Abstract

To reduce the impact of E-waste on the environment, there is a need to develop electronic products that leave minimum footprints on earth at the end of their lifespan. Organic and flexible electronics technology offers advantages over conventional electronics on this aspect with the possibility of fabrication on unconventional substrates that can have biodegradable nature. Organic field-effect transistors (OFETs) are the key devices of organic electronic circuits. Flexibility and performance are the crucial factors for utilizing them in bendable circuits and sensing applications. However, during the operation, these devices are encountered with various electrical, mechanical, and thermal stimulations. Thus, for reliable operation in practical applications, OFETs must be operationally stable. In this work, high performing OFET devices were demonstrated using TIPS-pentacene as an organic semiconductor. Successively, these devices were fabricated on unconventional substrates such as paper and kapton tape, and basic circuit operation was investigated.

Firstly, OFETs were optimized for process parameters such as the ratio of TIPS-pentacene and polystyrene in blends, and it was found that the devices with higher polymer content were offering higher electromechanical stability due to the formation of high-quality dielectric: semiconductor interface, governed by vertical phase separation. The 1:3 TIPS-pentacene: polystyrene devices have shown ~2% and ~11% decay in normalized drain current when stressed by external stress of V_{DS} = V_{GS} = -5 V for 1 h. for pristine and after 1.27 % (R_{bend} = 5 mm) tensile strain application respectively. In addition, the devices were also tested for stability under mechanical strain with a series of experiments and it was found that the blend OFETs have shown exceptional electromechanical stability as compared to their neat counterparts. Further, options for low-temperature high-k gate dielectrics were also explored. Optimized devices showed high performance with the maximum field-effect mobility (μ_{max}) up to 1.0 $cm^2\,V^{-1}\,s^{-1}$ and near-zero threshold voltage (V_{TH}) while operating at -5 V, along with high electromechanical stability.

Further, devices were fabricated on low-cost polyimide substrate (kapton tape) with HfO_2/PVP and HfO_2/PVA hybrid dielectric layer, which was used to provide a smoother surface for semiconductor film and to reduce the operating voltage. These devices exhibited μ_{max} of 0.4 $cm^2\,V^{-1}\,s^{-1}$ and 0.7 $cm^2\,V^{-1}\,s^{-1}$ for PVP/HfO_2 and PVA/HfO_2 respectively while operating at -10V. The devices exhibited excellent electrical and environmental stability for more than 5 months in ambient. In addition, external load inverter circuits were demonstrated.

Finally, OFETs with bilayer dielectric were demonstrated on paper substrate. PowerCoat™ HD 230 paper from Arjowiggins creative papers with an average surface roughness of 11.9(±4.0) nm (quite uneven for the device fabrication) was first planarized using PVA, which reduces the surface roughness significantly and also acts as a barrier layer for the paper substrate. These paper devices have shown excellent p-channel characteristics with μ_{max} of 0.44 $cm^2\,V^{-1}\,s^{-1}$ and average mobility of 0.22(±0.11) $cm^2\,V^{-1}\,s^{-1}$, with high current on-off ratio (I_{on}/I_{off}) ~10^5 while operating at -10 V. Remarkable bias-stress stability and repeatability of transfer scans were obtained. These devices displayed very stable electrical characteristics even after long exposure to humidity. In addition, the excellent shelf life of more than 6 months in the ambient environment was observed.

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