Organic TFT fabricated on ultra-thin flexible plastic with a rigid glass support

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Keywords : OTFT, polyimide, flexible, pentacene, detach

Abstract

We have fabricated pentacene OTFT on ultra-thin flexible polyimide film with a rigid glass support. Polyimide film of the thickness of 10 µm has formed on glass by spin coating from the solution. After the entire OTFT process, the OTFT exhibited a field-effect mobility of 0.4 cm^2*/Vs, an* I_{on}/I_{off} *ratio of* 10^7 *and a subthreshold swing of 0.7 V/dec. The OTFT on polyimide film has been detached from the glass support and laminated on a plastic support of 130 µm-thick PET film. After the detach process, in spite of the degrading of its field-effect mobility, the OTFT showed high* I_{on}/I_{off} *as high as ~*10^6*.*

1. Introduction

Recently, flexible displays have been paid much attention for the use under a ubiquitous environment due to their special features such as lighter weight, better portability, and better durability than conventional displays [1]. For flexible displays, typical glass substrates are commonly replaced by plastic or other bendable substrates [2]. In particular, organic thin-film transistor (OTFT) has attracted much attention as a possible basis for portable or ubiquitous devices [3] such as flexible displays [4] and radio-frequency identification tags [5] due to their low weight and mechanical flexibility. One exciting application for organic transistors, arising from their flexibility, is their use as drivers for paper-like electronic displays [6,7].

In this work, we fabricated pentacene TFT on flexible and ultra thin polyimide (PI) substrate with a glass support. Polyimide has been widely used in micro-electronics industry because of its excellent dielectric properties, radiation resistance, thermal/chemical stability, and the ability to be applied as planarization layer [8]. After the entire OTFT process, the OTFT on PI has been detached from the glass support. The characteristics are measured in air before and after the detach process.

2. Experimental

Figure 1 shows a cross-sectional view of a bottom contact pentacene OTFT, which was used for this work. The PI film was formed on glass from solution (PI-2545, HD Microsystems) by multiple spin coating. At a spin speed of 1500 rpm for 20 s, the thickness of the PI film was typically ~3.5 µm. For 10 µm thick polyimide, three coating were needed to buildup the thickness. The soft baking processes at 200 ℃ for 10 min were applied in between each coating to partially drive out the solvent. After the last layer was spun, a final curing was carried out at 200 ℃ for 30 min and 350 ℃ for 1 hour [8].

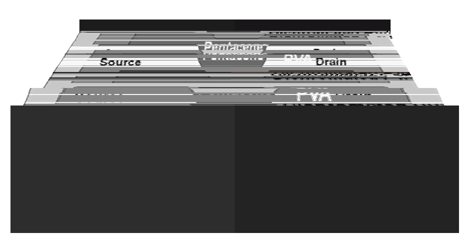


Fig. 1. Cross-sectional view of OTFT studied in this work

SiN_x was deposited on the PI film as a gas barrier. The surface roughness of SiN_x on the spin coated PI film is investigated with an atomic force microscopy (AFM). Figure 2 shows the AFM image of SiN_x on the PI film. The changes in the surface roughness before and after SiN_x deposition were summarized in Table 1. Surface root-mean-square (rms) roughnesses decreased after coating from 0.21 to 0.12 nm. The low surface roughness means suitable for the fabrication of high performance OTFT.

AlNd was deposited on SiN_x and patterned for gate electrode by photolithography. As the gate insulator, cross-linked poly(4-vinylphenol)(PVP), was spin coated from the solution, and cured in a vacuum oven. Then, Cr/Au layers were deposited on the gate insulator for source/drain electrodes. To obtain patterned pentacene islands using a self-organized process, O_2 plasma and octadecyltrichlorosilane were treated on the surface to define hydrophilic and hydrophobic areas [9,10]. Pentacene active layer was grown by organic vapor deposition and the thickness of the active layer was ~500 nm. The W/L, a ratio of channel width to channel length, of the pentacene OTFTs was fixed to be 300 μm / 8 μm for the all OTFTs studied in this work. After the pentacene deposition, the OTFT was passivated with double layers of polyvinylalcohol (PVA) and dichromated polyvinylalcohol(D-PVA) based on solution process [11].

To detach the PI film from the glass support, the film was cut at the substrate edges and detached mechanically. This process is simple compared with the laser detach method.

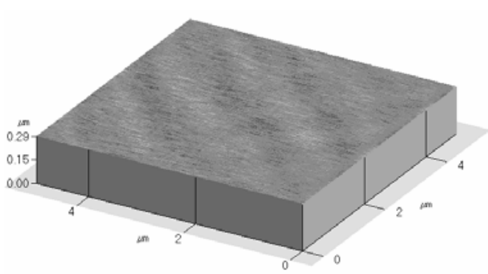


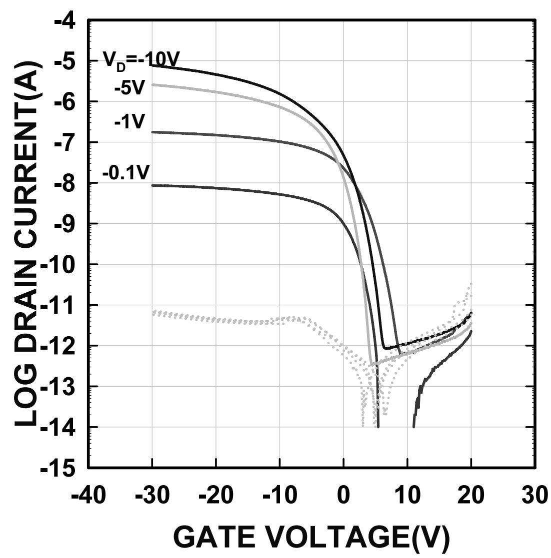
Fig. 2. AFM image of SiN_x on PI film.

Table 1. Surface roughness of PI film (I) and SiN_x on the PI film (II)

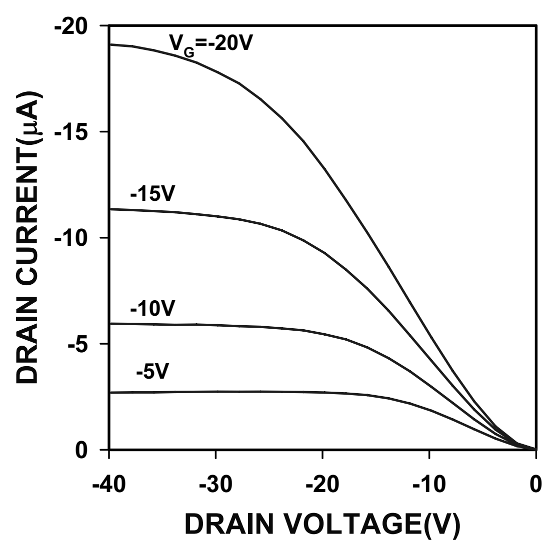
	R_{p-v} (nm)	R_{rms} (nm)	R_{ave} (nm)
I	2.2	0.21	0.38
II	1.34	0.12	0.07

3. Results and discussion

Figure 3 shows the initial characteristics of the OTFT before the detachment. The initial performance of the OTFT was the following: a field-effect mobility of 0.40 cm^2/Vs in the saturation region, a threshold voltage (V_T) of −2.0 V, a subthreshold swing (S) of 0.7 V/dec. and an on-off current ratio of 10^7. These indicate high performance among bottom contact type



(a)



(b)

Fig. 3. Initial transfer (a), output (b) characteristics of OTFT on PI coated on the glass support

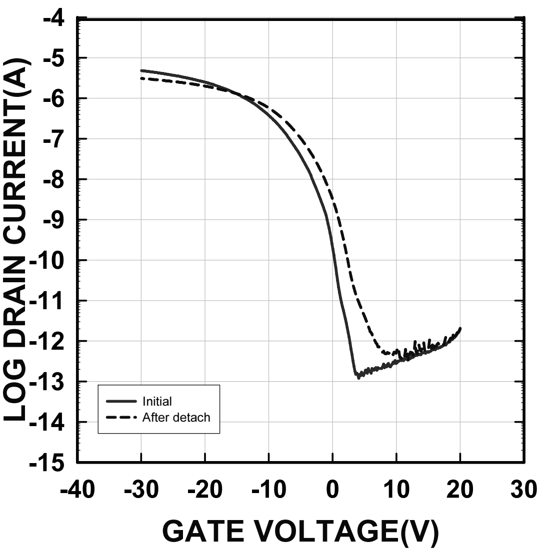


Fig. 4. Transfer characteristics of OTFTs before and after detach process.

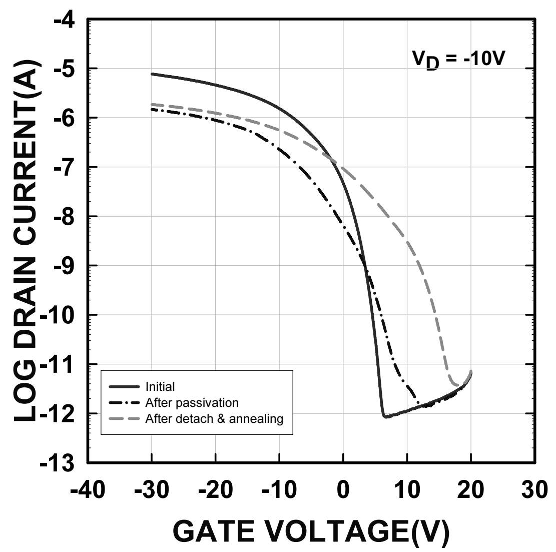


Fig. 5. Transfer characteristics of OTFTs before and after passivation and detach & annealing.

OTFTs with organic gate dielectric layer.

Detach process was carried out without passivation process in order to examine why OTFT characteristics was degraded. Figure 4 shows the transfer characteristics of the device at V_D of -10 V with and without detach process. After the detach OTFT process, the OTFT exhibited a field-effect mobility of range from 0.34 cm^2/Vs to 0.26 cm^2/Vs, an I_{on}/I_{off} ratio of ~ 10^7, and a threshold voltage from -9.0 V to -7.7 V. The degradation seems to be caused by the creation of defect states during the stress on film when it was detached.

Figure 5 shows the transfer characteristics of the OTFT at V_D of -10 V after the PVA passivation and after the detach process compared to its initial characteristics. The OTFT with the passivation layer exhibited the mobility of 0.13 cm^2/Vs and increase of the subthreshold currents. However, after the detach and annealing processes, the mobility was partially recovered to 0.23 cm^2/Vs with I_{on}/I_{off} of 10^6. This means that the created states and air impurities in the back surface during passivation and detach process could be relaxed after annealing in vacuum. Table 2 shows the results of the electric characteristics after detach process.

The surface roughness of rigid glass after detach process is investigated with an atomic force microscopy(AFM). Figure 6 shows the AFM image of detach process. Surface root-mean-square (rms) roughness decreased after detach process. The low surface roughness means the smooth SiNx surface after the detach process and it can be reused, resulting in the cost reduction of the process.

Table 2. Characteristics of OTFTs after detach process

	u_{sat} (cm^2/Vs)	V_{th} (V)	I_{on}/I_{off}
Initial	0.40	-2.0	10^7
After passivation	0.13	-9.8	10^6
After detach & annealing	0.23	-10.8	10^6

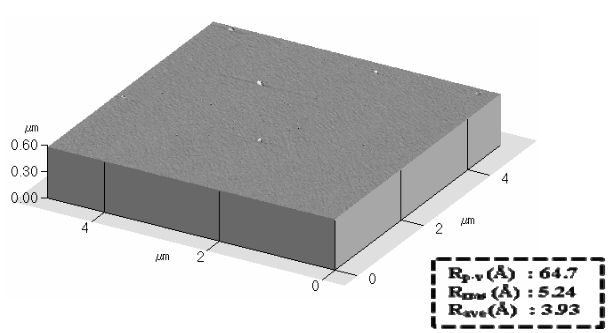
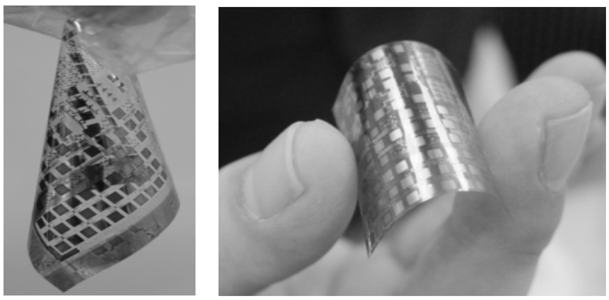


Fig. 6. AFM image of glass after detach process

As shown in figure 7 (a), the detached PI film was rolled up spontaneously because thickness of detached film is very thin and under stresses from the layers for



(a) (b)

Fig. 7. Photograph of the detached PI film (a) and with the PET support (b)

OTFT. Therefore, we laminated the PET film of the thickness of 130 μm as a plastic support before the detach process as shown in Fig. 7(b). The performance of OTFT was not changed after the lamination.

4. Summary

We fabricated pentacene TFT on flexible and ultra thin PI film with a rigid glass support. Because of the glass support, there was no misalign caused by thermal expansion and thus the manufacture process for inorganic TFTs could be used to make OTFTs. After the entire OTFT process, the OTFT on PI film was detached from the glass support. By this method, we could obtain the mobility of 0.23 cm^2/Vs with the on/off current ratio of 10^6. The surface roughness of the SiNx on glass support is the same as after detach process its initial roughness before the TFT process. As a result, this process can be a good solution for making flexible applications on plastic film.

4. Acknowledgements

This research was supported by a grant (F00040 82-2006-22) from Information Display R&D Cente r, one of the 21st Century Frontier R&D Program funded by the Ministry of Commerce, Industry an d Energy of Korean government.

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