Effect of Thermal Heat Treatment on the Characteristics of Vertical Type Organic Thin Film Transistor Using Alq_3 as Active Layer and Its Application for OLET

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Keywords : ***Alq_3, Morphology, Vertical type transistor, Deposition condition***

Abstract

We have fabricated vertical type organic thin film transistor using tris-8-hydroxyquinoline aluminum (Alq_3). The effects of the growth control of Alq_3 thin layer on the grain structure and the flatness of film surface have been investigated. In addition, we have fabricated light emitting transistor and then investigated electroluminescent properties.

1. Introduction

Organic field effect transistors (OFETs) are promising for the active devices for flexible [1], low cost [2], simple process and large area photoelectric devices [3]. However conventional field effect transistors (FETs) using organic materials have low-speed, low-power and high-resistivity because of their long channel length between drain and source electrodes. Vertical type static induction transistor (SIT) is a promising device to improve the problems because of the high-speed and high-power operation [4]. Also vertical type transistors have some advantages for organic photoelectric devices.

In this study, we have fabricated SITs of vertical structure using Alq_3 to improve the problems of conventional OFETs. Alq_3 has been commonly used as an organic light-emitting host as well as electron transport layer (ETL) in organic light-emitting diodes (OLEDs) [5,6]. In general, it can be argued that the characteristics of organic transistor were influenced by carrier mobility and density. The morphology of film surface affects carrier mobility and density. Thus, morphological effects of the growth control of Alq_3 thin layer on ITO substrate on the grain structure and the flatness of film surface was investigated. Alq_3 thin films containing various surface morphologies are controlled by changing the evaporation rate and substrate temperature. The substrate temperature and deposition rate were demonstrated to have a great effect on the performance of devices [7], in which Alq_3 was used as an active material.

In addition, we have investigated the feasibility of fabrication of OLET (organic light emitting transistor) based Alq_3 having electron transfer and emitting property.

2. Experimental

The vertical type OTFTs consisting of Al/Alq_3/Al/Alq_3/ITO/glass were fabricated. All layers were fabricated on patterned ITO (≤15 Ω/□) glass substrate using vacuum evaporation technique (ULVAC VTR-300M/1ERH evaporator) under 10^{-6} Torr. Before film fabrication, the patterned ITO substrates were immersed into ultrasonic bath of DI water, acetone and methanol for 60 min, subsequently. Then cleaned ITO glass substrates were rinsed in DI water and blown by N_2 gas.

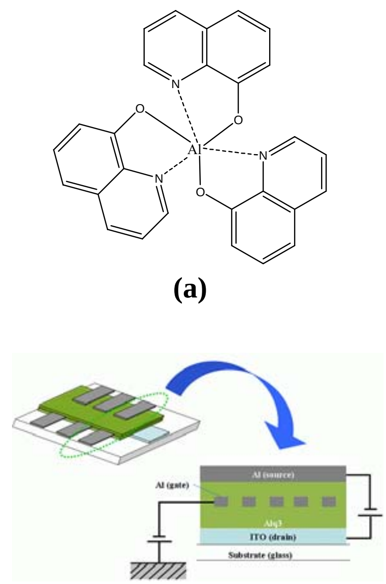
Firstly, Alq_3 (TCI Co., purity 99.5%) was deposited onto the patterned ITO glass substrate. In order to study the effects of morphology, active layers of Alq_3 films on ITO glass substrate were deposited under different conditions. The Alq_3 films were deposited by controlling the substrate temperature of 50, 100 and 150 ℃, respectively. The evaporation rate of Alq_3 was maintained at 1 Å/sec and 5 Å/sec for each substrate temperature. The thickness of Alq_3 layer was approximately 600, 800 and 1000 Å, respectively.

Then, a grid type Al gate electrode was formed on top of the deposited organic film by shadow evaporation technique. The structural control of Al gate electrode is very important in the performance of the vertical type OTFT [8,9]. Thus, the Al gate having 100 μm grid type was used in the present work. The thickness of Al gate electrode was 300 Å. The grid type Al gate electrode should be buried in Alq_3 active layer. Second organic layer was deposited onto the gate electrode by the same method of first organic layer. Lastly, Al films were deposited on the top of the organic layer with the thickness of 1000 Å on the same equipment. These devices had an effective area of about 0.04 cm^2.

The static characteristics of vertical type OTFT were investigated using Keithley 237 and 2400 programmable source meter. And radiance characteristics were measured by a Newport 1830-C photodiode. All tests were performed in N_2 atmosphere at room temperature. The surface morphology of Alq_3 layer under various deposition rates and substrate temperature was investigated with atomic force microscope (Park Scientific Instrument, AFM).

3. Results and discussion

The structure of Alq_3 and vertical type organic thin film transistor (OTFT) consisting of Alq_3 as active layer was shown in Fig. 1. Fig. 2. shows the current density-voltage (J-V) curve of vertical type organic transistor using Alq_3 with varying thickness of active layer. The thickness of active layer was demonstrated to have a great effect on the performance of vertical type OTFTs. At an operating voltage of 20 V, the currents of device fabricated at 1200, 1600 and 2000 Å are 11.71, 2.25 and 0.47 mA, respectively. It is found that the device fabricated thickness of 1200 Å has the highest current at an operating voltage. And the on-off ratio showed a maximum value of 91.36 at a thickness of 1200 Å, which implies that I_{DS} can be controlled effectively at the optimum thickness of active layer. In the case of the thickness is smaller than 1200 Å, the leakage current become large. Therefore the device couldn't control effectively. The Alq_3 acted as electron transporting material in our device. Drain-source current (I_{DS}) at a constant drain-source voltage (V_{DS}) decreased with increasing a gate voltage (V_G) as shown in Fig. 3. The electron carriers injected from the source electrode flow between source and drain electrodes through potential barrier near the gate electrode. The gate electrode blocks the carrier migration from source electrode to drain electrode due to the formation of double Schottky barriers [9]. The potential barrier is increased with the increase of gate voltage. Thus, I_{DS} could be controlled by the negative gate voltage.



(a)

(b)

Fig. 1. Structure of Alq_3 and vertical type organic thin film transistor using Alq_3.

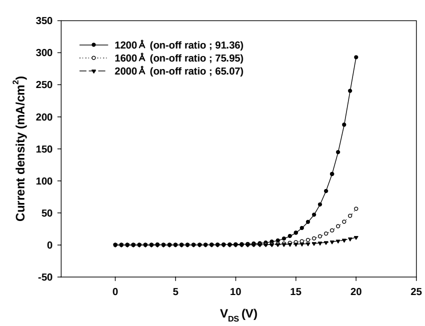
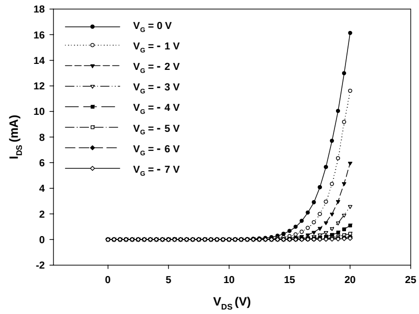
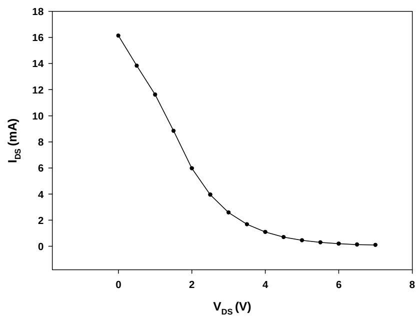


Fig. 2. Current density-voltage characteristics curve of ITO/Alq_3/Al/Alq_3/Al with varying Alq_3 active layer.

Fig. 4. shows AFM image of the Alq_3 thin films on ITO substrates with an area 3 × 3 $μm^2$. The images were taken from the film deposited under various growth conditions: substrate temperature of 50, 100 and 150 ℃; and deposition rates of 1 and 5 Å/s. Film thickness of all the films was 600 Å, as indicated by the deposition monitor. As shown in Fig. 3, the surface morphology strongly depends on the growth conditions.



(a)



(b)

Fig. 3. I-V characteristics of vertical type organic thin film transistor using Alq_3.

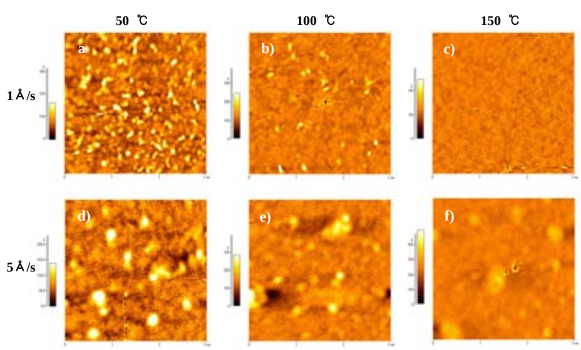


Fig. 4. AFM images of thermally evaporated Alq_3 thin films on ITO substrate with various deposition conditions.

A dense and smooth surface morphology was obtained at substrate temperature of 150 ℃ and deposition rate of 1 Å/s. When the substrate temperature increases and deposition rate decreases, the Alq_3 film becomes more uniform and has a smaller roughness than those fabricated at lower substrate temperature and higher deposition rate. The enhanced morphology of Alq_3 deposited at a higher temperature and low deposition rate might facilitate a better interface between Alq_3 and Al source electrode which might attribute to the current and on-off ratio improvement. Thought the substrate temperature does not change the chemical structure of Alq_3, the amorphous state of Alq_3 fabricated at different temperatures might be different because of different perpendicular orientation of the quinoline groups of Alq_3 in the films [10]. As shown Fig. 4. the Alq_3 amorphous state also contributes to the performance improvement of the device. Table 1. showed the transistor properties of device under various deposition conditions. The maximum on-off ratio of 169.71 was obtained when substrate temperature of 150 ℃ and deposition rate of 1 Å/s. Owing to the dense surface morphology, the on-current of device was improved. Thus, the higher on-off ratio was obtained. The deposition condition of Alq_3 is a critical factor in the performance of Alq_3-based vertical type organic thin film transistors due to its effect on film morphology.

TABLE 1. The characteristics of vertical type organic thin film transistor using Alq_3 depend on deposition conditions.

Deposition rate	Substrate Temperature	Current (mA)	On-off ratio
1 Å/s	50 ℃	V_G = 0 V ; 11.7126 V_G = -7 V ; 0.1282	91.36
	100 ℃	V_G = 0 V ; 14.5059 V_G = -7 V ; 0.1109	130.76
	150 ℃	V_G = 0 V ; 16.1289 V_G = -7 V ; 0.0950	169.71
5 Å/s	50 ℃	V_G = 0 V ; 5.5294 V_G = -7 V ; 0.0874	63.25
	100 ℃	V_G = 0 V ; 8.2847 V_G = -7 V ; 0.0792	104.62
	150 ℃	V_G = 0 V ; 12.6676 V_G = -7 V ; 0.0921	137.56

We have also investigated the emission characteristics from the vertical type organic transistors consisting of ITO(drain)/Alq_3(emitting layer)/Al(gate)/Alq_3(emitting layer)/Al(source).

Radiance-voltage characteristics of vertical type light emitting transistor were shown in Figure 5. The radiance at a constant V_{DS} decreased with increasing the V_G like I-V characteristics. It can be argued that the radiance of device can be controlled by applying gate voltage. However, our device has low light-emitting characteristics because of thicker active layer of Alq_3 film than active layer of OLEDs using Alq_3 and does not use hole-injection layers. Hence it must be worth studying organic light-emitting transistors

(OLETs) using Alq_3 in more detail.

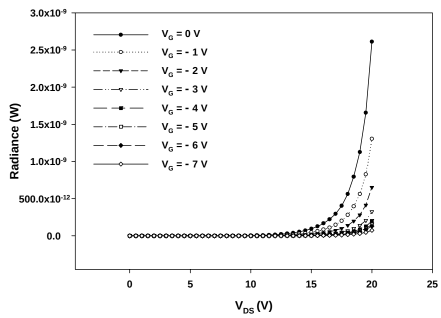


Fig. 5. I-V-L characteristics of vertical type organic lighting emitting transistor using Alq_3.

4. Summary

Vertical type organic thin film transistor using Alq_3 were fabricated by varying the substrate temperature and deposition rate of Alq_3 active layer. The surface roughness of Alq_3 decreased with increasing substrate temperature and decreasing evaporation rate because of the change in amorphous state of Alq_3. The deposition condition of Alq_3 is a critical factor in the performance of Alq_3-based vertical type organic thin film transistors due to its effect on film morphology. In addition, we have also investigated the emission characteristics from the vertical type organic transistors using Alq_3 as active layer. The light-emitting transistors showed switching characteristics. It should be emphasized that it is possible to fabricate the vertical type OLET using Alq_3.

5. Acknowledgments

This work was supported by the Basic Research Program of the Korea Science & Engineering Foundation (R01-2006-000-10196-0) and the second stage BK 21.

6. References

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