Field emission of nanostructured AlQ_3 amorphous film and the heat treatment effect

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Abstract

Amorphous AlQ_3 film with nanostructured protrusions on the surface was fabricated by vapor condensation. It exhibits better field emission property than those of AlQ_3 nanowires and nanoscaled crystalline film. The film becomes crystalline and the field emission becomes worse after heat treatment. The field emission property is rather related to the crytallinity, and the probable reasons are discussed.

Keywords : AlQ_3, thin film, amorphous, field emission.

1. Introduction

Since high efficiency and good performance of a bilayer organic light-emitting diode (OLED) was reported by Tang and VanSlyke in 1987 [1], there has been a particular interest in tris-(8-hydroxyquinoline) aluminum (AlQ_3)-based devices for development of large-area displays [2]. AlQ_3 is one of the most important electron transport and emitting materials for OLEDs. Lots of attention has been paid to this organometallic semiconductor due to the unique properties such as excellent flexibility, high photoconductivity, and nonlinear optical behavior. It is then of great interest to prepare AlQ_3 nanostructures and study their optoelectronic properties for potential applications in nano-optoelectronic devices [3, 4].

Previously it has been revealed that crystalline AlQ_3 film could be prepared by vapor condensation [5, 6], and some nanostructures of AlQ_3 could be synthesized on a liquid nitrogen-cooled substrate [7, 8]. The field emission properties of nanostructured film and nanowires of AlQ_3 have also been reported [5, 8]. It was subsequently found that the field emission performance of amorphous AlQ_3 thin film was superior to that of crystalline film. However, the field emission of the amorphous AlQ_3 film becomes worse after heat treatment. It has been frequently reported that the optoelectronic properties of materials are highly related to their crystallinity. To investigate the relationship between the crystallinity and optoelectronic properties of AlQ_3 is necessary before further practical applications. In this study, the field emission of AlQ_3 materials are examined and found to be related to their crystallinity.

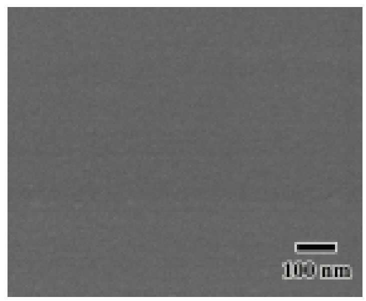
2. Experimental

The amorphous AlQ_3 film with nanostructured protrusions on the surface was fabricated by vapor condensation in a vacuum of 3×10^{-4} Pa. Commercial AlQ_3 powder (TCI Ltd., T1527) was placed in a graphite boat, and the silicon or ITO-coated glass substrate was placed under the stainless steel cold trap which was 10 cm above the graphite boat. AlQ_3 powder was sublimed when the temperature of the graphite boat reached 400°C. The temperature of the boat could be regulated by a power supply together with a K-type thermocouple. The detailed setup has been presented previously [7]. Field emission scanning electron microscopy (FESEM) was employed to examine the surface morphology, and atomic force microscopy (AFM) was utilized to examine the surface topography of the AlQ_3 film. A low angle X-ray diffraction (LAXRD) spectrometer equipped with a Cu target and an X-ray generator of 18 kW (400mA) was utilized to examine the crystallinity. Heat treatment at 190°C for 150 mins was executed in Ar under 1.33×10^4 Pa. The field emission properties before and after heat treatment were measured with a 50 μm gap between the anode and the cathode under a base pressure of 1.0×10^{-5} Pa. The anode-cathode configuration had a sphere-to-plate geometry. The high voltage was supplied by a power source, Keithley 237, and the current under the increasing applied voltage was recorded with a good accuracy to 10^{-13} A.

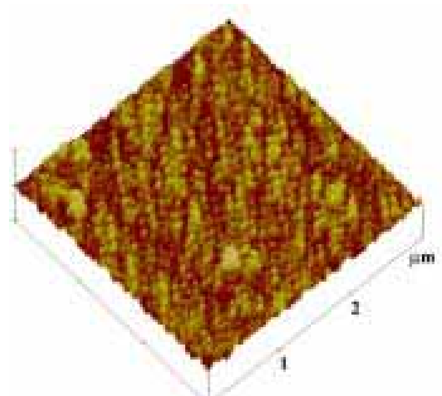
3. Results and Discussion

The amorphous thin film has a smooth surface with uniform morphology (Fig. 1a). The AFM image shows that there are many small nanoprotrusions on the surface, with the diameter of each protrusion being approximately 60 nm (Fig. 1b). The amorphism of the AlQ_3 thin film was demonstrated by the XRD pattern, as shown in curve A of Fig. 2. After heat treatment in Ar of 1.33×10^4 Pa at 190°C for 150 min, highly crystalline AlQ_3 can be obtained, as shown in curve B of Fig. 2.

A turn-on field of 6.5 $V\mu m^{-1}$ for field emission test is observed on the amorphous thin film as the current density reaches 10 $\mu A/cm^2$, as displayed in Figure 3. The inset shows the Fowler-Nordheim plot which yields a straight line at high applied fields displaying a typical field emission behavior. The amorphous AlQ_3 thin film exhibits a better field emission property than that of nanoscaled crystalline film with a turn-on field of 10 $V\mu m^{-1}$ as reported previously [5]. The highly crystalline AlQ_3 obtained from heat treatment also revealed a field emission characteristic, but much worse than those of nanostructured amorphous AlQ_3 and nanoscaled crystalline thin film. It exhibits a current density of 1 $\mu A/cm^2$ at a field of 18 $V\mu m^{-1}$. Apparently, the field emission property is quite related to the crystallinity, and higher crystallinity is detrimental to field emission. The domain size might have become larger and the domain boundaries decrease after heat treatment, so the number of channels for transporting electrons is reduced. Moreover, the domain boundary exhibits a larger geometric enhancement factor than that of the domain center. Therefore, it is deduced that smaller protrusions and more



(a)



(b)

Fig. 1. (a) FESEM image shows a smooth surface with uniform morphology of the amorphous AlQ_3 thin film.
(b) AFM image of the amorphous AlQ_3 thin film. The diameter of each protrusion is approximately 60 nm.

domain boundaries lead to better field emission of the as-prepared amorphous thin film.

4. Conclusion

In this study, nanostructured AlQ_3 amorphous thin film has been demonstrated to exhibit better field emission than those of as-prepared crystalline AlQ_3 film and the crystalline one obtained from heat treatment. More domain boundaries, larger geometric enhancement and the nanoprotrusions would contribute to better field emission of the amorphous thin film. The follow-up investigations have been carried out and will be reported elsewhere.

5. Acknowledgement

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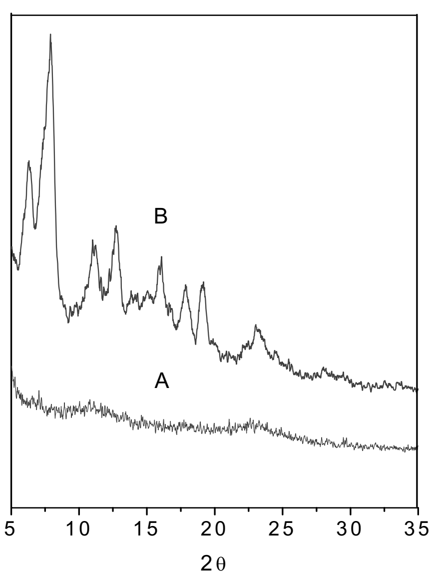

Fig. 2. LAXRD patterns of AlQ_3 thin film. Curves A and B are before and after heat treatment, respectively.

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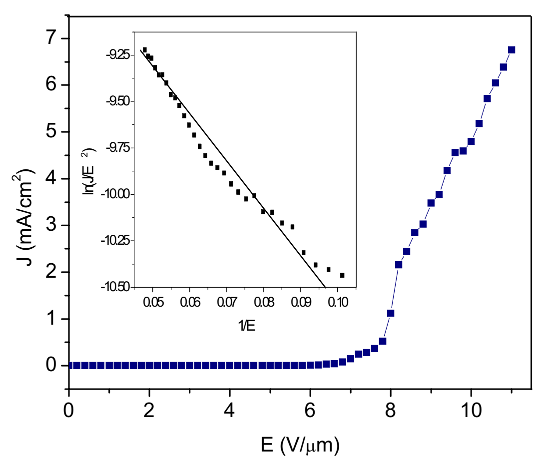

Fig. 3. Field emission J-E curve. The inset shows the Fowler-Nordheim plot which yields a straight line at high applied fields displaying a typical field emission behavior.