Electrical Characteristics of Organic Light-emitting Diodes Fabricated by Varying a Hole-size in Evaporation Boat

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Electrical characteristics of organic light-emitting diodes were investigated by varying a hole-size in evaporation boat in the device structure of ITO/tris(8-hydroxyquinoline) aluminum(Alq_3)/Al. The device was manufactured using a thermal evaporation under a base pressure of 5×10^{-6} Torr. The Alq_3 emitting organics were evaporated to be a thickness of 100 nm at a deposition rate of 1.5 Å/s. A cylindrical-shaped evaporation boat was made out of stainless steel with a small size of hole on top of the boat. Several evaporation boats were made having a different hole size on top; 0.8 mm, 1.0 mm, 1.5 mm, and 3.0 mm. We found that when the hole size on top of the evaporation boat is 1.0 mm, the average roughness is rather smoother compared to the other ones. Also, luminance and external quantum efficiency are superior to the others. Compared to the ones from the devices made with the hole-size of 0.8 mm boat. The luminance and external quantum efficiency of the device made with the hole-size of 1.0 mm boat were improved by a factor of seventy and thirty three, respectively. Also operating voltage is reduced to 2 V.

Keywords : Hole-size of evaporation boat, Average roughness, Luminance, External quantum efficiency, Operating voltage

1. INTRODUCTION

Since Tang and VanSlyke developed multilayered Organic Light-Emitting Diodes (OLEDs), many research groups are devoting their efforts to develop new type of flat-panel display because of potential display application[1-4]. One of the new types of displays is OLEDs. The OLEDs are attractive because of potential application in display, low operating voltage, low power consumption, low cost, self-emission, and the capability of multicolor emission by the selection of emissive materials[5-7]. Since the OLEDs are the devices which convert electrical energy to light by applying an electric field to the organic material which is lying in between the anode and cathode, lots of studies are going on in this field such as on a mechanism of charge injection, transport and recombination cathode materials, transparent anode, interfacial contact between the electrode and organic layer, buffer layer, highly efficient organic materials and etc[8]. In this paper, in order to consider how a hole-size in evaporation boat affects on the efficiency of OLEDs, we have studied the electrical and efficiency characteristics of OLEDs based on tris(8-hydroxyquinoline) aluminum(Alq_3) which is used for an electron-transport and emissive material.

2. EXPERIMENTS

Figure 1 shows a molecular structure of Alq_3 used for an electron-transport and emissive material. The ITO glass, having a sheet resistance of 15 Ω/□ and 170 nm thick, was received from Samsung. Co. The 5 mm wide ITO strip line was made by selective etching in vapor of solution by mixing with hydrochloric acid (HCl) and nitric acid (HNO_3) at a volume ratio of 3:1 for 10~20 minutes at room temperature. The distance between the ITO and etchant was about 2 cm. Then, the patterned ITO glass was cleaned by ultrasonication in chloroform for 20 minutes at 50 °C, after which the ITO glass was heated at 80 °C for 1 hour in a solution made with second-distilled water, ammonia water and hydrogen peroxide at a volume ratio of 5:1:1. We ultrasonically cleaned the substrate again in a chloroform solution for 20 minutes at 50 °C, and in distilled water for 20 minutes at 50 °C. After the ultrasonic cleaning, the substrate was dried with N_2 gas stream and was stored under vacuum.

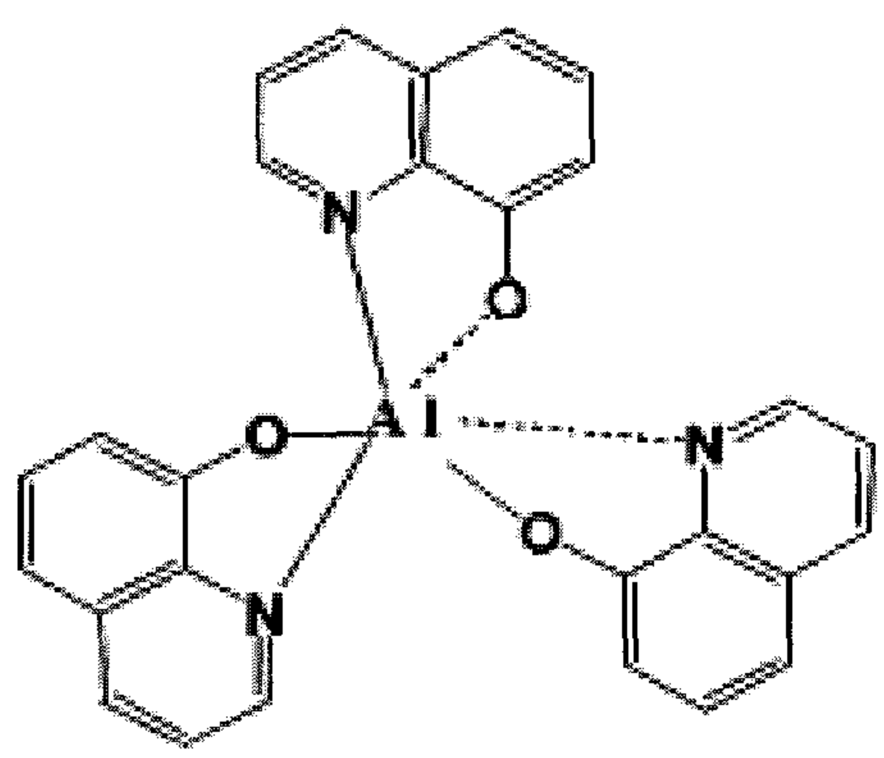


Fig. 1. Molecular structure of Alq_3.

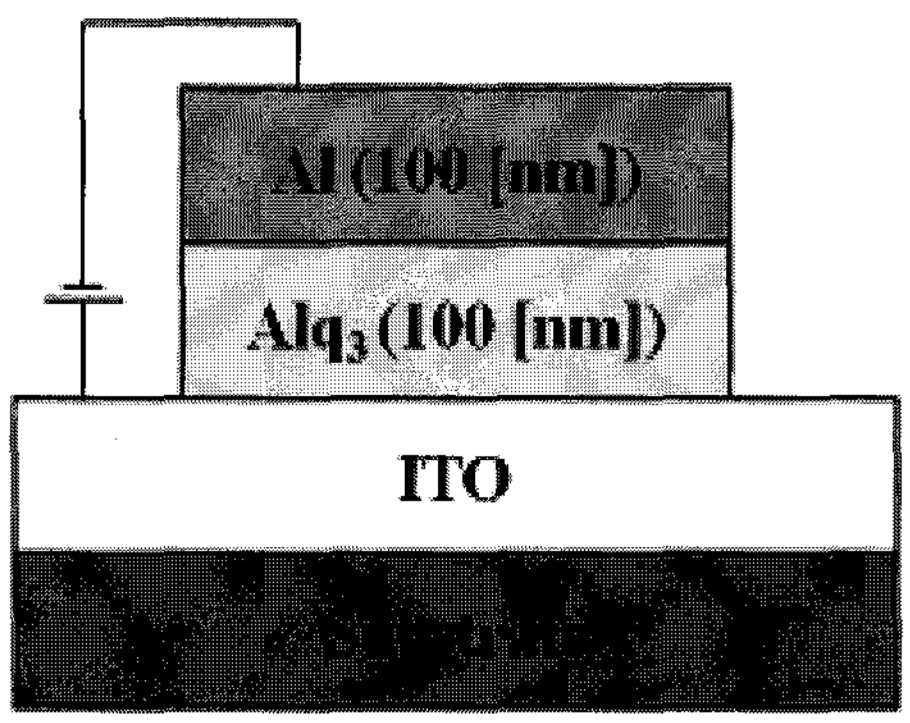
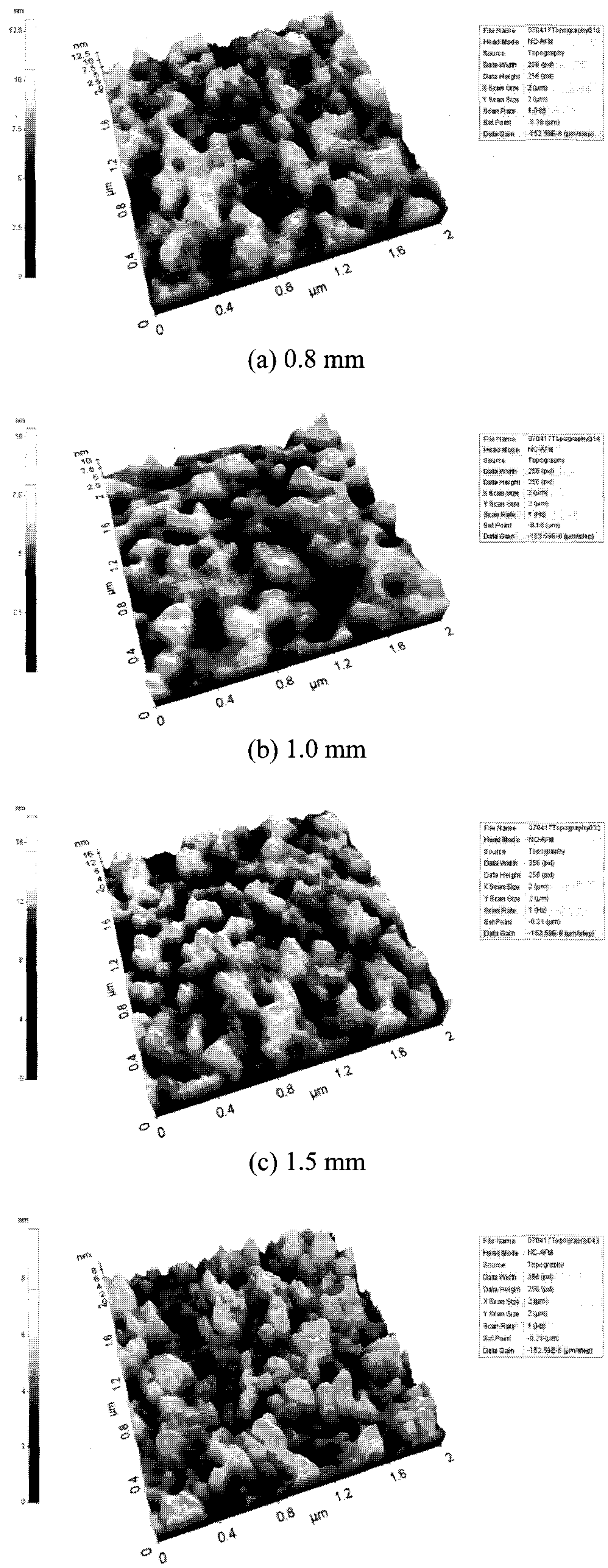


Fig. 2. Device structure of OLEDs.

Figure 2 shows a device structure of ITO/Alq_3/Al which was used to investigate the influence of hole-size in evaporation boat. The device was manufactured using a thermal evaporation under a base pressure of 5 x 10^{-6} Torr. The Alq_3 organics were evaporated to be a thickness of 100 nm at a deposition rate of 1.5 Å/s. A cylindrical-shaped evaporation boat was made out of stainless steel with a small size of hole on top of the boat.



(a) 0.8 mm

(b) 1.0 mm

(c) 1.5 mm

(d) 3.0 mm

Fig. 3. AFM image of surface morphology of Alq_3 layer made with a different hole-size in evaporation boat.

Several evaporation boats were made having a different hole-size on top; 0.8 mm, 1.0 mm, 1.5 mm, and 3.0 mm. A metal cathode was successively evaporated to be a thickness of 100 nm under a base pressure of 5×10^{-6} Torr. And a light-emitting area was made to be a size of 3 mm×5 mm. Electrical properties were measured using Keithley 2000 multimeter, 6517 electrometer, and Si-photodiode. And all instrumental control programs were performed using Labview software.

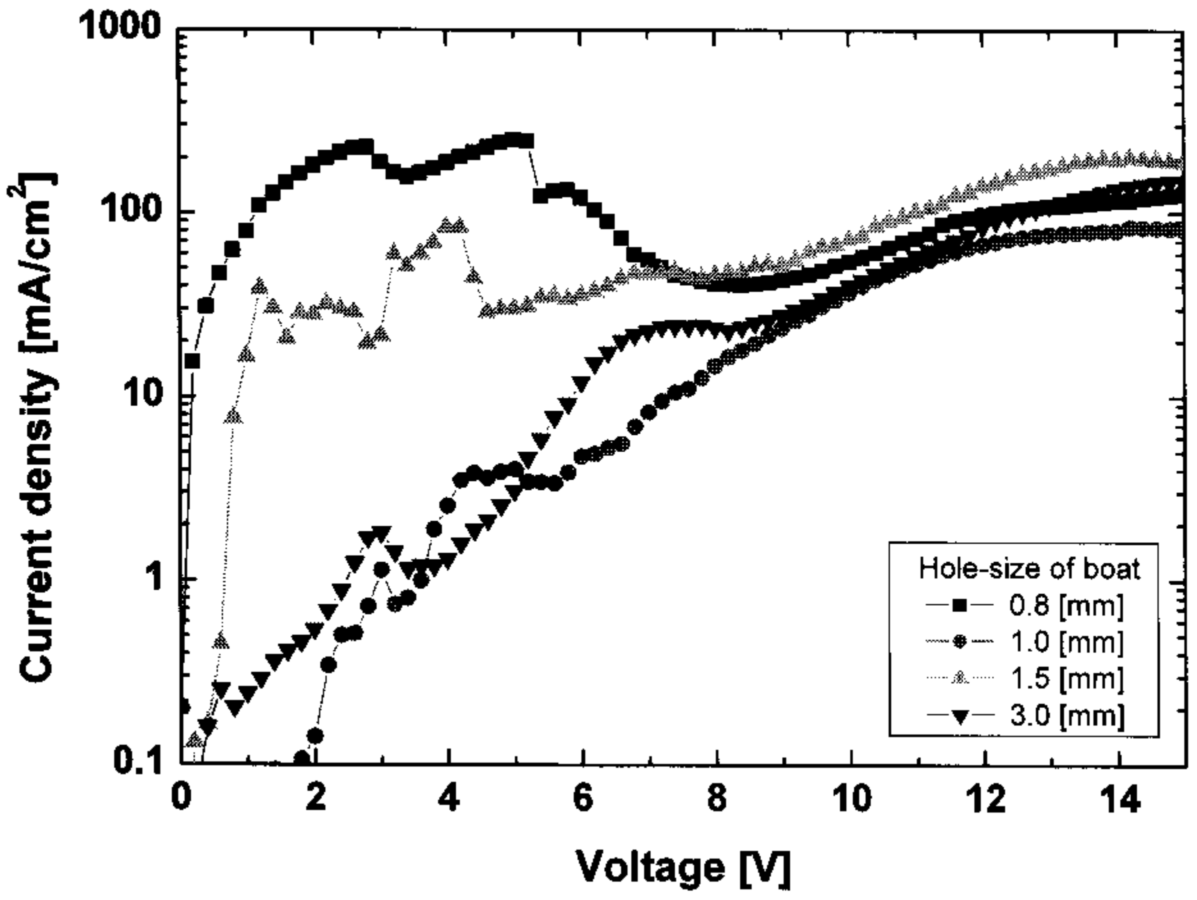
3. RESULTS AND DISCUSSION

Figure 3 shows AFM images of surface morphology of Alq_3 layer made with a different hole-size in evaporation boat. We can see that the surfaces are irregular, in general part.

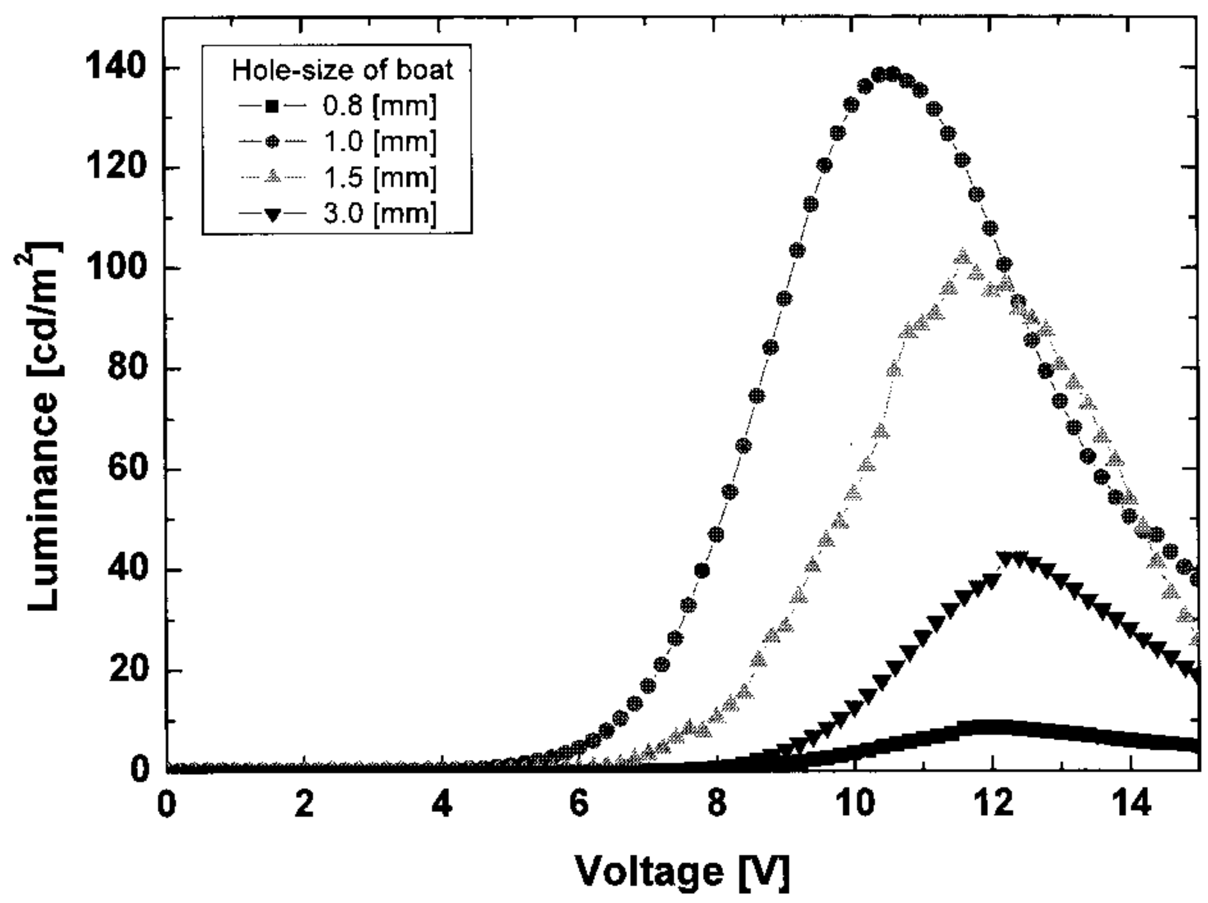
Table 1 shows an average roughness of Alq_3 layer surface for several a hole-size in evaporation boat. When the hole-size in boat is 1.0 mm, the average roughness is rather smoother compared to the other ones. Therefore, when the hole-size in boat is 1.0 mm, we confirmed that the distribution of surface roughness is better than the others Table 1 shows that the average roughness is 1.035 mm for a hole-size of 1.0 mm. Since this surface roughness is more or less uniform than the others, it is expected that the charge injection becomes easier. This may affect on the improvement in the device performance.

Table 1. Average roughness of Alq_3 layer surface for several hole-sizes in evaporation boat.

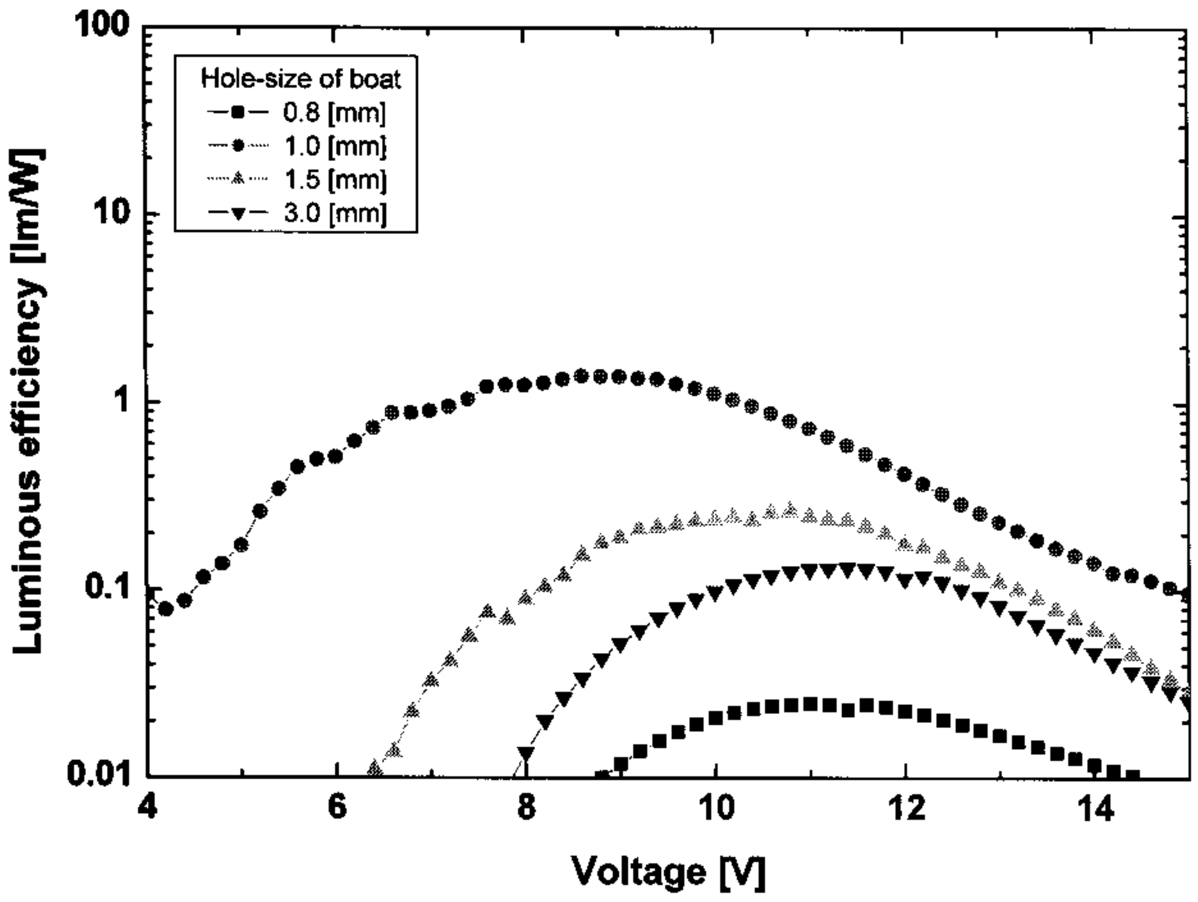
Hole-size in evaporation boat [mm]	Average roughness [mm]
0.8	1.197
1.0	1.035
1.5	1.159
3.0	1.313



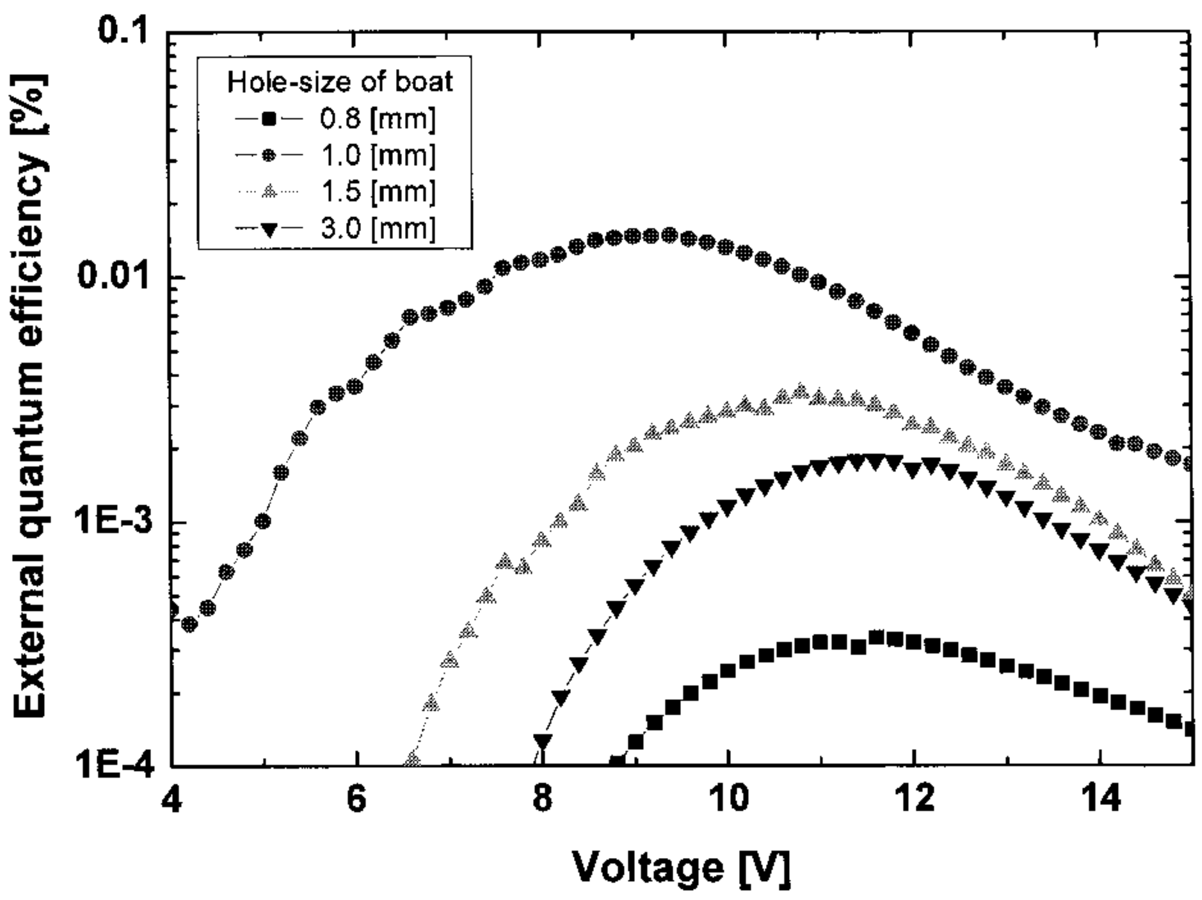
(a) Current density-voltage characteristics



(b) Luminance-voltage characteristics



(c) Luminous efficiency-voltage characteristics



(d) External quantum efficiency- voltage characteristics

Fig. 4. Electrical characteristics of the $ITO/Alq_3/Al$ device depending on hole- size in evaporation boat.

Figure 4(a) shows the current density-voltage characteristics of ITO/Alq_3/Al[9] device by varying a hole-size in boat from 0.8 mm to 3.0 mm. When the hole-size in boat is 1.0 mm, the overall current density is small compared to the others in the measured voltage range. This is thought that the Alq_3 hinders carrier injection, and thus a rate of recombination between electrons and holes becomes difficult. Figure 4(b) shows the luminance-voltage characteristics of OLEDs with the thickness variation hole-size in evaporation boat. When the hole-size in boat is 1.0 mm, the maximum luminance is 140 cd/m^2. Also, we confirmed that there is a reduction of turn-on voltage to 4 V. However, when the hole-size in boat increases to more than 1.5 mm, the maximum luminance decreases. It is thought that the physical property of the material changes as the surface roughness varies. Thus a recombination of holes and electrons becomes more difficult due to a difficulty of electrons and holes. Figure 4(c) shows the luminance-voltage characteristics of OLEDs with the thickness variation of hole-size in evaporation boat. Luminous efficiency is useful for the display application. It is given by $\eta = \pi L / JV$ [lm/W], where L is the outcoming luminance that is measured normal to the emitting surface, J is the current density, and V is the applied voltage. As the hole-size in boat increases, all devices show the maximum luminous efficiencies near 10~12 V. When the hole-size in boat is 1.0 mm, it gives a higher luminous efficiency of 1.4 lm/W. Compared with that of the one for hole-size in boat 0.8 mm, there is an improvement in luminous efficiency by a factor of seventy. Therefore, the efficiency strongly depends on charge balance. It was thought that a proper hole-size in boat reduces a work- function of the electrode. Thus, there is an improvement of device of performance. Figure 4(d) shows the external quantum efficiency-current density characteristics of OLEDs with the variation of hole-size in evaporation boat. When the voltage is about 9~11 V, the external quantum efficiencies are maxima in all devices. And, as the hole-size in boat increases further, the efficiency decreases a little bit. Particularly, when the hole-size in boat is 1.0 mm, the maximum external quantum efficiency becomes 0.02 %. Compared with the hole-size of boat 0.8 mm, there is an improvement in luminous efficiency by a factor of thirty three. Also, we confirmed that there is a reduction of operating voltage to 2 V. But, when the thickness hole-size in boat increases to 1.5 mm, the external quantum efficiency decreases and maximum emitting voltage increases again.

The adequate surface roughness helps more holes and electron to be injected into the emissive layer, and it acts either as a reducing a work- function of the hole and electron transport layer[10]. Also, operating voltage is reduced.

4. CONCLUSION

We examined electrical characteristics of organic light-emitting diodes fabricated by varying a hole-size in evaporation boat. We found that when the hole-size in evaporation boat is 1.0 mm, an average roughness of Alq_3 surface is low. Also, luminance, luminous efficiency and external quantum efficiency are superior to other devices. Compared with the hole-size in boat 0.8 mm, the luminance and external quantum efficiency of the device made with the hole-size of 1.0 mm boat were improved by a factor of seventy and thirty three times, respectively. Also, operating voltage of device is reduced to 2 V. Therefore, the use of suitable hole-size in evaporation boat contributes to an efficiency improvement as well as a lowering of operating voltage.

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