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Low-voltage Sputtering Deposition of Transparent Conductive GAZO Thin Films for Minimizing Damage to Organic Layers

SEULA LEE, JINSEON LEE, HYUNG WOOK CHOI, AND KYUNG HWAN KIM*

Department of Electrical Engineering, Gachon University, Gyeonggi, Korea

Organic electronics devices could have many advantages such as flexibility, simple process and low fabrication cost. Minimizing damage to organic layers during sputtering is important for the improvement of organic optoelectronic performance and lifetime. In order to achieve improved device performance, degradation of organic layers, which could be occurring during manufacturing, should be suppressed. Among the methods available for the fabrication of transparent electrodes, sputtering deposition possess many advantage over others, such as simple apparatus and procedure, high deposition rate, and wide deposition area. [1] Because of its unique structure, the use of a facing targets sputtering (FTS) system could effectively reduce damage during sputtering. [2] In this study, we prepared transparent, organic, GAZO thin films deposited onto Alq3 using an FTS system for the purpose of investigating the damage caused to organic layer by sputter deposition. To measure the damage sustained by organic materials during sputter deposition, we carried out depositions of transparent, conductive, gallium-aluminum doped Zinc Oxide (GAZO) thin films onto organic layers, using an FTS system.

Keywords GAZO; Photoluminescence; Facing targets sputtering; Low voltage; OLED

Introduction

Transparent displays are a next-generation display application with a broad potential market. [1, 2] In the OLED structure, BLU could be omitted because it includes self-emissive organic material. Because of the low prices of organic materials, it is possible to cut production costs. But, deposition of transparent electrodes onto organic emission layers is inescapable and can lead to the deterioration of the organic layers. To improve device performance, degradation of organic layers should be suppressed. Among the methods available for the fabrication of transparent electrodes, sputtering deposition possess many advantages. [3] Specifically, because of its unique arrangement of cathodes, the facing targets sputtering (FTS) system could suppress damage to organic layers during deposition more effectively than other sputtering methods. In this apparatus, two targets face each other and magnets are

*Address correspondence to Kyung Hwan Kim, Department of Electrical Engineering, Gachon University, 1342 Seongnamdaero, Sujeong-gu, Gyeonggi, 461-701, Korea (ROK). E-mail: khkim@gachon.ac.kr

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placed behind them. Thereby, dispersion of high-energy charged particles, can be restricted by the magnetic field between the targets. Substrates are placed outside the plasma region, [4] so, the number of high-energy particles that can reach the substrates were reduced. So, we carried out depositions of transparent, conductive, gallium-aluminum doped Zinc Oxide (GAZO) thin films onto organic layers, using FTS system.

Experimental

For the purpose of investigating the damage done to organic layers during sputtering, Alq3 (tris(8-hydroxyquinolinato)aluminum) thin films were deposited by thermal evaporation. Alq3 is an organic material that has been widely adopted for the emission layer. [5] In this study, glass substrates were used. They were ultrasonically cleaned in acetone, deionized water, and ethyl alcohol and then dried in nitrogen gas. For Alq3 deposition, the evaporation chamber was initially evacuated to a pressure of 4.0×10^{-6} Torr. By adjusting the input current, and the thickness of the Alq3 organic layer was fixed at 1000 Å. After deposition of the organic thin films, transparent, conductive, GAZO thin films were deposited using the DC FTS system. The base pressure of the sputtering chamber was 4.5×10^{-6} Torr. The deposited GAZO thin films were 100 nm thick and, in order to analyze the correlation between organic layer damage and sputtering voltage, input power was kept 25 and 50 W approximately using a voltage control. Investigation into organic layer damage was performed by comparing PL (photoluminescence) spectra. Also, Structural properties of the GAZO thin films were analyzed by X-ray diffraction (Rigaku, D.MAX 2200). The optical properties of the samples were evaluated using UV-Vis spectroscopy (Agilent, 8453). Electrical properties were investigated via Hall-effect measurements (Ecopia, HMS-3000).

Results and Discussion

Figure 1 shows the normalized PL intensities. PL emission was measured over a wavelength range of 460 to 600 nm, using an excitation wavelength of 350 nm. For this analysis, PL intensities were normalized to the peak intensity value observed in bare Alq3. The spectra of all samples included an emission peak near 520 nm, corresponding to a yellowish-green emitted light. This result agrees well with previously reported Alq3 emission properties. [6, 7] The PL intensities of the GAZO thin film samples decreased by 37–66% compared to that of the bare Alq3. When an input power of 50 W was used, relative PL intensities increased by 35 to 62%, depending on the working pressure, in the range of 1 to 5 mTorr. This suggests that organic layer damage can be suppressed during sputter deposition by varying the working pressure. When the working pressure is low, sputtered molecules can travel farther without collision, as a result of the low density of residual gas molecules. In other words, at low pressures sputtered molecules can have large mean free paths and retain their high energies until reaching the substrate. [8] At higher working pressures, there are more residual gas molecules and the energies of the particles that reach the substrate are lower. As a result, damage to organic layers during sputter deposition decreases with increasing working pressure. [9] This deduction agrees well with results obtained using an input power of 50 W. To determine the effects of input power, the same procedure was repeated using an input power of 25 W and results were compared with those obtained using an input power of 50 W. Using an input power of 25 W, relative PL intensities increased with increasing working pressure, as was observed when an input power of 50 W was used. Relative peak intensities for samples prepared using an input power of 25 W increased, compared to those prepared using an input power of 50 W, by approximately 7,

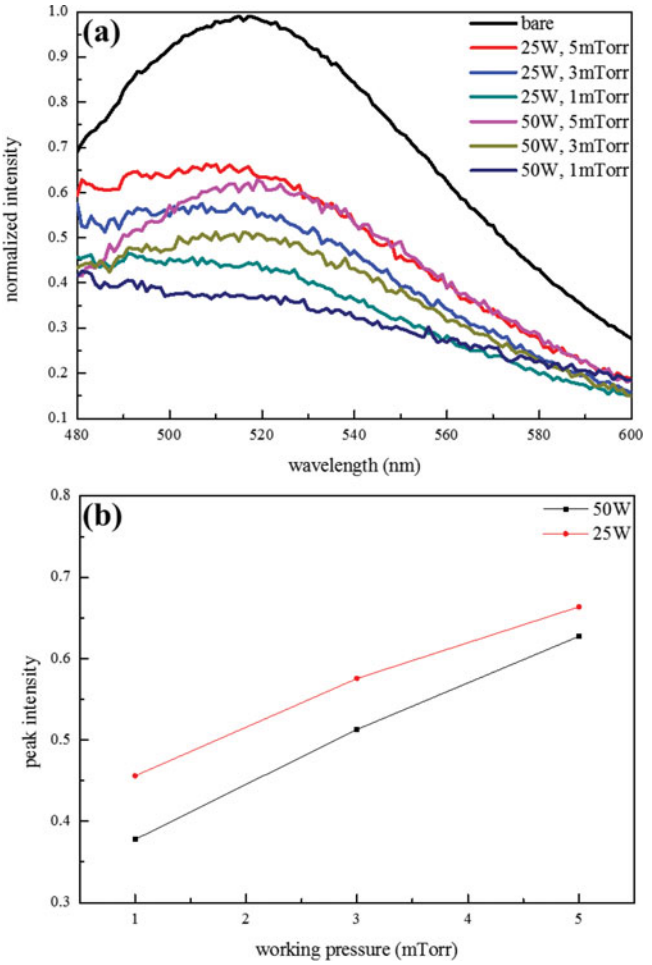

Figure 1. Normalized PL intensity of the bare Alq3 and the samples that the GAZO thin films were deposited onto Alq3 layer (a) and the relative intensity of the peak near wavelength of 520 nm (b) under various condition.

6, and 4%p at working pressures of 1, 3, and 5 mTorr, respectively. These changes are less significant than those observed working pressure was varied. This implies that the damage done to organic layers during sputter deposition is influenced more by working pressure than input power. The electrical properties of the electrodes produced were evaluated by hall-effect measurements and the results are presented in Figure 2. Figures 2 presents the resistivities, carrier concentrations, and mobilities of the GAZO thin films deposited under various conditions, respectively. Within the range of working pressures examined in this study, the thin films having the best electrical properties were obtained at a working pressure of 3 mTorr. At lower working pressures, carrier mobility was almost constant, irrespective of working pressure, but decreased by almost a half at higher working pressures. Carrier concentration increased by more than double when working pressure was increased to 3 mTorr from 1 mTorr. However, only a slight decrease in carrier concentration was observed at higher working pressures. The electrical properties were almost independent of input

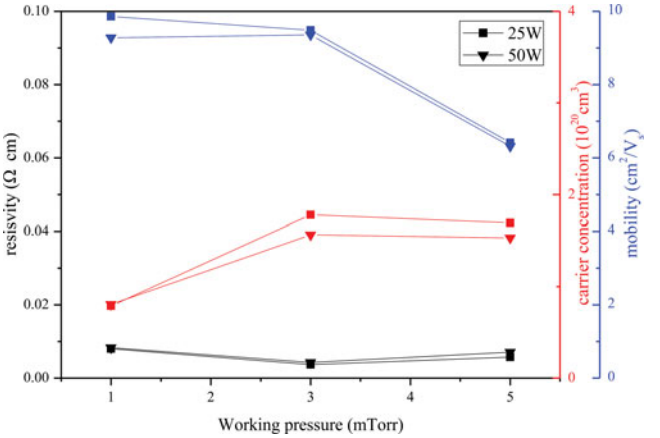

Figure 2. Electrical properties of GAZO films deposited under various condition

power. However, thin films deposited using an input power of 25 W had slightly better properties. This agrees with a previously reported relationship between input power and resistivity in thin films deposited by sputtering. [10] Figure 3 shows the XRD patterns of the GAZO thin films. The (002) peak near 34°, indicative of the ZnO crystal structure, was observed in all patterns. Neither metallic nor gallium oxide nor aluminum oxide peaks were identified in our XRD patterns. This could evidence substitutional replacement of gallium or aluminum for zinc in the ZnO lattice. [11,12] Figure 4 shows the optical properties of the GAZO thin films. Transmittances of 70% in the visible range were achieved under all deposition conditions and neither significant increases nor decreases were observed. The optical band gaps of the thin films ranged from 3.70 to 3.76 eV.

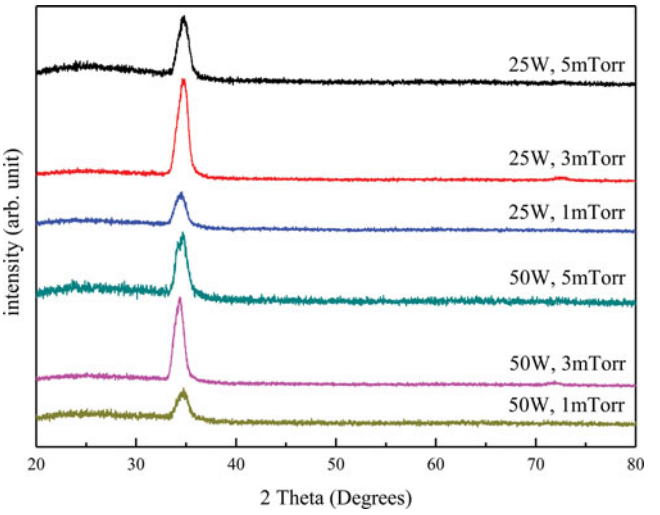

Figure 3. XRD patterns of GAZO thin films

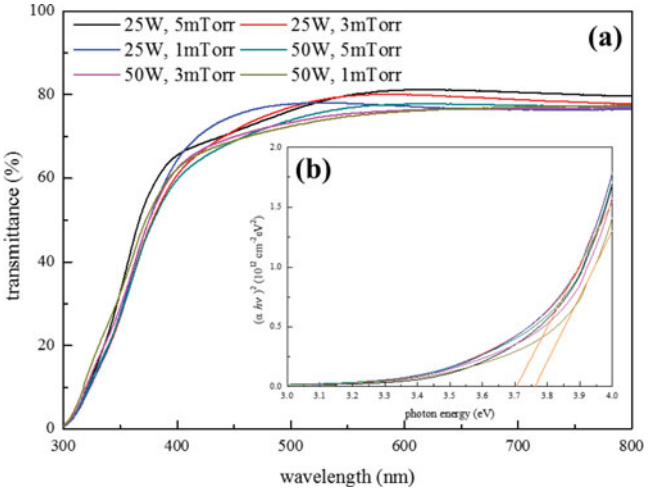

Figure 4. Optical properties of GAZO thin films: (a) Optical transmittance, (b) optical band gap.

Conclusions

GAZO thin films were deposited onto pre-deposited Alq3 thin films by facing targets sputtering. The damage inflicted on the organic layers during sputter deposition was measured by comparing PL spectra peak intensities of the as-deposited Alq3 thin film and the organic layers that the GAZO thin films were deposited on to. The minimum damage inflicted during sputter deposition occurred when the working pressure was 5 mTorr and an input power of 0.25 W was used. For the least damaged sample, PL intensity was 66% of that of bare Alq3. Under the aforementioned conditions, resistivity was found to be 5.75×10^{-3} Ω cm and optical transmittance in the visible region of the spectrum was found to be 75%. The optimum resistivity and optical transmittance values achieved were 3.7×10^{-3} Ω cm and 77%, respectively, under conditions of 3 mTorr and 25 W, and 1 mTorr and 25 W, respectively.

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