Novel AM-OLED with Light Extraction Enhancement

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Abstract

We investigated the effect on light extraction in OLED by introducing aluminum micro bump light scattering reflector. By attaching the micro bump reflector to a both side emission OLED, we found that the light extraction was 1.7 times larger than a simple flat reflector. We fabricated a 20.8" inch WXGA full color AM-OLED by integrating the micro bump scattering reflector.

1. Introduction

Full color active matrix organic light emitting display(AM-OLED[1]) has advantage over LCD and PDP because of its feature such as high contrast ratio, very wide viewing angle, and extremely fast response time, most suitable for high performance TV. However, there are issues on power consumption and lifetime of screen which needs to be solved when we consider the practical use of TVs. Although the recent progress in materials are remarkable, the performance is still not sufficient for TV application. One reason for this is that the extracted light is only 20% to 30% of the internal emission. The internal emission is trapped because of the high refractive index of the emission layer and the glass substrate which cause the increase of total reflection at the interface leading to lower the light extraction. Although several novel structures have been reported in order to extract light from the emission layer effectively [2][3][4][5][6][7][8], there are few reports that have been applied to actual displays due to the complexity of the device structure and process procedures. It is also because of the double image attributed to the parallax effect.

In this paper, we present a novel light extraction structure for AM-OLED by introducing aluminum micro bump light scattering reflector[9]. The mechanisms of the scattering reflector are discussed and we fabricated a 20.8 inch WXGA full color AM-OLED with this new method.

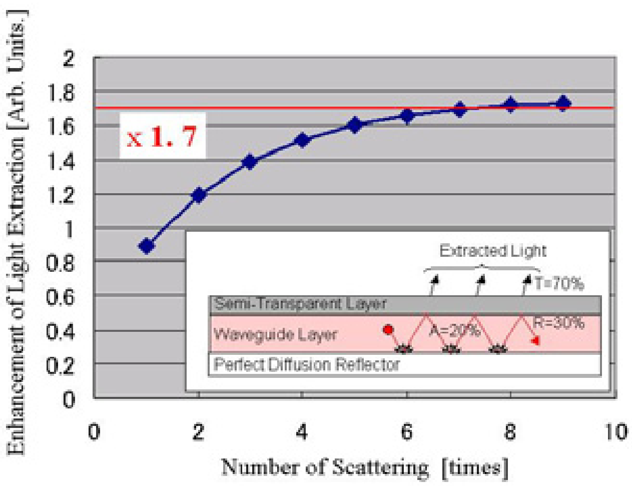

Fig. 1. Dependency of enhancement of light extraction on the number of scattering.

2. Light Extraction Effect

We considered the light extraction effect of OLED with a simple model structure of glass/EL/Al based on bottom-emission type OLED which has only flat aluminum reflection layer. By taking multiple reflection and interference effect into account, the extracted light was calculated to be 24% in our device. 32% was trapped inside the glass substrate and 44% was trapped in the EL layer. Therefore 76% of the light was trapped inside and could not be extracted. Next, we considered a aluminum micro bump reflector instead of a conventional flat aluminum reflector which scattering effect could be expected to enhance light extraction.

Figure 1 shows the dependency of enhancement of light extraction on the number of scattering. As shown in the subfigure, assuming the scattering performance to be a perfect diffused type and assuming the absorption loss of 20% in the aluminum reflector per one reflection, it is possible to achieve 1.7 times the light to be extracted compared to conventional flat reflector structure. In order to apply this principle to an actual display, the reflection layer has to be inserted close to the EL layer. Otherwise you will face the parallax issue. Top emission structure is also preferred in order to prevent parallax and to achieve high aperture ratio. Now, we discuss the light extraction effect of the aluminum micro bump light scattering reflector with top emission OLED structure.

3. Experiment & Results

Figure 2(a) shows the both side emission type OLED (transparent type OLED) and figure 2(b) shows the micro bump scattering reflector which we used in our experiment. Micro bump reflector was fabricated using acrylic resin with conventional photolithography patterning technique on glass substrate. The scattering reflection characteristic should depend on the slope angle of the micro bump and we adjusted it by changing the bump height. The bump pitch was 9um and we changed the height from 0.7 to 2.2um. The height and the shape of the bump were measured with AFM technique. Aluminum layer was sputtered on the bump shape resin to form the aluminum micro bump reflector. In order to evaluate the scattering characteristic, substrate (a) and substrate (b) was attached together with optical matching oil. Figure 3 shows the angular distribution of the total flux when substrate (a) was attached optically with perfect diffusion reflector of 97% reflectance. The angular distribution of the total flux for simple aluminum reflector is also shown as a reference. By comparing the two cases, light can be extracted at maximum of 2.14 times larger for scattering reflector rather than simple reflector. Figure 4 shows the dependence of the total flux on the micro bump height using integrating sphere photometer. We experimented for 90 and 180nm thickness of HTL. When the bump height is lower than 1.3um, the total flux tends to increase as the bump height increases. When the bump height is higher than 1.5um the total flux tends to saturate. In figure 4, we selected the bump height as a parameter, but as we mentioned, the scattering characteristic should depend on the slope shape. We measured the slope angle of the micro bump per unit length area by AFM and calculated the histogram of the slope angle statistically. We defined the highest frequency angle as the peak slope angle. The total flux and the peak slope angle showed good correlation described in reference [9].

We also considered the HTL thickness. When the HTL thickness is 180nm, less light can reach the micro bump scattering reflector compared to 90nm HTL. This is due to the interference effect, which the effect of the thickness of HTL becomes critical. At the HTL thickness of 90nm, light can reach the scattering reflector efficiently [9].

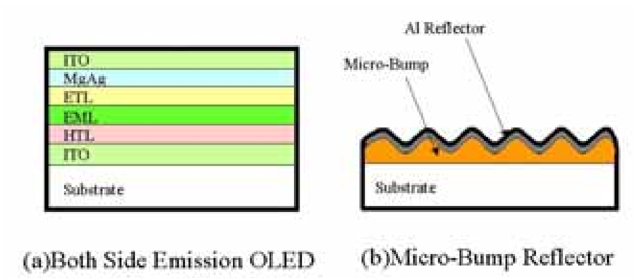

Fig. 2. Cross-section views of experimental devices.

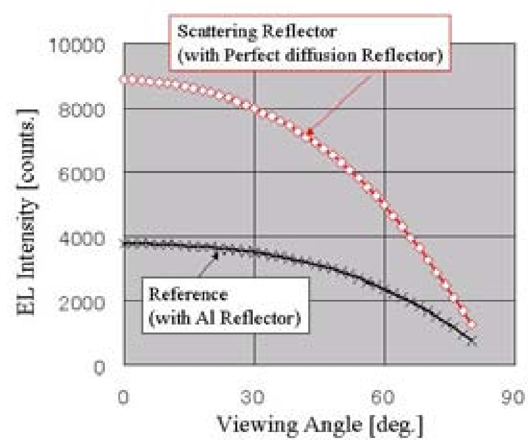

Fig. 3. Angular distribution of EL intensity.

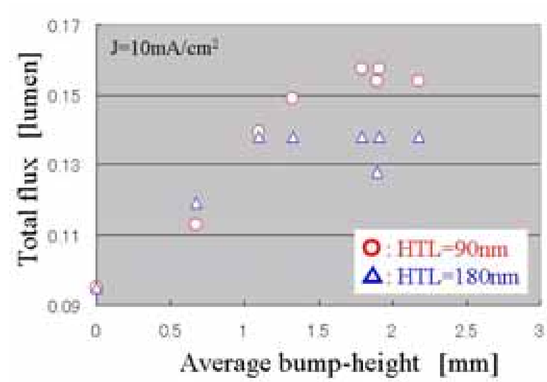

Fig. 4. Total flux dependency on bump height.

Figure 5 shows the summary of the enhancement of light extraction. We set the aluminum flat reflector case as 1. The actual device case with micro bump reflector is also shown at the right end. In the actual device case, the enhancement of light extraction was 1.36. The light absorption of the planer layer could not be neglected and the enhancement of light extraction decreased compared to the experimental micro bump reflector case. The process of fabrication and the materials of the actual device case was the same as the large size display which we presented in section 4.

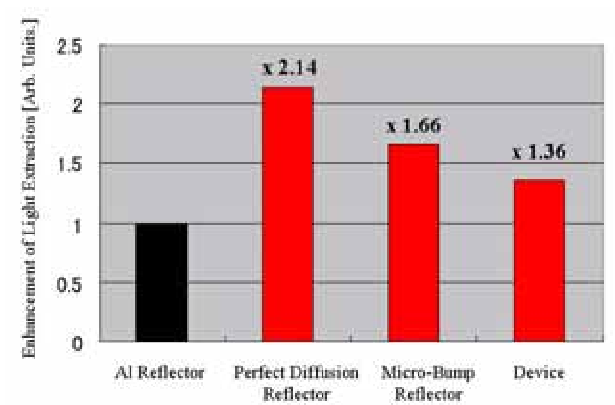

Fig. 5. Summary of enhancement of light extraction.

4. 20.8" AM-OLED Display

We fabricated the 20.8 inch WXGA full color display by introducing the enhancement of light extraction with aluminum micro bump scattering reflector. Figure 6 shows the picture image. The specification of the display is shown in table 1. The low temperature poly-Si (LTPS) array was applied as the backplane. Top emission structure was introduced in order to increase the aperture ratio and to prevent parallax. The polymer type light emitting layers were selectively ink-jetted to the RGB pixels. The thickness uniformity was less than 5% over the display panel. Circular polarizer was attached in front of the panel in order to reduce the reflection of outside light.

Figure 7 shows the cross-section view of the AM-OLED device with micro bump reflector. The bump pitch was 9um and the height was 1.9um. The aluminum micro bump reflector was inserted just beneath the EL layer and no parallax could be confirmed in the display.

When the micro bumps are designed by arranging it regularly, there is a concern of anisotropy according to the viewing angle. Figure 8 shows the picture image of the display from various viewing angle. The dependency of colors on the viewing angle, which is often caused by the micro-cavity effect, was not confirmed in this display.

Fig. 6. Picture image of 20.8 inch OLED display.

TABLE 1. Specification of 20.8 inch OLED display

Display size	20.8inch diagonal
Number of pixels	WXGA (1280 x 768)
Resolution	72ppi
Number of colors	260K
Gray scale	64 levels
Backplane	LTPS-TFT
Emission type	Top emission
Light extraction	Micro-bumps reflector
Emission layer process	Polymer Ink-Jet printing
Peak luminance	> 600 cd/m2
Contract ratio	> 10,000 : 1
Thickness	1.7 mm

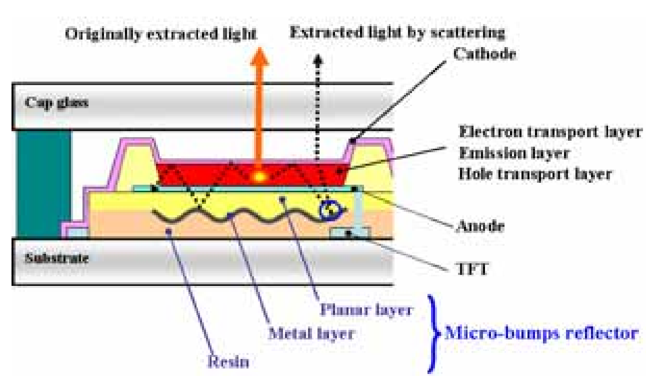

Fig. 7. Cross-section view of AM-OLED device.

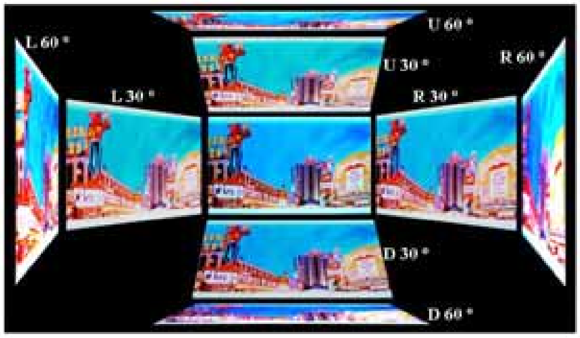

Fig. 8. Picture Image from various viewing angle.

Contrast ratio is over 10,000 at the viewing angle from 0 to 120 degrees. A circular polarizer is attached to the panel to prevent reflection from outside light so high contrast ratio can be obtained.

Due to the limitation of materials that we could use in our facility, the enhancement of light extraction of the display was 1.36. By using silver(Ag) rather than aluminum as the reflection metal, and also by using low light absorption planer layer, the enhancement of light extraction is expected to improve up to 1.7. This effect is equivalent to improving the luminous efficiency, so the contribution to low power consumption and long lifetime of the display is expected to be remarkable.

5. Summary

We presented a new top emission OLED display with aluminum micro bump light scattering reflector and improved the enhancement of light extraction. Although we had limitation of materials and process, we confirmed that the enhancement of light extraction was 1.36. We clarified the main mechanism of enhancement of light extraction and improved it up to 1.7 in our fundamental experiments. According to these results, we fabricated a 20.8 inch WXGA full color AM-OLED display. By optimizing materials and optical designs, further enhancement of light extraction can be expected. We think that this is a promising technology which provides low power consumption and long lifetime for OLED display.

6. Acknowledgements

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7. References

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