Passivation Layers for Organic Thin-film-transistors

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Inorganic layers, such as SiOxNy and SiOx deposited using plasma sublimation method, were tested as passivation layer for organic thin-film-transistors (OTFTs). OTFTs with bottom-gate and bottom-contact structure were fabricated using pentacene as organic semiconductor and an organic gate insulator. SiOxNy layer gave little change in characteristics of OTFTs, but SiOx layer degraded the performance of OTFTs severely. Inferior barrier properties related to its lower film density, higher water vapor transmission rate (WVTR) and damage due to process environment of oxygen of SiOx film could explain these results. Polyurea and polyvinyl acetates (PVA) were tested as organic passivation layers also. PVA showed good properties as a buffer layer to reduce the damage come from the vacuum deposition process of upper passivation layers. From these results, a multilayer structure with upper SiOxNy film and lower PVA film is expected to be a superior passivation layer for OTFTs.

Keywords : Organic thin-film-transistors, Passivation, Degradation

1. INTRODUCTION

Organic thin-film-transistors (OTFTs) have been attracting much attention due to their low-temperature and low-cost fabrication process, and therefore their potential for application to novel, low-cost and large-area flexible electronics[1,2]. OTFTs can be used as switching devices for active-matrix flat-panel-displays (FPDs)[3-5], RF identification tags[6], sensors[7], etc. Among many organic semiconductors, pentacene has been showed the best performance until now[8-10]. Its mobility and switching ratio are no worse than those of a-Si:H TFT that is used for active-matrix liquid-crystal-displays (LCDs).

Pentacene OTFT is easily degraded with exposure to oxygen or water vapor. Therefore, a passivation layer is needed on pentacene layer to keep it from exposure to outer environment. Normally, organic layers are used as passivation layers to avoid the damage owing to plasma and ions of deposition processes of inorganic layers. However, organic passivation layers have no enough barrier properties to insure the reliability of OTFT to a commercial level. Therefore, we have considered using inorganic materials to passivate OTFTs because of their good barrier properties compared to organic materials. In this study, a plasma sublimation method was used for inorganic-layer deposition to reduce the damage of deposition process.

In this paper, we have studied SiOx and SiOxNy films as passivation layers for OTFTs by measuring the performance of OTFTs with those. These insulating films are widely used in FPD industries due to their easy and stable fabrication process and their good film qualities.

2. EXPERIMENTS

We made OTFTs using pentacene as organic semiconductor. At the first step, a gate electrode was fabricated on glass using aluminum (Al). Al was deposited using thermal evaporation and patterned using photolithography and wet etching process. On the gate electrode, an organic gate insulator[11] was made using spin coating and thermal curing. The thickness of gate insulator was 700 nm. On the gate insulator, a source and a drain electrode were made from gold (Au). Au was deposited using electron-beam evaporation and patterned using photolithography and wet etching process. The thickness of these electrodes was 50 nm. On these electrode patterns, pentacene was deposited using thermal evaporation and patterned by shadow mask. The thickness of pentacene layer was 70 nm. The width and the length of channel were 1000 μm and 100 μm, respectively. Figure 1 shows the schematic of OTFT fabricated following the procedure described above. Following this procedure, we made bottom-gate and bottom-contact structured OTFTs. Their transfer curves (that is, drain current according to the variation of gate bias voltage) were measured after these fabrication processes. Before the measurement, samples were thermally annealed during an hour at 100 °C in N_2 environment. The bias voltage for drain and source were -20 V and 0 V, respectively. The gate-bias voltage was varied from 20 V to -40 V. This measurement was done in N_2 environment to protect the organic semiconductor from air exposure. After this measurement of OTFT without passivation layer, a passivation layer was deposited on the upper side of OTFT. As inorganic passivation layers, SiOx and SiOxNy were used. Plasma sublimation method was used for the deposition. With this method, we could restrict the energy and density of ions that exist around the surface of substrate lower, so that the damage during the process could be reduced compared to that of conventional plasma-enhanced-chemical-vapor-deposition (PECVD) or sputtering method. The source material for these layers was SiO. The environments in the deposition chamber for SiOx and SiOxNy were oxygen and nitrogen, respectively. The thickness of inorganic passivation layer was 200 nm and the substrate temperature during deposition was controlled under 80 °C. Thermal annealing during one hour at 100 °C was applied before measuring the transfer curve of OTFT with passivation layer. In addition, polyurea monolayer and double layer of polyurea on polyvinyl acetates (PVA) were used as passivation layers to make OTFT samples for comparison with the OTFT with inorganic passivation. The same procedures for sample fabrication and measurement except changes of passivation layers were used. Polyurea layer was fabricated using vacuum polymerization deposition (VPD) method with the substrate temperature under 100 °C. The thickness of polyurea was 2000 nm. PVA layer was made using spin-coating and thermal curing at 100 °C. The thickness of PVA was 500 nm.

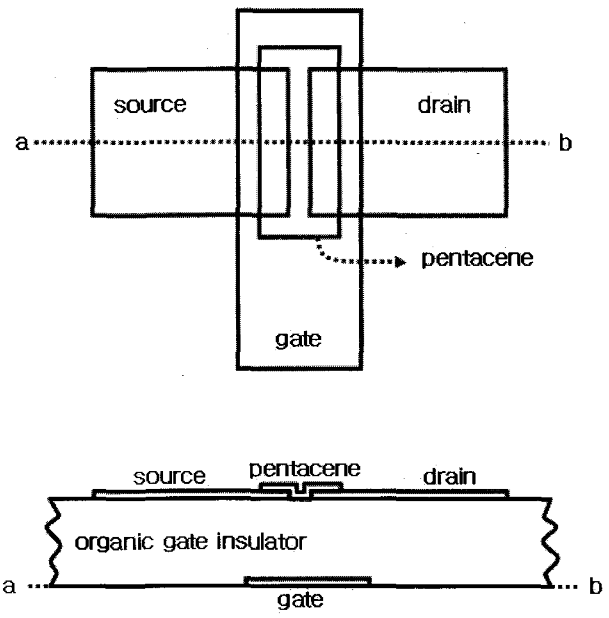

Fig. 1. Schematics of OTFT without passivation layers in plan view and cross-sectional view.

3. RESULTS AND DISCUSSION

As can be seen in Fig. 2(a) and 2(b), the SiOxNy passivated sample showed some degradation after a passivation process. On-state current was lowered and off-state current was raised. A similar phenomenon was observed in case of SiOx passivated sample; however, degradation was much larger than that of SiOxNy passivated one. Figure 2(c) shows the transfer curves of OTFT without passivation layer, right after SiOx passivation layer deposition and after thermal annealing. The performance of OTFT became worse after the thermal annealing process. SiOxNy seemed to be more adequate as a passivation layer than SiOx from the results of Fig. 2(a) and 2(b). This difference could be caused by the superior barrier properties of SiOxNy and the less damage during deposition of SiOxNy layer.

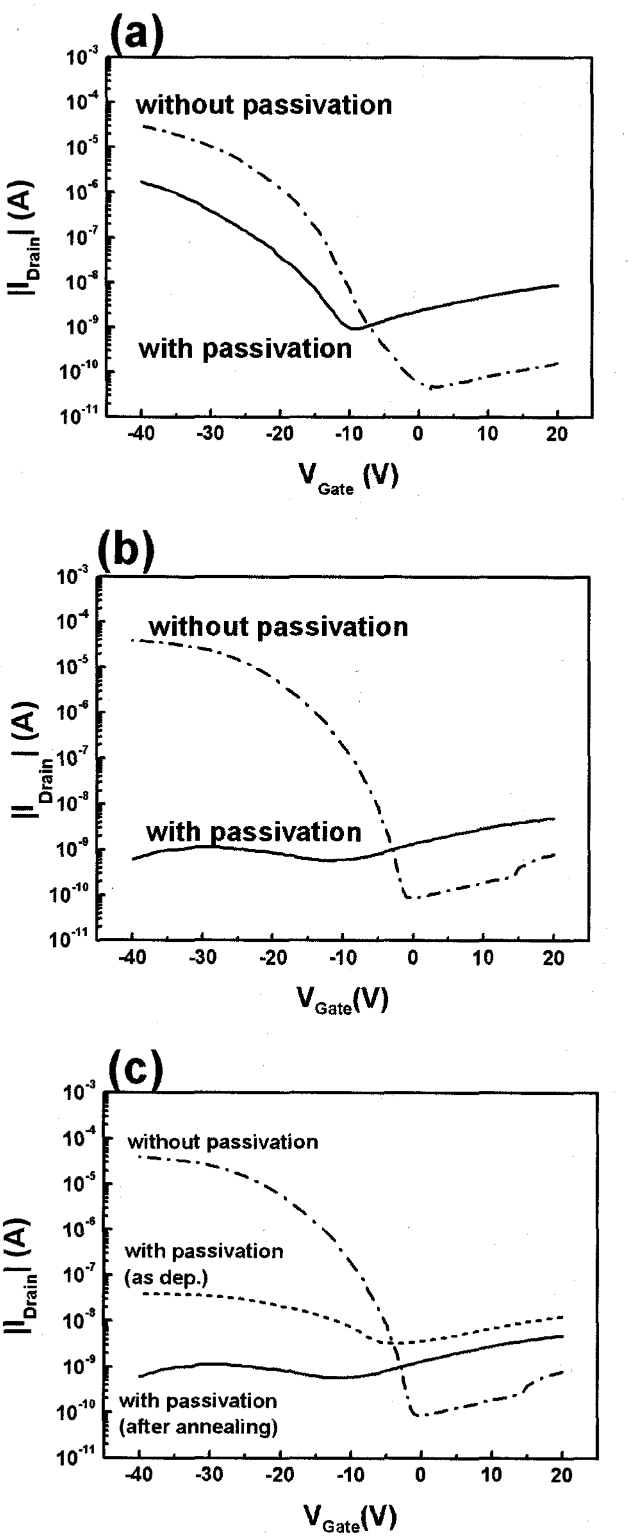

Fig. 2. (a) Transfer curves of OTFT without passivation layer and with SiOxNy passivation layer. (b) Transfer curves of OTFT without passivation layer and with SiOx passivation layer. (c) Transfer curves of OTFT before passivation, right after SiOx passivation and after thermal annealing. Source voltage was zero, drain voltage was -20 V and gate voltage was swept from 20 V to -40 V.

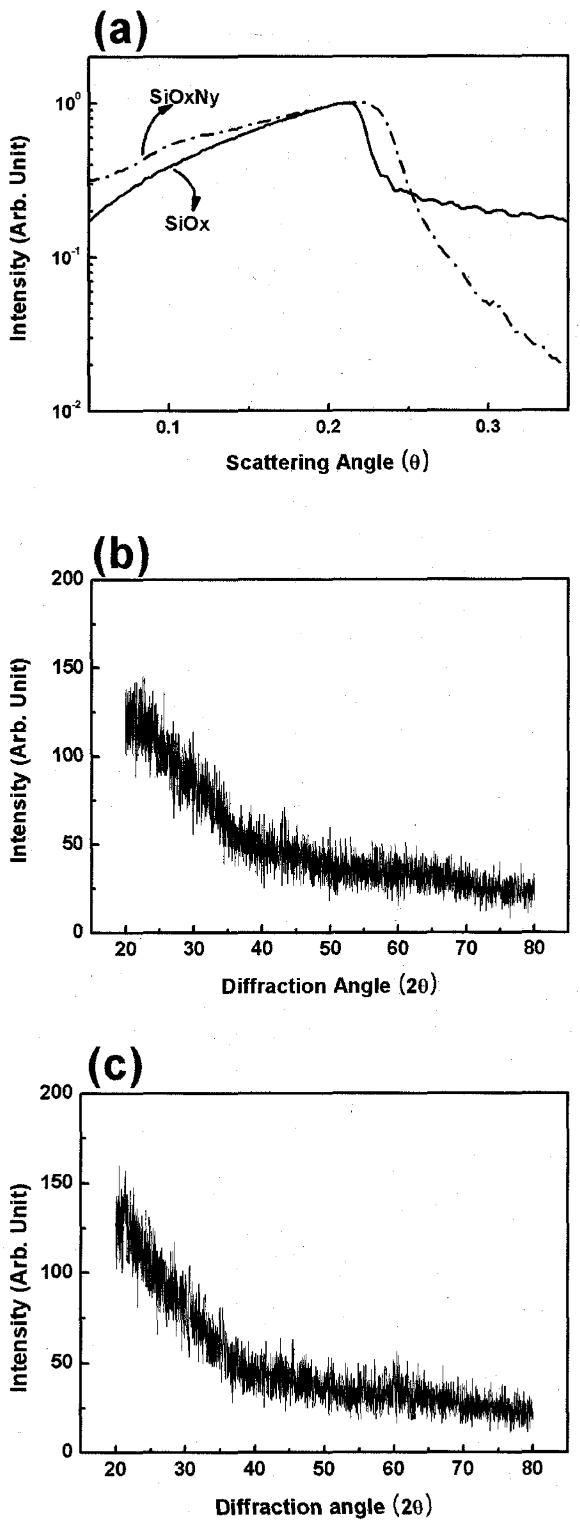

Fig. 3. (a) Results of X-ray reflectivity (XRR) measurements of SiOx and SiOxNy film. (b) Result of X-Ray diffraction (XRD) measurement of SiOx film. (c) Result of XRD measurement of SiOxNy film. The film thickness was 200 nm and the fabrication conditions were the same as those used for the deposition of passivation layers of OTFTs.

As shown in Fig. 3(a), we carried out X-ray reflectivity (XRR) analysis of SiOxNy and SiOx film to examine the difference of films. From these XRR measurements, we got the film densities as 2.64 g/cm^3 for SiOxNy and 2.3 g/cm^3 for SiOx. This higher film density of SiOxNy could be related to its better barrier property. Figure 3(b) and 3(c) shows the results of X-Ray diffraction (XRD) measurements of SiOx and SiOxNy, respectively. Both of films were amorphous phase. Water vapor transmission rate (WVTR) of 200 nm thick SiOxNy layer was less than 10^{-2} g/m^2/day; it was much lower than that of SiOx film. However, the degradation of OTFT performance after SiOx deposition was too large to be explained by the poor barrier properties of SiOx only. Generally, the performance of pentacene OTFT goes worse with exposure to oxygen environment[12]. SiOx film was deposited in oxygen environment using plasma sublimation method. Therefore, the oxygen and ions in the chamber could degrade the performance of OTFTs. Normally, degraded performance come from air exposure can be restored by thermal annealing near 100 °C on the contrary to the result of Fig. 2(c). From these facts, it seemed that the highly activated oxygen gas in the deposition chamber made some irreversible defects in the pentacene layer. It is not clear until now what the mechanism of this irreversible degradation is.

Figure 4(a) shows characteristics of OTFT without passivation layer and with polyurea passivation layer. The on-state current and the off-state current were reduced simultaneously. Defect generation and charge trapping on the backside hinder the band bending; as a result, the carrier accumulation of on-state and the carrier depletion of off-state are made harder. Therefore, backside defect creation and charge trapping could explain this lower performance. We also tested OTFT with double-layer passivation (PVA/polyurea) and the results are shown in Fig. 4(b). There was nearly no degradation for in case of double-layer passivated OTFT. PVA is normally used as passivation layer of pentacene OTFT because PVA material itself and its coating process do not make irreversible damage on pentacene layer. It could be said from the result of Fig. 4 that PVA protected the pentacene layer from the damage due to the following deposition process.

From the results of Fig. 2 and Fig. 4, it seemed that vacuum deposition process caused the pentacene OTFTs to be degraded. However, we had to use the vacuum-deposited inorganic layer as a part of passivation layers because the spin-coated organic insulating layers such as PVA were not good enough to protect OTFTs from outer environments. From the results of Fig. 2, SiOxNy deposited in non-oxygen atmosphere was more suitable as the passivation layer for OTFTs than SiOx made in oxygen atmosphere. This seemed to be because of its lower degradation effect and higher barrier properties. From the results of Fig. 4, it seemed that PVA could be used as a buffer layer to reduce the damage from the process of upper layer deposition.

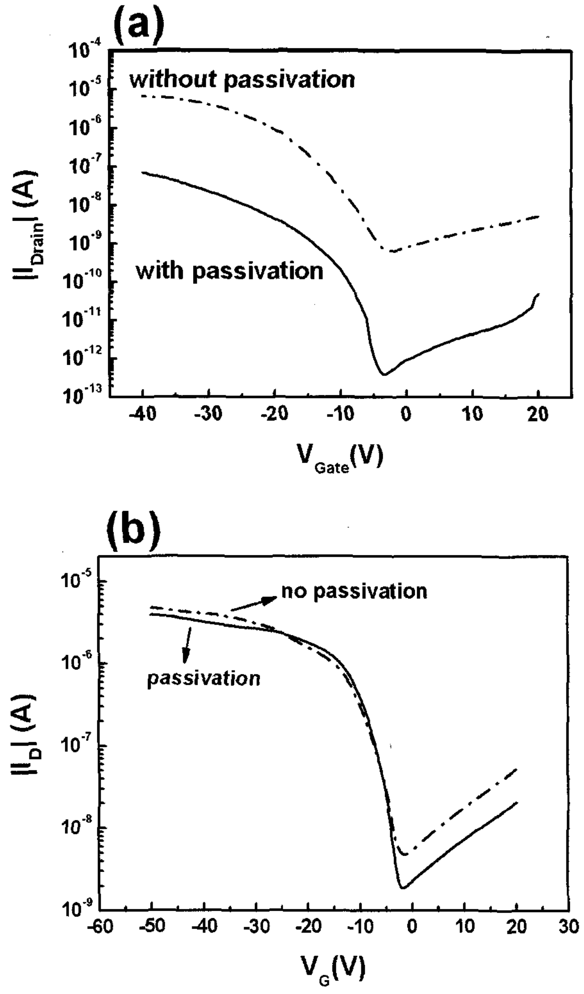

Fig. 4. (a) Transfer curves of OTFT without passivation layer and with polyurea passivation layer. (b) Transfer curves of OTFT without passivation layer and with polyurea/PVA double-layered passivation layer. Source voltage was zero, drain voltage was -20 V and gate voltage was swept from 20 V to -40 V.

4. CONCLUSION

SiOxNy and SiOx were studied as inorganic-passivation layers for OTFTs. Moreover, polyurea and PVA were tested as organic-passivation layers. The OTFT with SiOxNy passivation layer showed better performance than that with SiOx passivation layer. The better barrier property of SiOxNy related to its higher film density and oxygen environment during process of SiOx could cause this difference. PVA under layer protected pentacene layer from the damage due to the vacuum deposition process of upper passivation layer.

From this study, a multilayer structure with upper SiOxNy film having good barrier property and lower damage and under PVA film as buffer layer is expected to be a promising passivation layer for OTFTs.

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