Enhancement of External Quantum Efficiency in OLEDs by Electrode Surface Morphology

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Abstract

By forming lens-like shapes on the electrode surfaces in OLEDs, the external quantum efficiency is enhanced. The external quantum efficiency of the proposed structure can be much more increased compared to that of the flat structure by decreasing the length of major axis and increasing the length of minor axis for the lens-like shapes.

1. Introduction

Organic light-emitting devices (OLEDs) based on both small-molecule and polymer thin films seem to attract much interest due to their consideration with high performance flat panel displays for the next generation [1-2]. Since longer lifetime as well as lower power consumption is required in OLEDs, the attainment of high quantum efficiency is one of the most important issues for the applications of OLEDs.

The external quantum efficiency related to the luminance is low as the factor of $\approx 1/(2n^2)$, where n is the refractive index of the OEL materials, expressed as the ratio of the surface emission to all emitted light. Therefore, the external quantum efficiency in OLEDs is estimated approximately to be about 20% from the simple calculation of ray-optics because of the total internal reflection within the devices [3-4]. This is one of the major reasons why the luminance efficiency of OLEDs remains low. Some Groups have reported the improvement of external quantum efficiency by using microcavity effects [5-6]. An increase of external quantum efficiency by modifying the device configurations has been shown [7-8]. Recently,

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Tsutsui group achieved two-fold increase in the external quantum efficiency by inserting thin silica aerogel layers of low refractive index between glass substrate and ITO anode [9].

In this study, we investigate the improvement of external quantum efficiency in OLEDs by forming lens-like shapes on the cathode metal as well as the interface between ITO and glass substrate using ray-optics.

2. Results and Discussions

When an electric field is applied, the light generated by electron-hole recombination is emitted uniformly in all directions. However not all generated lights are emitted out into the air because the light is trapped due to the total internal reflection, is scattered as edge emission, and is absorbed by the materials. The six-ray paths denoted by A, B, C, D, E, and F in Fig.1 are described by the ray-trace through the materials. Only those rays that have an angle from less than the critical angle (θ_C) to the normal enter the air. Those with angles greater than θ_C are reflected and can't escape from the structure, and so external quantum efficiency is low. According to the classical ray-optics theory, quantum efficiency of the external, waveguide of glass substrate or edge emitted, and waveguide of glass substrate or ITO/glass internal reflection are about 20%, 30%, and 50%, respectively [4]. Because the luminance efficiency of OLEDs remains low, we propose to increase the external quantum efficiency in OLEDs by forming lens-like shapes on the cathode metal as well as the interface between ITO and glass substrate.

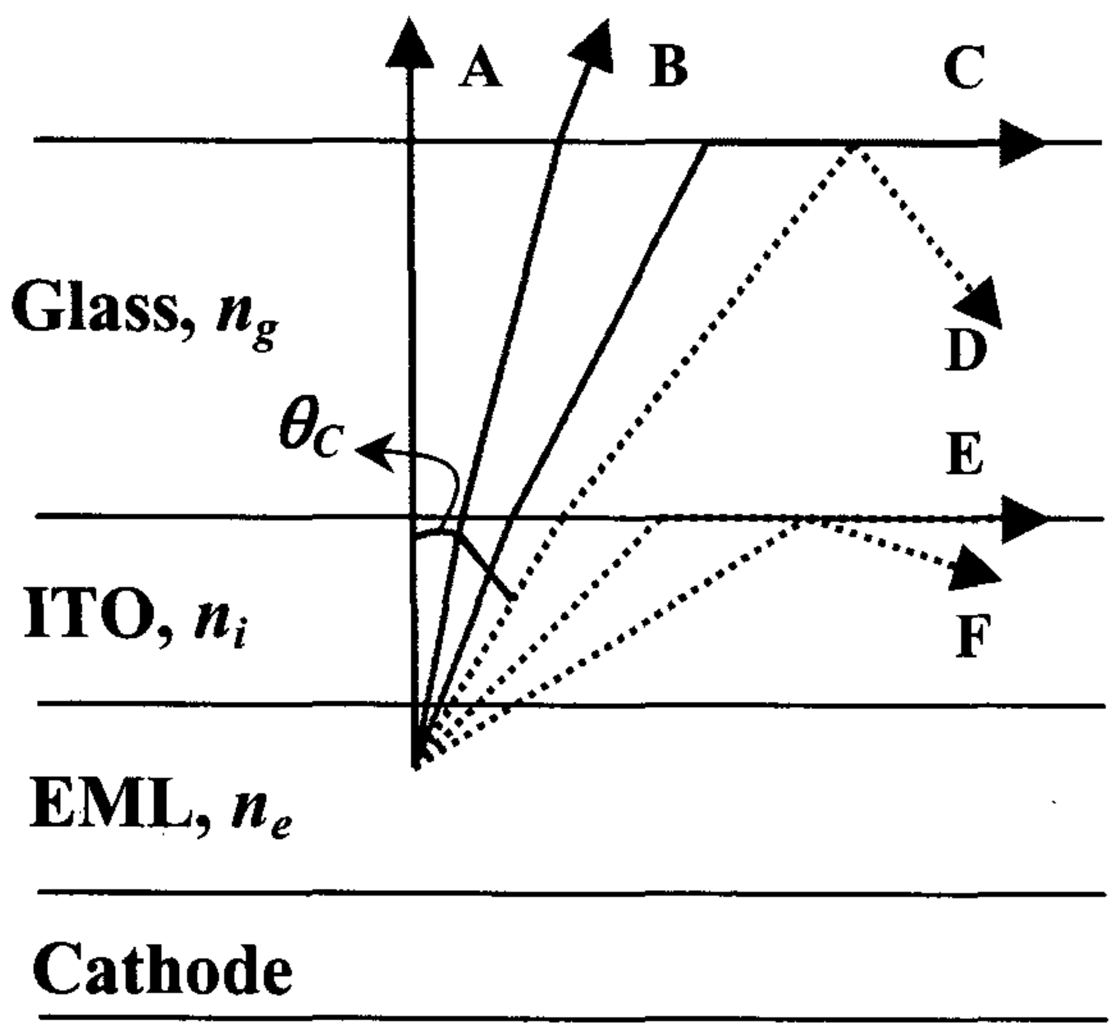


Figure 1. Description of ray-trace for conventional OLEDs ($n_i > n_e > n_g$) ; ray A and B are surface emission, ray C and E are edge emission, and ray D and F are waveguide emission. ($n_e = 1.7$, $n_i = 1.8 \sim 2.1$, $n_g = 1.53$)

We propose two structures: One is forming a convex lens shape on the interface between ITO and glass substrate and the other is forming a concave mirror shape on the cathode metal. The reason why external quantum efficiency is increased is illustrated in Fig.2. The convex lens shape structure on ITO surface enables the emitting lights to meet the interface at a smaller incident angle in comparison with θ_C. As the result, the external quantum efficiency is increased because more emitting light are escaped into the air. In case of forming the cathode metal, we design a shape of concave mirror to collect the emerging light into emitting layer. By decreasing the length of major axis, b, and increasing the length of minor axis, a, for both cases, the external quantum efficiency is improved.

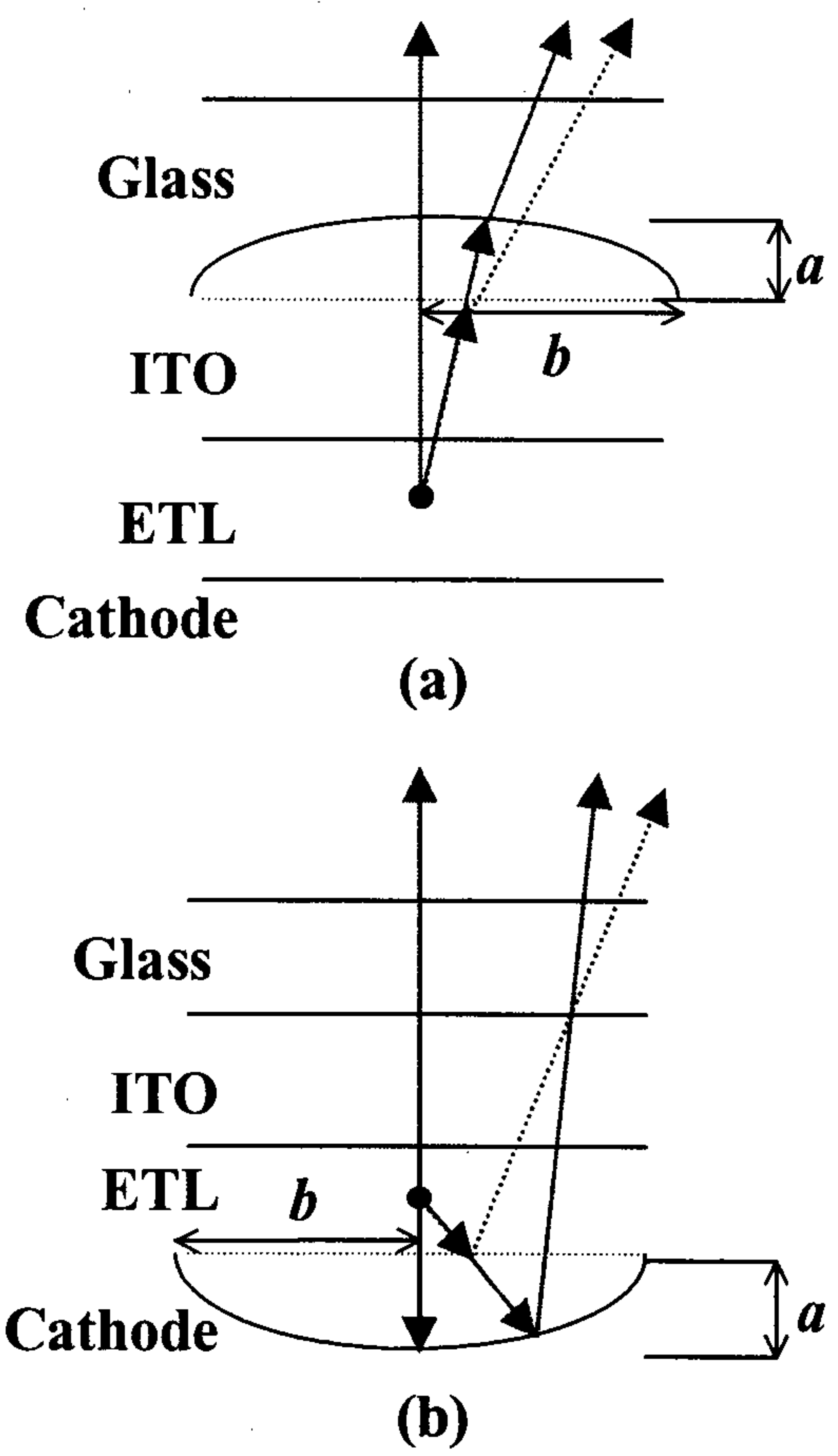


Figure 2. The structure to enhance the external quantum efficiency in OLEDs by forming lens-like shapes on the electrode surfaces: (a) The convex lens shape structure on ITO surface, and (b) the concave mirror shape on cathode metal.

Figure 3 shows the normalized external intensity for the surface emission angle. The External intensity is normalized with the intensity of surface emission angle 0°. High external quantum efficiency is achieved by decreasing the length of major axis, *b*, and increasing the length of minor axis, *a*, for both cases. Not only the convex lens shape structure on ITO surface but also the concave mirror shape on cathode metal play a role in enabling the emitting lights to meet both ITO/glass substrate interface and glass substrate/air interface at a smaller incident angle in comparison with critical angle. After all, the external quantum efficiency is improved because more emitting lights are escaped into the air.

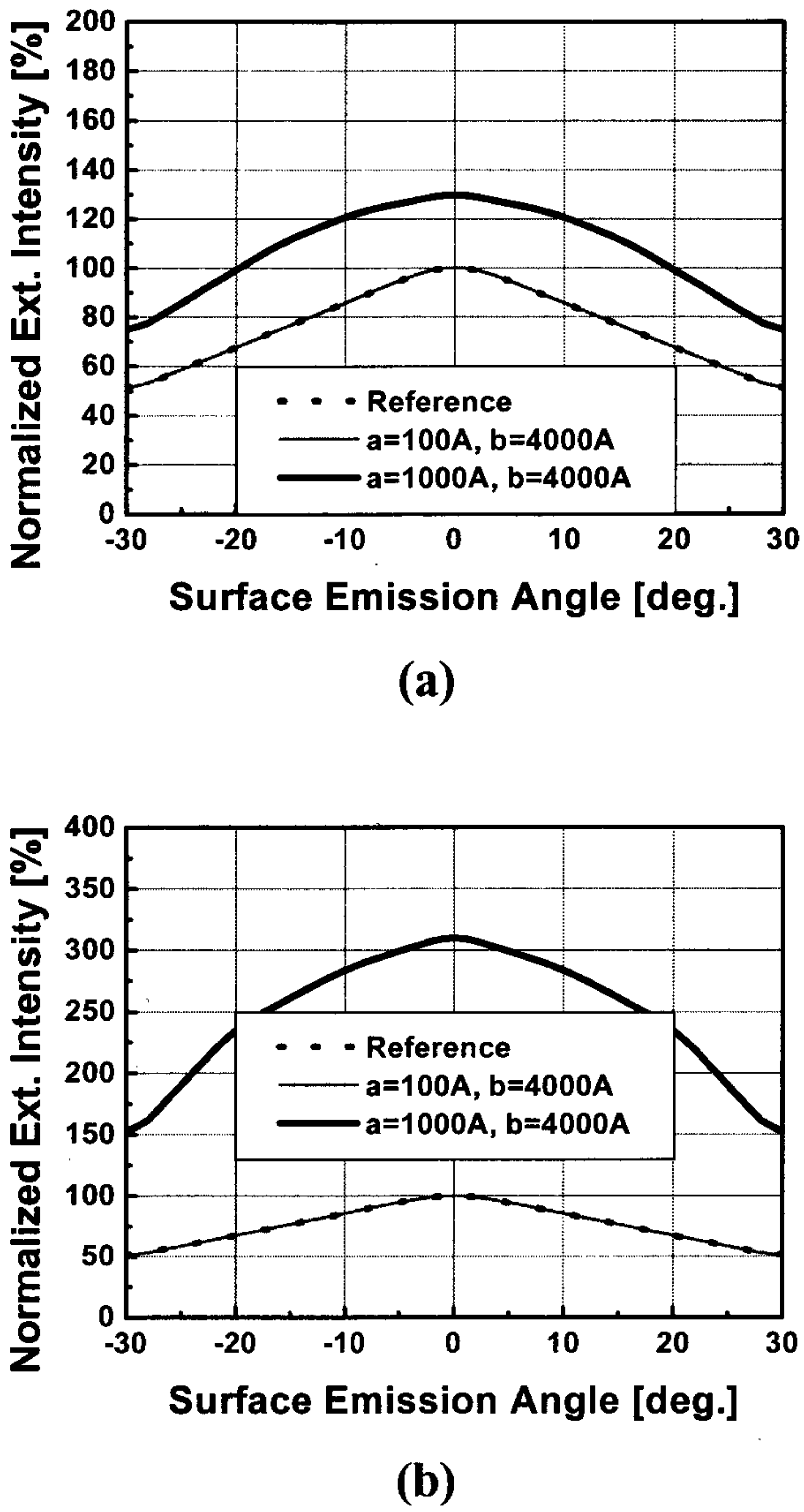
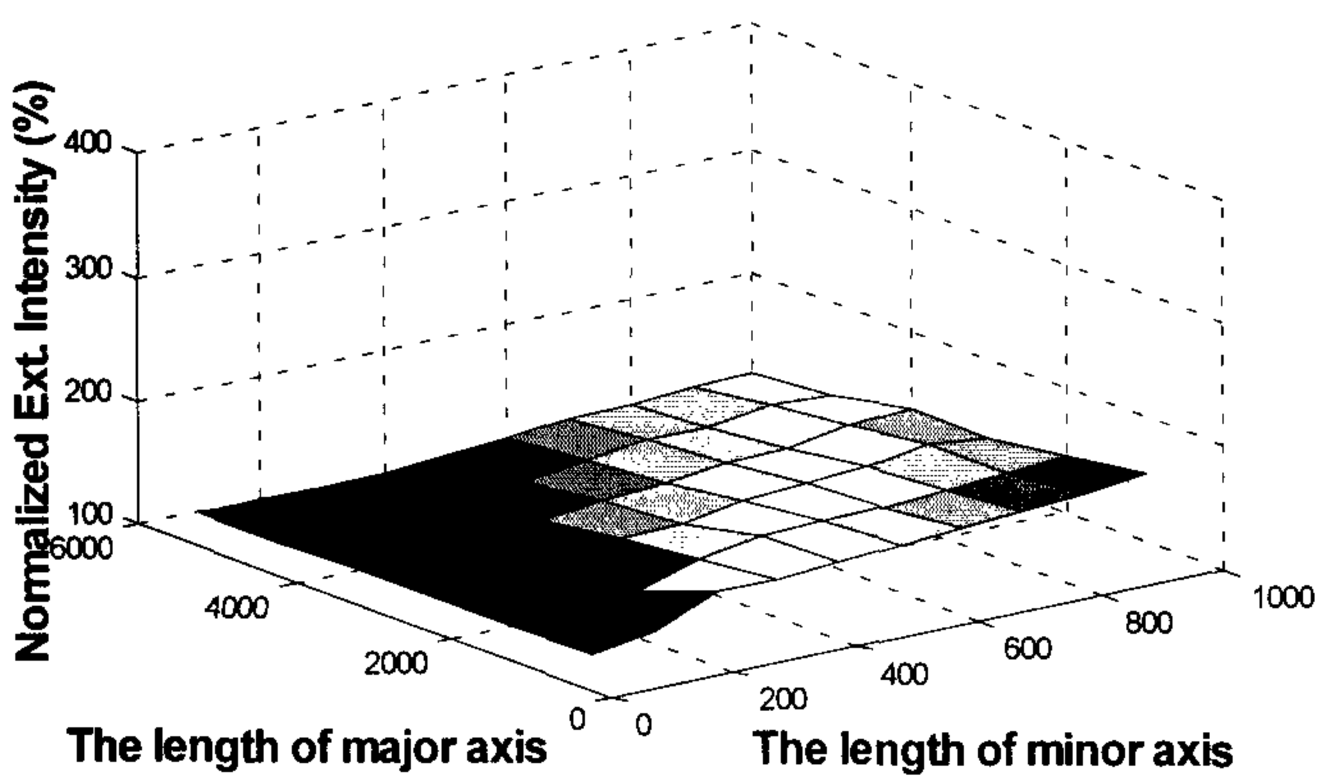
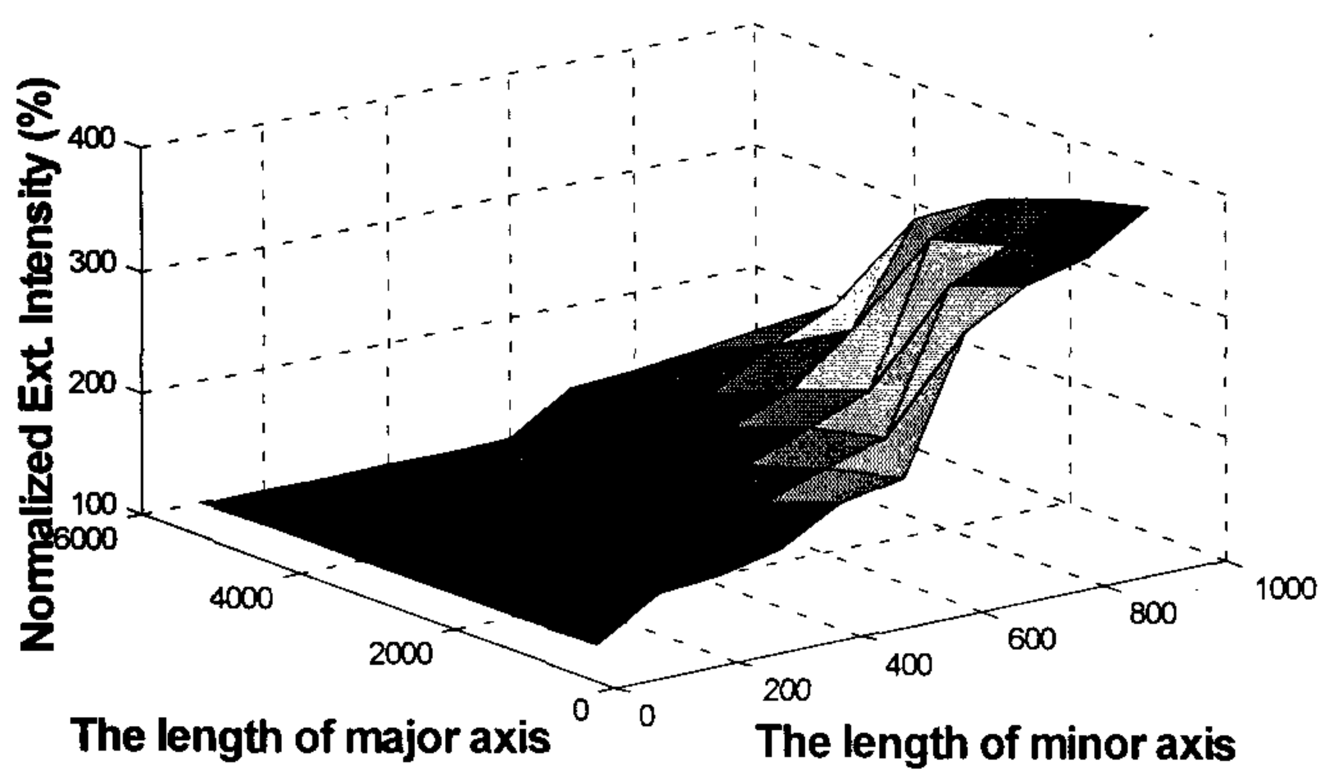


Figure 3. The normalized external intensity versus the surface emission angle for the lens-like shapes on the electrode surfaces (The external intensity is normalized with the intensity of 0°.): (a) The convex lens shape structure on ITO surface, and (b) the concave mirror shape on cathode metal.



(a)



(b)

Figure 4. The conditions that enhance the external quantum efficiency for both the length of major axis and minor axis: (a) The convex lens shape structure on ITO surface, and (b) the concave mirror shape on cathode metal.

The external quantum efficiency for both the length of major axis and minor axis is shown in Fig.4. The forming in cathode metal has more influence on exter -nal quantum efficiency than that in ITO surface.

3. Conclusions

In this paper, it is shown that the external quantum efficiency of the proposed structure can be much more improved compared to that of the flat structure by decreasing the length of major axis and increasing the length of minor axis for the lens-like shapes.

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4. References

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