A Study of Encapsulation Structure for TFT Reliability in Top Emission OLED Display

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ABSTRACT

Preventing hydrogen and water vapor from permeating through encapsulation layer plays an important role in TFT Reliability. To improve a blocking characteristic, enca psulation inorganic layers were studied. A multilayered ino rganic deposition method for Organic Light Emitting Displ ay has been developed to obtain a reliable performance. SiN_x and SiO_2 were used to create a multilayered structur e of the inorganic encapsulation and its blocking ability against hydrogen, water vapor permeation was compared with a single inorganic encapsulation. In conclusion, the inorganic multi-structure of encapsulation has shown an advanced performance in blocking.

1 INTRODUCTION

A top emission type Organic Light Emitting Diode (OLED) is widely using in mobile industry such as smartphone and smartwatch. The OLED Display is attractive because of its high contrast ratio, high resolution, high luminance, low power consumption and flexibility.

A Reliability of Oxide Thin Film Transistor (TFT) in the Top Emission OLED Panel is common interests for display concerned companies. An OLED Panel is manufactured by organic, inorganic, metal and oxygen-metal compound active layer; especially active layer can be deteriorated easily under exposure to hydrogen and moisture.

As an active layer in TFT, we used amorphous Indium Gallium Zinc Oxygen (a-IGZO). Since the active layer can become conductive under hydrogen and water vapor, it degrades TFT's characteristics and make white spot defect in the OLED panel. To prevent the defect from hydrogen and water vapor, a high barrier performance is required with low hydrogen amount [1], low Water Vapor Transmittance Rate (WVTR) [2]. The barrier film is deposited under low temperature less than 100°C to avoid burning out of organic material, low heat resistance is also demanded. [3].

To meet these requirements, many encapsulation structures were reported. Y. G. Lee et al. suggested multilayer structures using an intermediate layer to transparent inorganic barrier films such as Al_2O_3 films by sputtering and SiNx/SiOx multilayer films by Chemical Vapor Deposition (CVD).[4] To enhance barrier properties, a half organic and a half inorganic intermediate layer using hexamethyldisiloxane (HMDSO) was used and showed good transparent.[5] SiN_x/SiO_xC_y films were formed using a surface wave plasma chemical vapor deposition (SWP-CVD) method with five alternately laminated layers and were confirmed a high WVTR results.[6]

Many Products that are produced in recent years, as an encapsulation barrier layer, multilayers are used with inorganic-organic-inorganic structures. And as an inorganic film, SiNx thin film which is deposited in low temperature CVD is widely applied.

There are two types of panel defect caused by encapsulation damage. Foreign defects which are flowed in during encapsulation process appear usually inverted shape as shown in Fig.1, and gases can permeate easily through the inverted point. Hydrogen permeation in electroluminescence layer has been reported to cause dark spot defects in panel driving. Fig. 2(a) shows a permeation concept of hydrogen and water vapor from encapsulation layer itself. The penetrated hydrogen make the oxide layer conductive and as a result white spot defects are caused in a panel as shown in Fig.2(b).

In this study, we investigated the reliability of TFT characteristics by developing encapsulation structure. An encapsulation inorganic layer deposition concept is shown in Fig.3. Instead of single layer deposition in batch process, a multilayer was performed consecutively every 100nm as shown in Fig.4. The sequence of two inorganic layers was performed without breaking the vacuum in the different chamber.

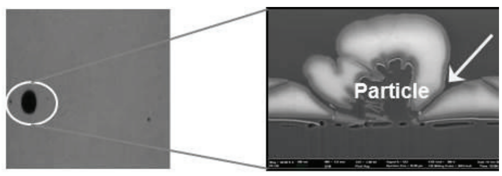
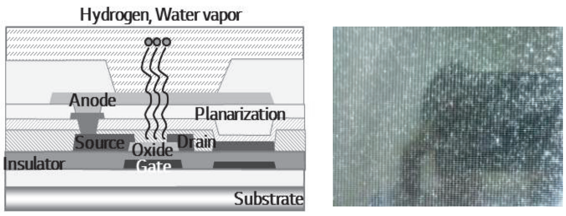


Fig.1 Sample of electroluminescence layer damage caused by a particle

2 EXPERIMENT

For encapsulation barrier layer, multilayers were used with inorganic-organic-inorganic structures, and as an inorganic film, SiN_x/SiO_2 was fabricated using plasma enhanced chemical vapor deposition (PECVD) at 100°C temperature with minimal damage to the low heat resistance organic materials. SiNx was deposited with SiH_4, NH_3 and N_2 gas was used as carrier gas. The gas flow rates were 3500sccm (N_2), 600sccm (NH_3), 100sccm (SiH_4). The total gas pressure was maintained at 1500mTorr and power was fixed at 1100W. SiO2 was deposited with SiH_4, N_2O gas and the gas flow rates were 3900sccm (N_2O), 65sccm (SiH_4). The Power was fixed at 1000W. The distance between the dielectric plate and the substrate stage was 470mils. The organic film was epoxy resin fabricated by coating method, which was 10micron thickness. The encapsulation film structure was as follows; inorganic /epoxy resin / inorganic.

To measure water vapor transmission rate (WVTR), it was implemented that test sample size 50cm2 in condition of 40±1°C, 100% RH. For the WVTR test, the new structure inorganic film in Fig. 2 was deposited on the PET substrates and it is compared with a reference value 1.45 $g/m^2 \cdot day$ WVTR of bare PEN substrate. To measure hydrogen transmission ratio, gas transmission ratio (GTR) tests were performed. The test is based on differential pressure method described in ISO15105-1:2007. The coated sample is located in the middle of upper and under chamber, and we read the differential pressure of those chambers. The coated samples on the PEN substrate (125micron thickness) were set 35°C, 10bar.



(a) (b)

Fig.2 Defect source inflow concept and defective product panel sample. (a) concept of H_2, H_2O permeation (b)sample of white-point-defects

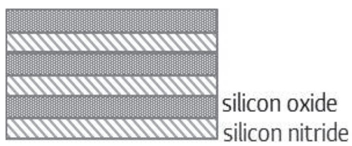
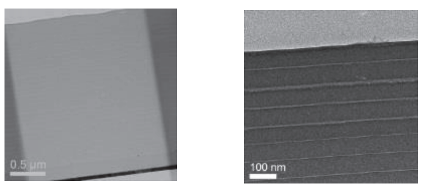


Fig.3 Concept of encapsulation inorganic layer



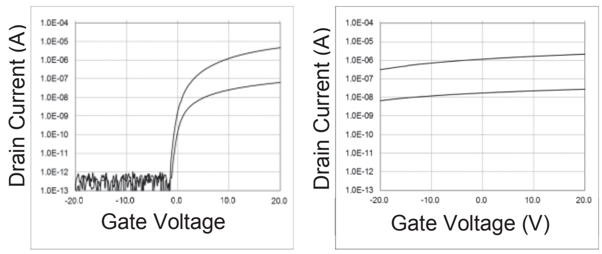
(a)SEM Image (b)TEM Image

Fig.4 SEM and TEM Image as a method of Fig.3

3 RESULTS and DISCUSSION

Fig.5 shows the representative transfer characteristics of Fig.2(a) a-IGZO oxide TFT device. The oxide TFT with SiN_x inorganic encapsulation exhibited threshold voltage (V_{th}) (-)1.5V at initial status, but the V_{th} showed negative shift characteristics over (-)10.0V after Negative Bias Temperature illumination Stress (NBTiS). In contrast with Fig.5(b), the oxide TFT with SiO_2 inorganic encapsulation showed V_{th} (-)1.5V after NBTiS with the same initial status. To explain the different V_{th} shifts of above devices, SIMS depth profiling of related species was performed and WVTR was measured.

It is shown in Table 1 that summary of inorganic encapsulation layer characteristics which are affecting device performance. It was observed that hydrogen amount in oxide layer is higher in the case of SiN_x encapsulation layer than SiO_2 encapsulation layer after NBTiS test. Hydrogen amount in SiN_x inner layer is higher than SiO_2 inner layer and we can presume that hydrogen is originated from encapsulation layer. It is estimated that hydrogen which is emitted from SiNx makes device unstable Vth shift because WVTR and GTR characteristics are better in the case of SiNx encapsulation layer than SiO_2 encapsulation layer.



(a) (b)

Fig.5 Current-voltage characteristics of oxide TFT (a) Initial Status (b) after NBTiS status

Table1. Summary of inorganic encapsulation layer characteristics

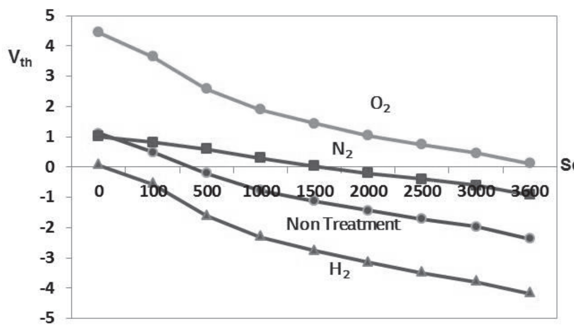
	SiN_x	SiO_2	SiN_x/SiO_2	Unit
SIMS	3.2~7.7	1.8~12.0	1.8~12.0	1H/In mean count in oxide layer
WVTR	$\sim10^{-4}$	$\sim10^{-1}$	$\sim10^{-4}$	g/m^2•day
Hydrogen Content	20~34%	5~8.5%	5~8.5%	%
GTR	~3.0	~20	~3.0	cc•m/atm• m^2•day

A high pressure annealing (HPA) test was performed to confirm a source from where hydrogen and water vapor came. We applied H_2,N_2,O_2 gases with 150°C, 9atm and maintained 10min. The test structures were shown in Fig.6. One is a bare device without encapsulation and the other is a device with a conventional inorganic/organic double encapsulation. NBTiS test results were shown in Fig.7.

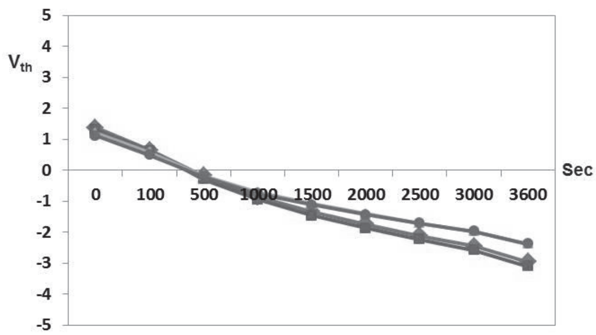
V_{th} variation was not shown in the case of encapsulation layer application in Fig.7(a), while V_{th} variations were observed in the case of no encapsulation layer in Fig.7(b).Under H_2 applied condition, the V_{th} shift took more severe than other gases, through this test, we confirmed that hydrogen is come from inorganic inner site and combined with oxygen in IGZO active layer.

(a) **(b)**

Fig.6 Cross plane of pressure and anneal experiment (a) encapsulation applied case and (b) non encapsulation layer case



(a) encapsulation layer applied case

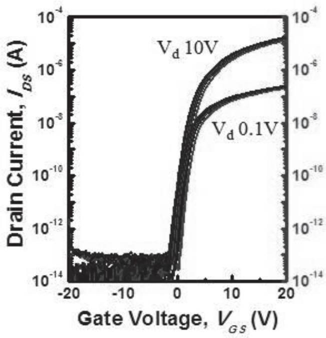


(b) non encapsulation layer case

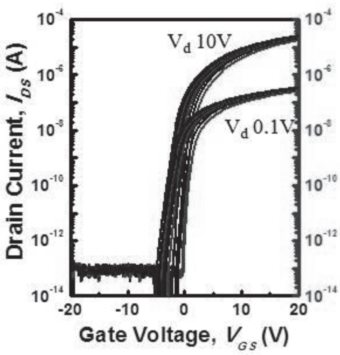
Fig.7 V_{th} shift of NBTiS after HPA treatment

Some of the incorporated hydrogen species act as shallow donors. Therefore, the tailing states below the conduction band minimum of a-IGZO semiconductor for the multilayer will be less filled because of the lower hydrogen donated free electrons. Kamiya et al., explained hydrogen doping in active layer forms –OH bonds, which ionizes the doped hydrogen to H+ and generates a free electron and the hydrogen work as a donor [7].

As shown in Table 1, SiNx encapsulation layer has a better quality in WVTR, GTR characteristics than SiO_2 encapsulation one, on the other hand, SiO_2 layer is more stable in V_{th} shift than SiNx layer. With the two inorganic layers alternating combination, as shown in Fig.3 and Fig.4, we were intended to obtain synergy effect of WVTR, GTR and V_{th} stability. The 1.0micron thickness encapsulation structure was demonstrated with five alternating SiN_x 100nm/SiO_2 100nm. As a results, it was shown that a similar characteristics with SiO_2 only layer, WVTR ~10-4 g/m^2·day, GTR 3.2 cc·m/atm·m^2·day. The composite structure showed a good quality in WVTR and GTR. A TFT characteristic was shown in Fig.8 with NBTiS 1hr testing. The last Vth shift was about (-) 5.0V and less than SiNx only layer in Fig.5(b), but there was a need to improve the encapsulation layer quality until Vth lower than (-)1.5V as same as Fig.8(a). We made a panel sample with the composite structure encapsulation and it showed a good quality without a white-spot defect, but gate driver TFT degradation was shown after high temperature timing test with dimming.



(a) SiO_2 encapsulation layer



(b)SiN_x/SiO_2 multi-encapsulation layer

Fig.8 Current-voltage characteristics of oxide TFT after NBTiS

4 CONCLUSIONS

To prevent hydrogen and water vapor from permeating through encapsulation layer, we have developed a multilayered inorganic deposition method with SiN_x and SiO_2 layers. When comparing with a single inorganic encapsulation, the multilayered encapsulation has been shown an advanced performance in blocking hydrogen and water vapor. But Vth shift was not perfectly improved. For better improving the inorganic layer quality, we are intended to try combining SiON or SiOC layers.

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