Characteristics of directly sputtered Al cathode film using twin target sputtering system for OLEDs

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Abstract

Characteristics of Al cathode films deposited by using specially designed twin target sputter (TTS) system were investigated. It was found that Al cathode films prepared by TTS were amorphous structure with nanocrystallines due to low substrate temperature and OLEDs fabricated using TTS system have low leakage current density at reverse bias because of effective confinement of energetic particles during sputtering process.

1. Introduction

Organic light-emitting diodes (OLEDs) are attracting considerable attention because of its potential applications in flat panel displays and flexible displays.[1,2] In the fabrication of OLEDs, thin metal electrode layers such as Al and Mg-Ag are conventionally deposited by resistive heating-induced thermal evaporation method. However, thermal evaporation method has critical drawbacks such as creeping up of Al on the crucible wall, difficulty in achieving a stable rate control and a large area deposition. For these reasons, sputtering method has been considered as alternative deposition technique for metal cathode preparation. Sputtering is one of the commonly used deposition technique in semiconductor and displays due to its simplicity, high throughput and excellent adhesion.[3-5] However, the bombardment of energetic particles during the sputtering process can result in damage to the underlying organic layers.[6] Despite many efforts to prevent plasma damage effect during the sputtering process, the development of direct cathode metal sputtering technique is still under way. Therefore, the development of direct sputtering method for Al cathode layer on organic layer without buffer or protective layer is imperative to solve the problems of Al thermal evaporation and applying sputtering process in fabrication of large area OLEDs.

In this experiment, we report on the plasma damage free Al cathode sputtering technique using specially designed twin target sputtering system for OLEDs. Al films deposited on glass substrate exhibited amorphous structure with nanocrystallines due to the low temperature process and OLEDs with Al cathode layer prepared by TTS system showed very low leakage current density at reverse bias. This indicates that TTS is one of the promising metal deposition techniques for large area OLEDs.

2. Experimental

To deposit Al metal cathode on organic layer directly, we employed a specially designed TTS system. The TTS system not only has several advantages, such as low working pressure, low substrate temperature, low damage, and high plasma density, but also obviates the bombardment of energetic particles during conventional sputtering processes. Originally it was developed to deposit transparent top cathode layer in top-emitting OLEDs by sputtering technique without plasma damage effect on organic layer. Prior to fabricate TTS system, magnetic field simulation for high efficiency and effective confinement of electrons during sputtering process was carried out using Maxwell, a finite element solver. To optimize deposition condition, Al films were deposited by TTS system as function of power, target to substrate distance and working pressure. Structural and surface properties of Al films were examined by synchrotron x-ray scattering and field-emission scanning electron microscopy. Variation of substrate temperature during sputtering process was measured by thermo couple and thermal tape. To confirm plasma damage effect during sputtering process using TTS system, fluorescent organic light-emitting devices consist of ITO/glass anode, 60 nm-thick 2-TNATA, 20 nm-thick NPB, 60 nm-thick Alq_3 and 1.5 nm-thick LiF were fabricated. Then Al cathode layer was deposited on LiF layer by TTS system. For comparison, OLEDs with Al cathode layer deposited by DC magnetron sputter system was prepared. Current-Voltage (I-V) characteristics of OLEDs using TTS system and DC magnetron sputter system were measured by parameter analyzer at room temperature.

3. Results and discussion

Figure 1 shows a schematic diagram of TTS system and picture of plasma confined between two Al targets. Two Al targets are placed face-to-face generating high magnetic field lines entering and leaving between the Al targets perpendicularly.

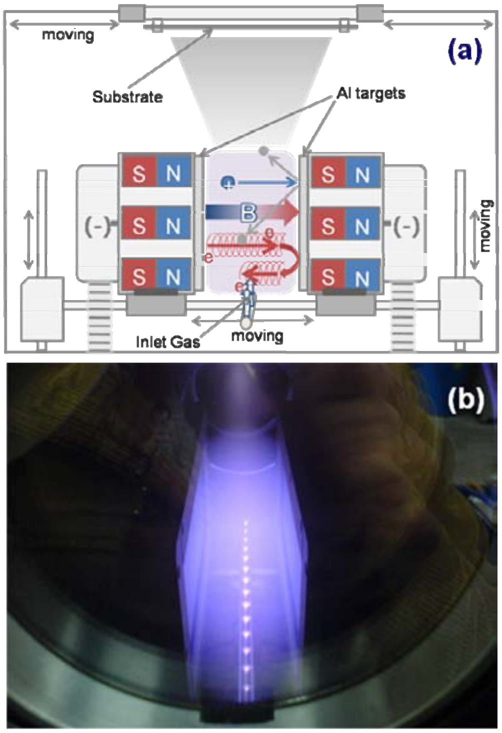

Fig. 1. (a) Schematic diagram of specially designed twin target sputter system and (b) picture of confined plasma between two Al targets.

During the sputtering process, electrons due to negative voltage of both targets are held by Lorentz force spiraling with the helix pitch and oscillate between two Al targets placed face-to-face. Thus, most of energetic particles could be confined within the magnet field as shown in Fig. 1(a). Confined plasma shape due to confinement of electrons between the Al targets was shown in Fig. 1(b). To achieve high efficient deposition process and effective confinement of energetic particles during sputtering process, it is important to design the magnet arrays in twin target gun. To optimize magnet array, we performed magnetic array simulation. Figure 2 shows a magnetic field simulation results according to several types of magnet arrays. In case of conventional facing target array in Fig. 2(a), high magnetic fields are observed at side region due to existence of magnet at edge of facing target sputter gun. In this case magnet array, effective sputtering process is difficult because of relatively low magnetic field density for center position of sputter gun. However, through the additional magnets in center of sputter guns like ladder, strong and uniform magnetic field density can be obtained as shown in Fig. 2(b). Due to existence of ladder type magnet, the efficient confinement of high-density plasma at the center region of rectangular shape gun is possible. Furthermore, through decreasing target to target distance with optimized magnet arrays, the uniformity of magnetic fields between the Al targets can be improved as shown in Fig. 2(c).

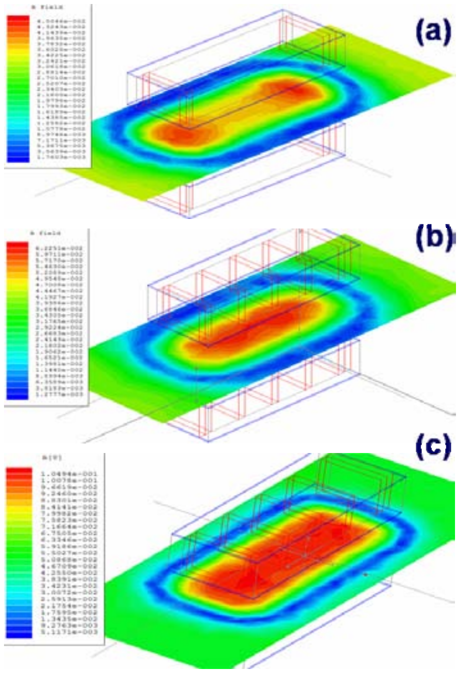

Fig. 2. Magnetic field simulation results. (a) conventional facing target magnet array, (b) ladder type magnet array used in TTS and (c) ladder type magnet array with short target-to-target distance.

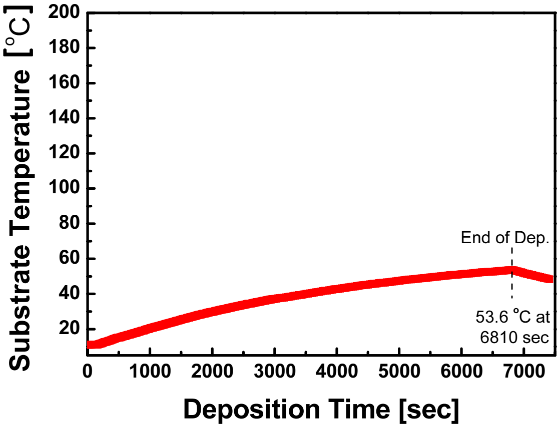

Fig. 3. Temperature variation of substrate during sputtering process.

Figure 3 shows temperature variation of glass substrate during TTS process as a function of sputtering time. The temperature of center region of glass substrate was *in-situ* measured by thermo couple during TTS process for 2 hours. It is noteworthy that substrate temperature during TTS process is kept below 53.6℃ even though sputtering process is carried out for 2 hours. This indicates that bombardment of energetic particles to substrate during sputtering process was effectively restricted by confinement of plasma between the Al targets.

Surface properties of Al films deposited by TTS system as function of DC power was examined by FESEM analysis. Figure 4 shows surface FESEM image of Al cathode film grown by TTS. It was shown that surface image of Al film deposited using DC power of 400 W (Fig. 4(a)) is very smooth without surface defects such as crack or pinholes. Due to low substrate temperature during TTS process, surface of TTS-grown Al film with power of DC 400W exhibits very fine grains. In addition, TTS grown Al film prepared with DC power of 1200 W exhibit more dense and well-ordered surface than that of Al film grown at DC 400W.

Figure 5 shows synchrotron x-ray scattering result of Al film deposited on glass substrate by TTS system. Very weak x-ray diffraction peaks of (111) and (222) direction indicated that the Al film is deposited on low substrate temperature due to effective confinement of high density plasma between Al targets. This is consistent with measured substrate temperature which is shown in Fig. 3. From the synchrotron x-ray scattering result, it was thought that TTS grown Al film is amorphous structure with nanocrystallines.

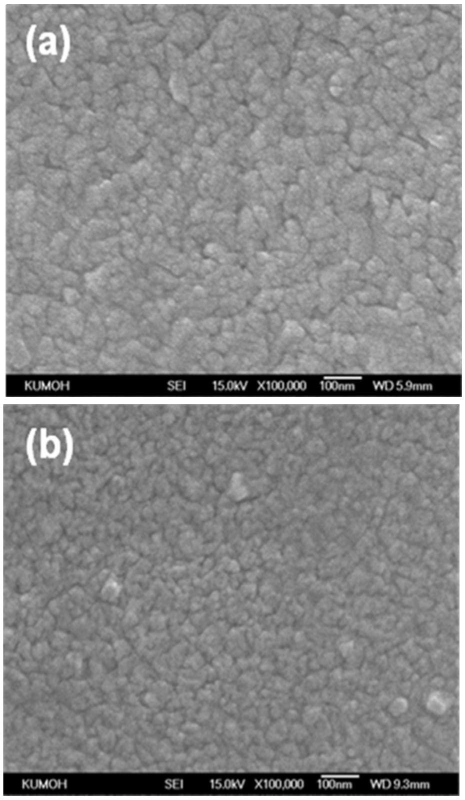

Fig. 4. Field-emission scanning electron microscopy results of Al films deposited by TTS system as function of power. (a) 400 W, (b) 1200 W.

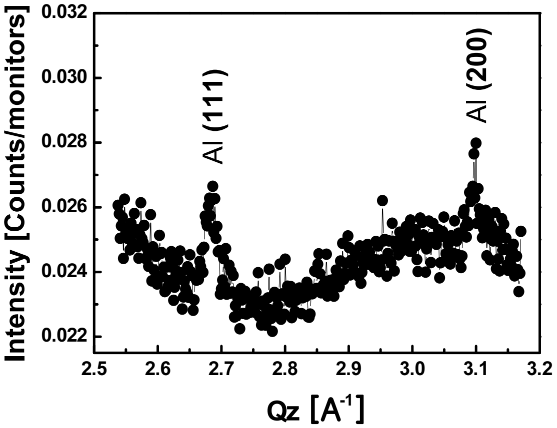

Fig. 5. Synchrotron x-ray scattering result of Al film prepared by TTS system.

Figure 6 shows current density-voltage characteristics of OLEDs with Al cathode deposited by TTS system and DC magnetron sputter system. OLEDs with Al cathode deposited by TTS system exhibited very low leakage current density of 3×10^{-6} mA/cm^2 at reverse bias of -6 V. But OLEDs with DC magnetron sputter system grown Al cathode exhibited high leakage current density of 6.5×10^{-4} mA/cm^2 at -6 V. High leakage current density of OLEDs prepared by DC magnetron sputter system is believed to be caused by the bombardment of energetic particles during the Al sputtering.

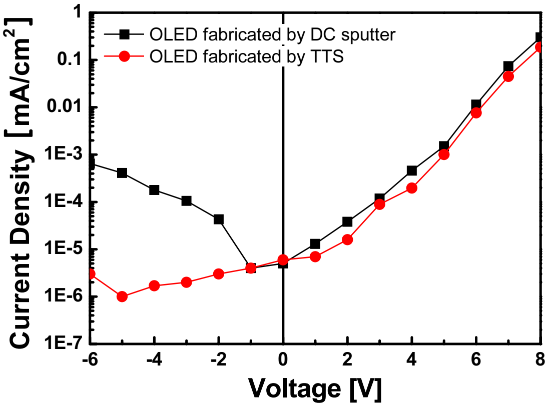

Fig. 6. Current-voltage characteristics of OLEDs with Al cathode layer deposited by TTS system and DC magnetron sputter system.

4. Summary

We successfully achieved direct Al cathode sputtering on organic layers without plasma damage effect by using TTS system. The effective confinement of plasma and energy dispersion of the energetic particles in the confined plasma region permitted OLEDs with directly sputtered Al cathode to be prepared. TTS technique is expected to apply organic based optoelectronics due to its low process temperature and plasma damage free deposition.

5. References

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