Metrology Issues of Non-Planar Light Sources with Measurement Field Comparable Radii

K. Käläntär[1,2], Tomonori Tashiro[1], Yasuki Yamauchi[1]

[1]Yamagata University, Yonezawa-Shi, Yamagata-Ken 992-8510, Japan
[2]Global Optical Solutions, R&D Center, Tokyo 193-0832, Japan, Japan
Keywords: Non-planar light source; OLED; FLS; curved display; arbitrary curvature; single curvature; curved light source

ABSTRACT

We have studied the effect of small curvature radius on characteristics of non-planar light sources (NPLS). The change in optical characteristics with radius was investigated using flexible OLEDs as NPLSs. The bending effect on light emission through the substrate or superstrate was approximately simulated and the issues extracted. The metrologies of NPLSs were studied and the contour of the measurement fields (MF's areas) on cylindrical and cone light sources were simulated. For comparison the on-axis plane and off-axis plane light sources were simulated as well. The contours of MFs depend on the shape of the light sources and require new metrology methods.

1 INTRODUCTION

Development and integration of non-planar displays have increased the application of curved devices, e.g. distinct or curved-back large-size wall displays or foldable signage displays, as well as commercial wearable and handheld devices. The measurement methods of large displays have been studied and documented [1,2].

Since light sources are used for displays as well as lighting, the issues of non-planar light sources (NPLSs) are considered in this paper.

Since bending a planar light source (PLS) alters the optical properties of the device, the measurement and the evaluation of optical performance of the light source in a curved state (strain, e.g. stretched or contracted) is indispensable for manufacturing societies. In contrast to planar light source, the NPLSs introduce new issues and measurement challenges [3-7]. Nevertheless the issues of NPLS with small radius, i.e., the degree of flatness and the surface geometric structure, hitherto have not been studied. Optical characteristics of NPLSs should be evaluated to assure the integration of the light sources with other devices (e.g. fixtures and displays) because the characteristics such as spatial and angular luminance, luminance uniformity or virtual luminance uniformity i.e., relative comparison of luminance at different positions, chromaticity distribution, chromaticity uniformity, luminous intensity distribution, local luminous flux and etendue of the NPLS change with decreasing radius of curvature.

The intent of this work is to use analytical geometry to analyze and to extract issues of NPLSs with single small radius of curvature comparable to measurement fields (MFs), i.e., the cross-section of cone of a light measurement device (LMD) and to characterize their precise optical metrologies and evaluations. Therefore, in this paper we study the metrology issues of the curved NPLS and measure the total luminous flux and chromaticity of NPLS OLED panels versus the curvature radius. Special attention has been given to the intrinsic characteristic change of the flexible OLED in this study.

2 MF CONTOURS ON PLS AND NPLS

2.1 MF Area-Contour on Planar Light Source

A convex and a concave light sources with measurement field comparable radii and the measurement system are shown in Fig.1 [3-6]. However, in case of curved NPLSs, a depth of field or depth of focus issue exists in the measurement system.

The conventional light measurement devices are used for measurement of the on-axis planar or the off-axis planar (tilted) light sources [3-6]. We simulated MFs on planar light sources in on-axis and off-axis states as shown in Fig.2(a). The MF of on-axis state is a circle, however, the MF contour in the off-axis state is an ellipse [3-6]. The conditions for this simulation are as follows: the measurement angle, β_{MF}=30°, the measurement distance, $D_{LMD}=\sqrt{3}$ mm, the measurement field radius, R_{MF}=1 mm, and the PLS's tilt angle with respect to optical axis of the light measurement device, α=0°, 30°, 45° [6].

2.2 MF Area-Contour on Cylindrical Light Source

To compare the measurement area or the contour of MF with that of a planar, the contour of MF on a cylinder light source was simulated. The contour of MF is shown in Fig.2(b), where the smaller contour is the MF projection on the outer surface of the cylinder and larger contour is the MF projection on the inner surface of the cylinder. The field of focus point is assumed to be at the center of the cylinder including the cylinder's axis. The conditions for this simulation are as follows: the measurement angle, β_{MF}=2°, the measurement distance, D_{LMD}=100 mm, the measurement field radius, $R_{MF} \fallingdotseq$ 1.745 mm and the cylinder's radius R_{FLS} or R_{NPLS}=1.745 mm [3-6].

2.3 MF Area-Contour on Cone Light Source

In continuation of our study we simulated the MF contour on a cone light source, i.e., a tilted cylindrical light source. The light source has a height of H=60 mm and bottom radius of R=60 mm. These were simulated for a measurement distance of D_{LMD}=1000 mm, the height of the focus point was z_0=30 mm, from the bottom, where the cone's axis coincides with z-axis. As shown in Fig.2(c). The front and back MF contours are slightly different when the center of the depth of field is at the center of the cone including the axis and a plane perpendicular to the LMD. The conditions for simulation are as follows: $\beta_{MF}=2°$, D_{LMD}=1000 mm, MF radius, R_{MF}=17.455 mm. Here, the definitions for the parameters are the same as mentioned above.

3 BENDING AND OPTICAL CHARACTERISTICS

One of the issues in NPLS is the light extraction in bent state, when a NPLS has a substrate (or superstrate). A bending in substrate results in change of light transmission, i.e., the change in critical angle. In this study we employ flexible OLEDs as NPLS. We simulate the critical effective angle for curved state such as spherical and cylindrical flexible OLEDs. As shown in Fig.3(a), the emitted light in the OLED is partially extracted and confined in the substrate of the planar light source. The light is guided in the substrate based on total internal reflection (TIR). The rays having higher incident angles than the critical angle are guided in the substrate. However, an OLED in spherical or cylindrical shapes can be a convex with outward radiation as shown in Fig.3(b) or concave with inward radiation as shown in Fig.3(c).

The critical angles for both cases were simulated for spherical and cylindrical shapes as shown in Fig.4. For spherical shape, the emission varies with zenith angle (θ) only, in both outward and inward emission [8]. The cross section of the sphere be taken as cylinder, having the same emission, in which the emission varies with the zenith (θ) and azimuth angles (ϕ). Here, we assume a spherical coordinate system at the center of the light emission source. The substrate of OLED is assumed to be PET (Polyethylene terephthalate) with thickness of 125 μm and refractive index of 1.58. In this simulation the substrate is assumed to be thick enough, i.e., comparable to that of the curvature radius. However, in general, a thinner substrate is used in fabrication, therefore lower parts of the graphs are useful, i.e., the variation of ratio, (R-r)/r, is between 0 and 0.125.

4 EXPERIMENT RESULTS

4.1 OLED Panel Structure and Bending Concept

An OLED panel consists of very thin layers on the substrate as shown the structure in Fig. 5(a). Few organic stacked layers are sandwiched between cathode and anode. The thickness of organic layers is normally several tens of nanometers and the thickness of an OLED panel including the substrate is, in general, less than 1 mm. Glass or plastic thin film is used as substrate. When a rigid glass substrate is used, the OLED panel cannot be bent. However, the OLED can be bent or can be a flexible in case of a thin substrate plastic foil [9-11].

The OLED panels are current driven light sources, the light emission is proportional to the number of electrons passing through the light-emitting layer.

The light emission concept in case of flat and bent are shown in Fig.5. Since the higher order emitted light cannot be extracted, the light radiation pattern changes that can be presented by power (p) of cosine of more than 1 ($\cos^p(\theta)$; θ: zenith angle, i.e., an angle with respect to the surface normal) in Lambert law. In both cases the result is the reduction in emitted luminous flux on the OLED in bent case [6].

4.2 OLED Panel and Experiment Tool

To measure the effect of single curvature on a NPLS (OLED), we prepared 5 OLED panels. The panel is made of a reflective substrate and diffusive front surface, and the size is about W=50 mm (width), L=200 mm (length), t=0.41 mm (thickness), with an emission area of 189$\times$39 mm^2.

For the purpose of bending and fixing the panels during the measurement, we used off-shelves pipes for general applications (vinyl chloride resin) and cut them into the designed shapes as shown in Fig.6 (a). The radii of these jigs and their shapes are shown in Fig.6 (b) (c).

4.3 Luminous Flux

To measure the total luminous flux of each panel, the integrating sphere (Lab Sphere 3 m in diameter) was used. Each OLED bended around each jig and the luminous flux was measured. The luminous flux of the panel P#5 was shown in Fig.7. The variation of luminous flux (Φ_v) with curvature radius (panel P#5) decreases with the curvature radius. The slope of the graph is about -0.267 lm/mm. This result is almost the same for five panels, P#1 to P#5. Because of lack of space in this paper, the results of optical measurements will be presented at the conference.

5 DISCUSSION AND CONCLUSION

Metrology of emerging flexible light sources, for displays or lighting with an arbitrary curvature is the main issue. The study of a NPLS with small single curvature radius gives basic understanding of curved NPLS. Therefore, a single curved NPLS was analytically studied and experimentally verified for first time. The structure of a NPLS under a curved condition changes and as a consequence, the intrinsic optical properties of device vary and differ from that of the planar.

We found that the luminous flux decreases with bend radius and the luminous intensity distribution lessen in the half-width full maximum angle, that can be explained by increasing in power of the cosine in Lambert law ($\cos^p(\theta)$; θ: zenith angle) [6]. For example, the bent with radius R=56.7 mm, shows $[\cos(\theta)]^{0.72}$ for barrier layer of 100 nm, and $[\cos(\theta)]^{1.39}$ for barrier layer of 150 nm. Furthermore, the chromaticity C_x increases with curvature (1/radius).

REFERENCES

[1] IEC CDV 62715-5-1:2016, Flexible display devices – Part 5-1: Measuring methods of optical performance.

[2] IEC CDV 62715-5-2:2016, Flexible display devices – Part 5-2: Measuring methods of optical characteristics for curved displays.

[3] K. Käläntär, et al, “Optical measurement methods for flexible OLED elements with arbitrary geometric curvature,” Proc IDW’17, pp.500-503, (2017).

[4] K. Käläntär, et al, “Optical characteristics of flexible display light sources with arbitrary curvatures,” Technical Digest, SID2018, pp.157-160 (2018).

[5] K. Käläntär, et al, “Optical characteristics and metrology of flexible light sources (FLS),” Proc IDW’18, (2018).

[6] K. Käläntär, et al, “Optical Characteristics of Curved Flexible Light Sources (FLSs) with Small Radius and Metrology Issues,” Technical Digest, SID2019, No.43.2, pp.593-596 (2019).

[7] M.E. Becker, et al, “Curved Displays Challenge Display Metrology,” Information Display 1/18, p.21, (2018).

[8] C Zih-Rou Cyue, Wei-Kai Lee, Li-Yu Yu, Guo-Dung Su and Chung-Chih Wu, “Optics of Curved OLEDs,” Technical Digest, SID2019, P-179 pp.1907-1910 (2019).

[9] T. Mori, et al, “Development of a Barrier Film for Flexible OLED Lighting,” Konica Minolta Technology Report Vol.11, pp.83-87 (2014) (in Japanese).

[10] I. Hiromoto, et al, “Development of flexible OLED,” International Workshop on active-matrix flat panel displays and devices (AM-FPD) proceeding, pp.21-24 (2014).

[11] T. Kawabata, Y. Ohno, “Optical measurements of OLED panels for lighting applications,” J. of Modern Optics,2013, http://dx.doi.org/10.1080/09500340.2013.806681.

.

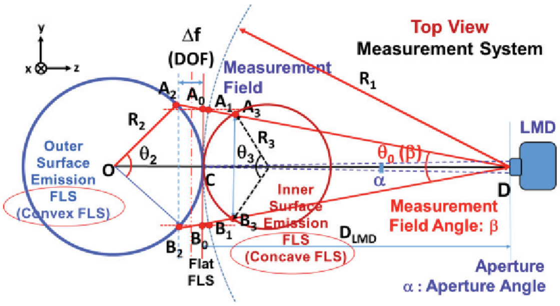
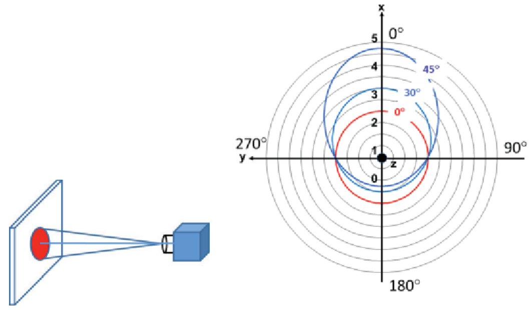
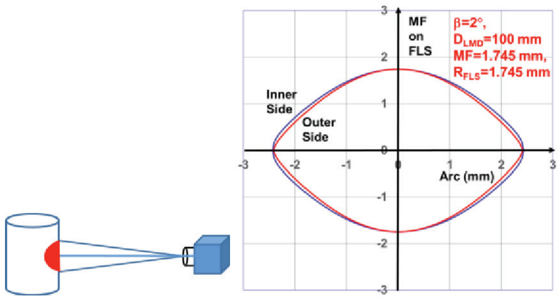


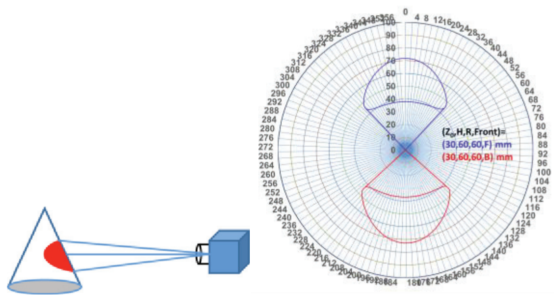
Figure 1. Geometry of optical quantity measurement system. The defocus (depth of focus; DOF) due to NPLS/FLS curvature (single) is Δf, and the MF diameters are A_0B_0 (conventional measurement) and A_1B_1, A_2B_2, A_3B_3, for NPLSs (FLSs) with the radii of R_1, R_2, and R_3.



(a)



(b)



(c)

Figure 2. Contours of the measurement fields. (a) Contours on a non-tilted PLS and tilted PLS (β_{MF}=60°, D_{LMD}=√3 mm, R_{MF}=1 mm, tilt angle α=0°, 30°, 45°). The simulation is an exaggerated example. (b) Contours on cylindrical NPLS (F: front, B: back). (c) Contour on conical NPLS (β_{MF}=2°, height: H=60 mm, bottom radius, R=60 mm, measurement point at z_0=30 mm).

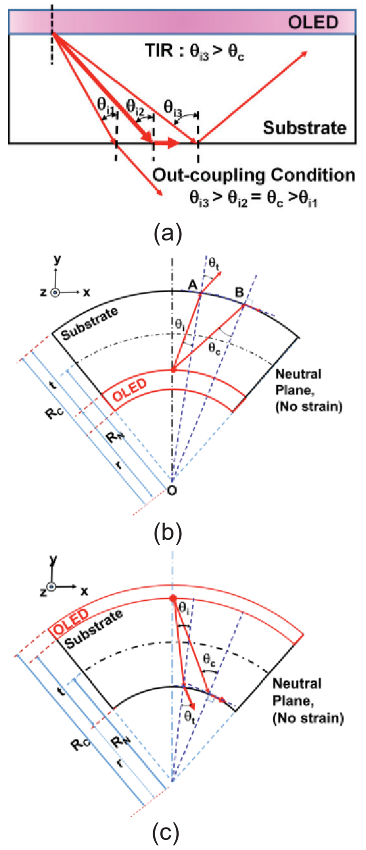


Figure 3 Schematic illustration of extracted and propagated light in an OLED. The thickness of the substrate and the bending radius affects the TIR condition. (a) Flat light source. (b) Outward emission OLED and TIR in curved case. (c) Inward emission OLED and TIR in curved case.

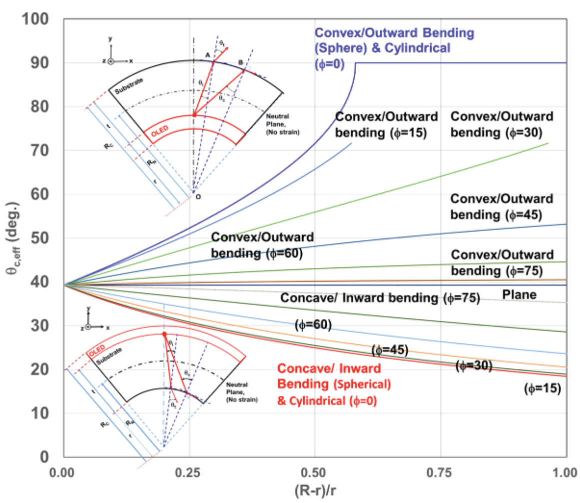


Figure 4 Variation of critical angle with the ratio of (R-r)/r (the substrate thickness divided by the bending radius). These cases are shown in Fig.3 (a) and (b). The zenith angle dependency relates to spherical case and azimuth angle dependency related graphs are for cylindrical cases.

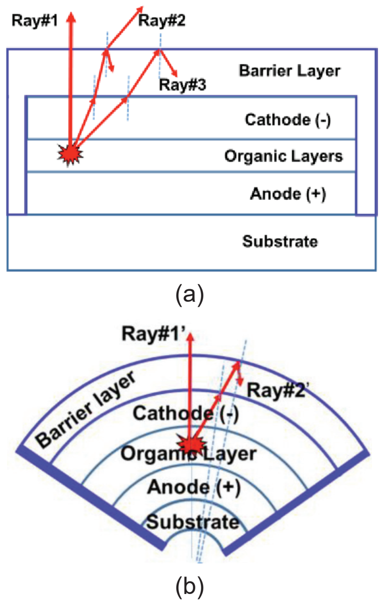


Figure 5. Schematic illustration of OLED structure. (a) Planar state. (b) Bended state. The trapped emitted light in the barrier layer, are guided as higher order modes, resulting in the change of luminous intensity on the OLED surface, and the reduction of luminous flux.

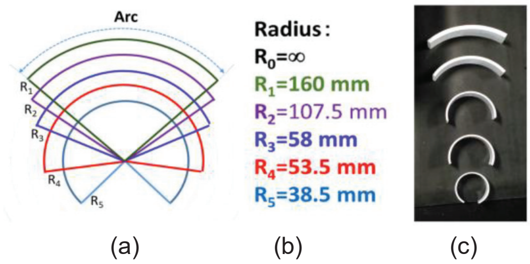


Figure 6 (a) Designed curvatures for bending the OLED panels. (b) Radii of the designed jigs. (c) Jigs were fabricated for bending the OLED and measurement.

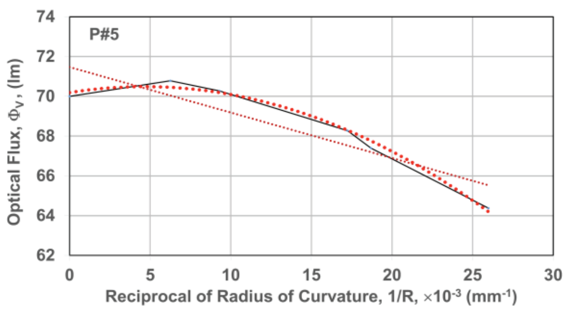


Figure 7 Variation of luminous flux (Φ_V) with curvature radius for panel P#5. The slope of the graph is about -0.267 lm/mm^{-1} (dotted straight line: first order of approximation; dotted curve: second order of approximation). This property is almost the same for five panels, i.e., P#1 to P#5.dotted line). This property is almost the same for five panels, i.e., P#1 to P#5.