Abstract

Organic field-effect transistors (OFETs) have gained tremendous attention from researchers due to its suitability for applications in large area flexible electronics. Solution processing of organic semiconductors, which act as active layer in these devices, is preferred for its attractive advantages of low cost and simplicity. The quality of active layer and dielectric-semiconductor interface are some of the crucial factors which regulate the performance of OFETs. However, improvement in these aspects is quite challenging due to numerous intricate issues related with material properties and processing conditions. In this work, the organic semiconductor TIPS-pentacene is explored for demonstration of high performance OFETs in bottom gated top contact (BGTC) architecture, which has become the conspicuous choice for OFETs due to its inherent high mobility and air stability. Successively, two types of flexible OFETs have been fabricated which are used to demonstrate high electromechanical stability and sensing phenomenon depending on their suitability.

Firstly, the effect of structural dissimilarity of the additive solvent from the main solvent on the properties of the resulting crystals of TIPS-pentacene and corresponding device performance on rigid Si/SiO_2 substrates is comprehensively studied. With toluene as the main solvent, benzene, cyclohexane, and hexane were used as additives for making solutions of TIPS-pentacene. It was found that a higher structural dissimilarity of the additive in the binary solvent mixture promotes a better molecular aggregation and higher crystallinity in the active layer and improved electrical characteristics in the corresponding OFETs. OFETs fabricated from toluene/hexane solvent resulted in improved field-effect mobility higher than 0.1 $cm^2 V^{-1} s^{-1}$ compared to 0.05 $cm^2 V^{-1} s^{-1}$ for toluene solvent.

Subsequently, blending of insulating polymer binder polystyrene (PS) with TIPS-pentacene was studied for phase separation and resulting high performance and electrically stability in OFETs. Drop casting of blend solution and solvent evaporation on Si/SiO_2 rigid substrates resulted in a vertically phase separated, tri-layer semiconductor-polymer-semiconductor structure. Though the dielectric capacitance density decreased from 10.6 nF cm^{-2} (300 nm SiO_2) to 3.1 nF cm^{-2} due to phase separated additional PS dielectric layer, the average process transconductance parameter (product of mobility and capacitance density) improved by a factor of ~4, with maximum mobility as high as 2.6 $cm^2 V^{-1} s^{-1}$ in saturation region for -30 V operation. These devices exhibited average mobility of 1.5 $cm^2 V^{-1} s^{-1}$, threshold voltage of 1.4 V, and high current on-off ratio of ~8×10^6 with better stability under bias stress compared to neat devices.

For future flexible electronics, low voltage operated and high performance OFETs on flexible substrate are required, for which two device strategies were employed on PET substrates. First type of devices were fabricated with an active layer of neat TIPS-pentacene on HfO_2-PVP hybrid gate dielectric, whereas the other type of devices were fabricated with TIPS-pentacene:PS blend films on HfO_2. At an operating voltage of -10 V, neat TIPS-pentacene devices exhibited average and maximum mobility of 0.11 and 0.23 $cm^2 V^{-1} s^{-1}$, average threshold voltage of 0.1 V and current on-off ratio of ~10^5, whereas TIPS-pentacene:PS blend devices showed average and maximum mobility of 0.44 and 0.93 $cm^2 V^{-1} s^{-1}$, average threshold voltage of -0.3 V and on-off ratio of ~10^5. Blend devices outperformed neat devices due to a better quality of dielectric-semiconductor interface, which was developed because of vertical phase separation.

Due to their better electrical performance, TIPS-pentacene:PS blend OFETs were further explored for demonstration of low voltage operation and high electro-mechanical stability. At further reduced operating voltage of -5 V, an average and maximum mobility of 0.5 and 1.1 $cm^2 V^{-1} s^{-1}$, average threshold voltage of -0.5 V, current on-off ratio of ~10^5, and low sub-threshold swing of 0.3 V/dec. were achieved. In addition, low drain current decay of 10% and a very small threshold voltage shift of 0.3 V were observed for 1 hr bias stress at V_{DS} = V_{GS} = -5 V,

indicating to very high bias stress stability in these devices. For a bending radius of 5 mm, high stability in electrical characteristics was found with increasing duration of mechanical strain, where average mobility changed from 0.43 to 0.30 $cm^2 V^{-1} s^{-1}$ for a very long strain duration of 2 days. Upon application of 100 cycles of tensile and compressive strain, mobility of representative device changed from 0.32 to 0.29 $cm^2 V^{-1} s^{-1}$, indicating very high electromechanical stability in these devices.

Further, flexible OFETs with active layer of neat TIPS-pentacene on HfO_2-PVP hybrid gate dielectric were used to examine the photo-sensitivity of TIPS-pentacene to visible and UV lights because of relatively simplified device structure and purity of semiconductor layer. Photo-sensitive OFETs exhibited maximum response to blue light illumination with intensity of 1.7 mW/cm^2, showing a current modulation as high as ~10^5 at low operating voltage of -5 V. Enhancement in the photo-response was observed with increasing time of visible illumination and gate bias during illumination. However, increasing UV irradiation time resulted in an enhanced positive threshold voltage shift and reduced mobility. The saturation drain current at biasing conditions of V_{GS} = -10 V and V_{DS} = -5 V was found to rise slightly for smaller values of irradiation time, however decreased for higher values of illumination time. A similar trend of positive shifting of V_{TH} and mobility roll-off was observed when gate bias during UV irradiation was increased.

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