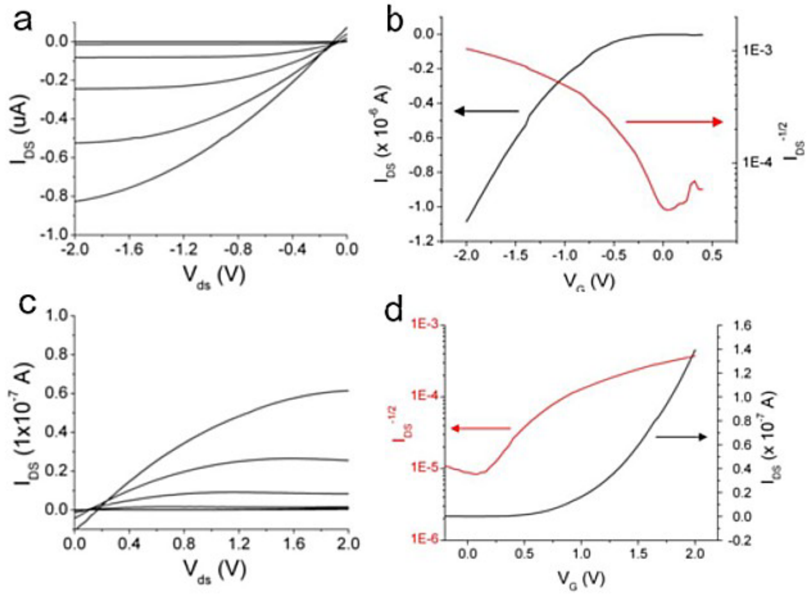

Figure 1: a) Output characteristics for **DDFTTF**, b) transfer characteristics for **DDFTTF**, c) output characteristics for **FCuPc**, and d) transfer characteristics for **FCuPc**.

Solution-processed films of trimethyl-[2,2';5',2";5",2"']quaterthiophen-5-yl-silane (**4TTMS**) and 5,5‴-dicyclohexyl-[2,2′;5′,2″;5″,2‴]quaterthiophene[3] (**CH4T**) also exhibit acceptable device characteristics under low operating voltages, with mobilities as high as 0.09 cm2/Vs and 0.02 cm2/Vs, respectively, with on/off ratios greater than 1000. Highly crystalline films can be achieved on the cross-linked dielectric layer by dropcasting using phenylbromide under saturated vapor at a substrate temperature of 90°C. The top-contact architecture is completed by evaporating gold contacts through a shadow mask.

Thin-film transistors are demonstrated on flexible substrates using commercially available aluminum foil, which serves as the gate electrode. After spin-coating and curing the dielectric blend, pentacene is thermally evaporated at 65°C substrate temperature followed by shadow mask patterned gold electrodes. The flexible device is measured in the flat (as possible) state, followed by bending to a radius of curvature of 7 mm followed by 2 mm, then returned to the flat state. Figure 2 shows the transfer characteristics at each bending radius with an inset of output characteristics measured after the bending sequence.

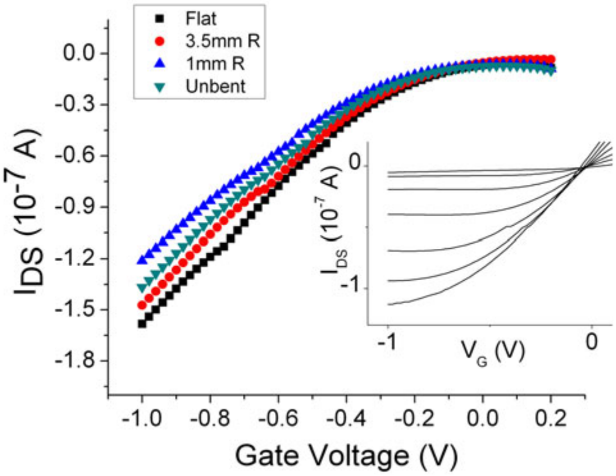

Figure 2: Transfer characteristics with bending radius for pentacene thin-film transistors fabricated on aluminum foil with (inset) output characteristics for an operating voltage of 1V.

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