Hybrid Passivation for Organic-Thin Film Transistor on Plastic

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Abstract

We studied hybrid passivation using parylene-C, metal, photoacyl and indium zinc oxide for pentacene OTFT to assure stability in subthreshold region. After the passivation, the changes in S and V_{on} of OTFT were negligible and I_{off} maintained its initial value of ~ 10^{-12} A. Therefore, the hybrid passivation is suitable for practical applications based on OTFT.

1. Introduction

The performance of an organic thin-film transistor (OTFT) has been improved remarkably during the last decade and thus it is at least the same as that of amorphous silicon thin-film transistor which is currently used for the manufacturing of TFT-liquid crystal display. However, the performance of the OTFTs degrades significantly in air[1]. Therefore, the passivation of the OTFT is necessary to elongate its lifetime by protecting the organic active layer from ambient air.

Recently, several researches on passivated OTFT using polytetrafluoroethylene[2], parylene-C[3,4], epoxy[5], Al[6] and SnO_2[7] were reported. Even though they successfully maintained on-currents(I_{on}) after the passivation, there are still some changes in subthreshold region. The off-currents (I_{off}), subthreshold swing(S) and turn-on voltage (V_{on}) are significant because they affect power consumption and operation voltage range. Therefore, passivation should maintain not only I_{on} but also I_{off}, S and V_{on}. As a promising barrier, organic/inorganic multi-layer stacks named Barix™ encapsulation was developed by Vitex Systems Inc. for OLED encapsulation[8]. The key of this encapsulation is to use an organic layer on inorganic barrier surface to avoid defect creation, which can be a path of water permeation.

In the present work, we passivated pentacene OTFTs using hybrid multi-layer (HML) of parylene/Au/photo-acryl(PA)/indium zinc oxide(IZO). This structure can be used in LCD and EPD using organic planarization layer and indium tin oxide (ITO) or IZO for a pixel. The water vapor transmission rate (WVTR) of the HML was found to be less than 10^{-3} g/m^2/day which is the limit of MOCON measurement and this value is required for stable OTFT. Note that organic single and bilayers using PVA, PA and parylene have the WVTR of 10^{-1} ~ 10^{-2} g/m^2/day according to our measurements.

2. Experimental

Fig. 1 (a) and (b) show the cross-sectional view of a bottom contact pentacene OTFT using hybrid passivation layer and its optical image fabricated on plastic substrate. As shown in the figure, pentacene layer is sandwitched between IZO/PA/Au(/Cr)/ parylene (top) and SiN_x/PEN/SiN_x/AlNd/PVP (bottom). Therefore, the organic semiconductor is passivated by organic/inorganic layers, showing a good barrier performance against water and oxygen permeations.

Polyethylenenaphthalate (PEN, Dupont Teijin) was used as a substrate after annealing at 180 ℃ for 4 hrs for degassing and then 100 nm-thick silicon-nitride (SiNx) was deposited on both sides as gas barriers. Ductile metal, AlNd, was sputtered on the gas barrier as a gate electrode. On gate electrodes, gate insulator of poly(4-vinylphenol) (PVP) with cross-linking agent was spin-coated and cured in a vacuum oven at 180 ℃ for 4 hrs. Then, PVP was etched to make holes for electrical contacts. As source / drain electrodes, Cr / Au were deposited by sputtering and

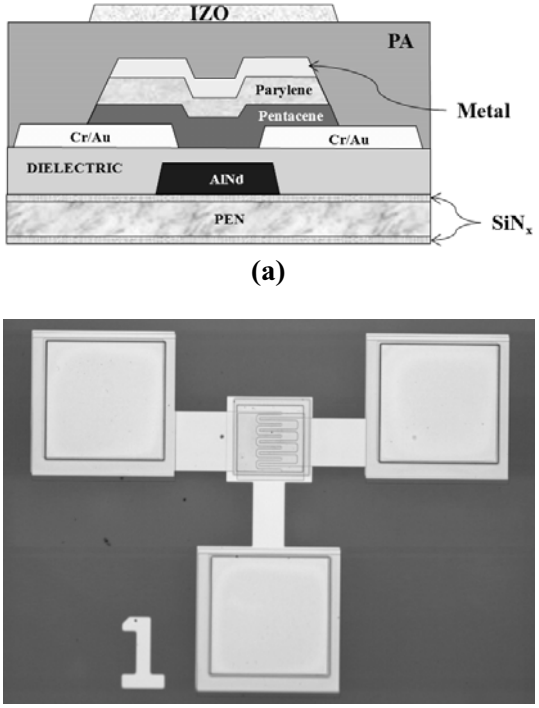


Fig. 1. A cross-sectional view (a) of a bottom contact pentacene OTFT using HML-passivation and its optical image (b) fabricated on plastic substrate

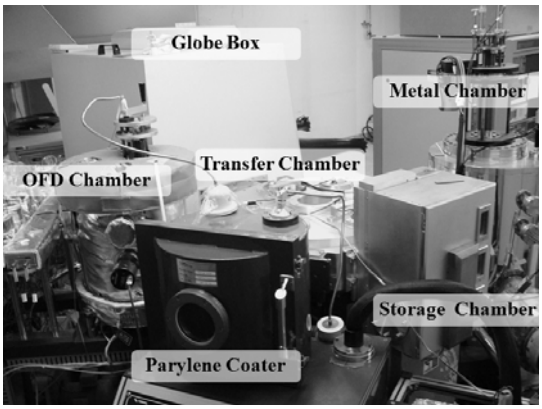


Fig. 2. An OFD system for HML-passivation used in this work

patterned by photolithography. After the covering the Cr / Au electrodes with polyvinylphenol (PVP), the backplane was treated with octadecyltrichlorosilane to enhance the OTFT performance of pentacene organic semiconductor[9].

Pentacene was deposited by organic flow depositi-

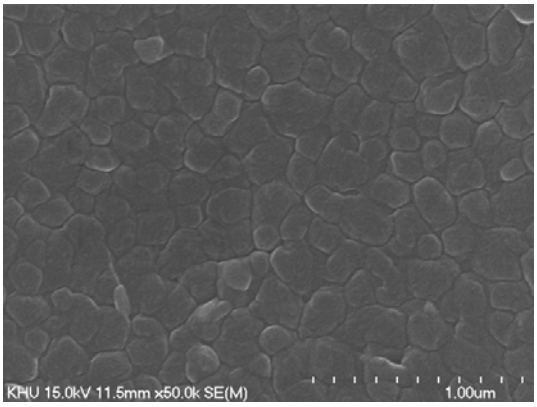


Fig. 3. SEM image of pentacene grains deposited by OFD

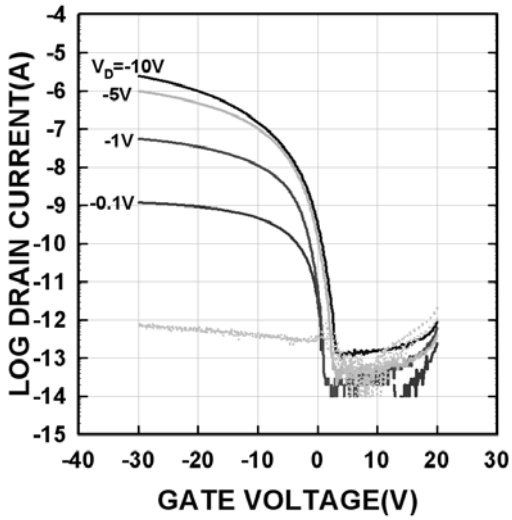
on (OFD, ADP Engeering) at the pressure of 1 Torr. After the pentacene deposition, parylene-C and metal were deposited on pentacene active layer and patterned by photolithography and oxygen plasma. In our equipment shown in Fig. 2, a pentacene chamber is connected to a parylene chamber, therefore, both materials can be deposited without vacuum break.

After the plasma etching, 1-μm-thick PA (Dongjin Semichem) was spun on the substrate and patterned by UV exposure to make holes for electrical contacts. The patterned PA was cured at 150 ^{o}C for 1 hour. Finally, 100-nm-thick IZO was sputtered and patterned on the substrate.

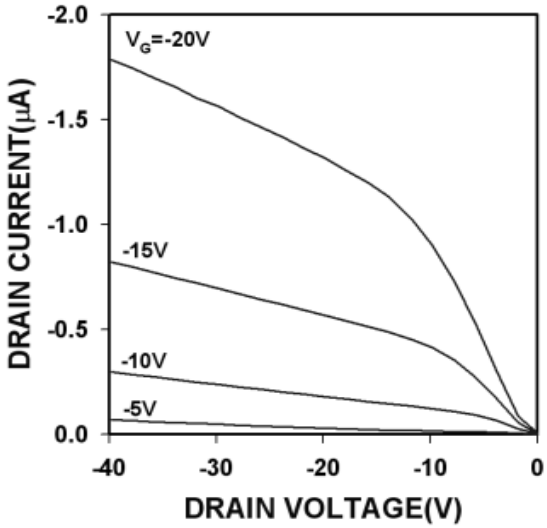
3. Results and discussion

Fig. 2 shows SEM image of pentacene film deposited by OFD. The grain size in pentacene film is about 0.2 μm and the grains are densely packed on the channel region. Even though small size of grain gives birth to lower μ_{fe} due to high energy barrier at grain boundary, uniformity could be enhanced because of random orientation of pentacene grains and randomly distributed grain boundaries in the channel region.

Fig. 3 (a) and (b) show the transfer and output characteristics of OTFT passivated with the hybrid passivation layer, which width and length are 500 μm and 8 μm, respectively. The performance exhibited the field-effect mobility (μ_{fe}) of 0.1 ~ 0.3 cm^2/Vs, threshold voltage (V_T) of -13.4 V with I_{on}/I_{off} of 10^7. In spite of the small pentacene grains, μ_{fe} is comparable to that fabricated by evaporation through shadow mask. Furthermore, OTFT was fabricated by using photolithography, oxygen plasma and sputtering, in this work. Generally, organic semiconductors can be

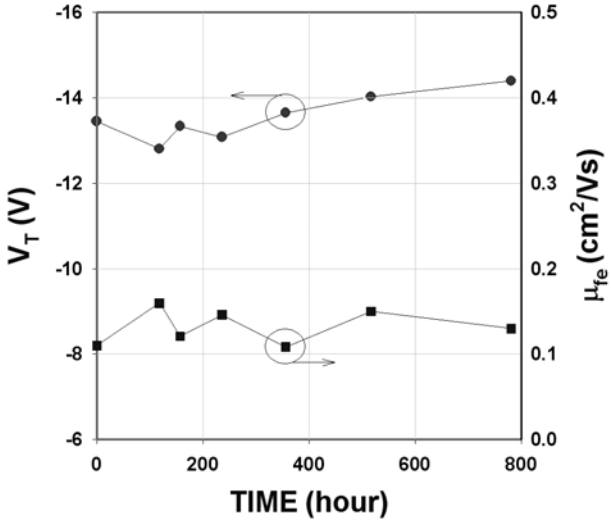


(a)

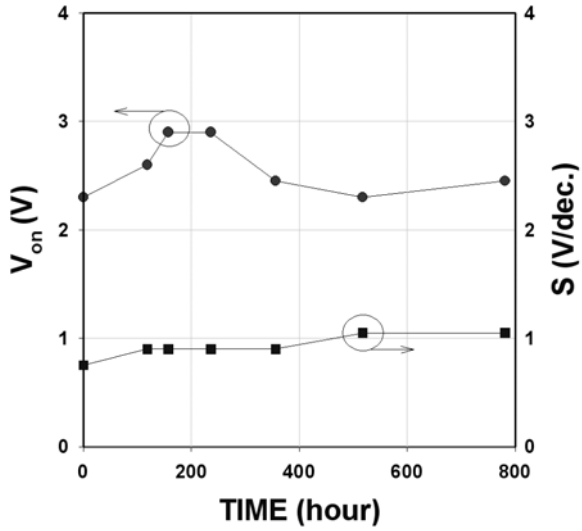


(b)

Fig. 4. The transfer (a) and output (b) characteristics of the HML-passivated OTFT.



(a)



(b)

Fig. 5. The changes in V_T, μ_{fe} (a), V_{on} and S (b) as a function of storage time for 781 hours in ambient air

easily damaged under UV exposure and plasma. However, this process can make high resolution display and sensor applications due to no usage of shadow mask.

Figure 5 (a), (b) show V_T, μ_{fe}, V_{on} and S as a function of storage time for 781 hours. In our previous work, the bilayer of PVA and PA was used for OTFT passivation[10]. In that case, V_T shifted to positive direction and thus compensated for the degradation in μ_{fe}. That effect was explained by oxygen doping effect. In the present work, the changes in μ_{fe} and I_{off} were negligible after the storage of 781 hrs in air.

This means that the doping effect is not dominant because of high barrier performance of HML. The small negative shift of V_T shown in Fig. 5 (a) seems to be caused not by impurities from ambient air but bias-stress effect during the repeated measurement.

4. Summary

We fabricated pentacene OTFTs using HML of parylene/Au/PA/IZO, which is consistent with organic/inorganic combination. The HML-passivated OTFT exhibited μ_{fe} of 0.10 ~ 0.30 cm^2/Vs with high

I_{on}/I_{off} of 10^7. The HML-passivated OTFT was stable during the storage time of 781 hours and the changes in on-, off- and subthreshold currents were negligibly small. These indicate that HML-passivation is suitable for making stable OTFT array.

5. Acknowledgement

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