Characterization of Non-Planar Light Sources using Near Field Goniometric Measurement Method

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ABSTRACT

We have studied the metrology issues of non-planar light sources (NPLSs) by using an imaging light measurement device (LMD). The measurement area on the non-planar light source is a patch of a positive or negative curved surface that requires a spot LMD to be focused on all points of the patch. The near field (NF) goniometric measurement method is a solution to the focusing or the depth-of-field issue for characterizing the NPLSs. By means of the NF method, we have obtained the luminance image, the luminous intensity, the spectra, the chromaticity and the correlated color temperature of the cylindrical light sources as function of the ray angles, i.e., the zenith and the azimuth angles in spherical coordinate system. The NF light rays have been used to obtain the characteristics of the light source at far fields by post processing. The results of the NPLS metrology and the features of the NF goniometric measurement system are reported in this paper.

1 INTRODUCTION

LEDs and OLEDs are being used for lighting in recent years. These are indispensable parts of the present and future power saving lighting technologies.

In the structures of the aforementioned light sources a thin film glass or plastic film is used as substrate which is flexible and bendable. Since these characteristics are attractive the non-planar light sources (NPLSs) have been developed, and increased in the market in the past few years. These NPLSs can be a part of ceiling or entire wall, which are different from the conventional incandescent lamps or fluorescent lamps.

A NPLS is different in form from a light source that has been widely used so far. The measurement methods used for a conventional light source should be applied to NPSs with more care. When a planar light source (LS) is bent or deformed, the total luminous flux or other optical characteristics change with geometrical change which are of great concern. Therefore, the changes in optical characteristics of bent LSs and their measurement methods are the themes of our studies.

The measurement of planar light sources (PLSs) require very short depth-of-field (DOF) for the light measurement device (LMD). However, the measurement and the evaluation of optical performance of the NPLS (under strain, e.g. stretched or contracted) require a LMD with a longer DOF. Since the existing LMDs have rather short DOF, especially when the local radius on a NPLS decreases, the DOF issue becomes sever, particularly if the NPLS has a non-Lambertian light emission characteristic.

In this paper we employ near field (NF) goniometric measurement method using imaging LMD to study the optical characteristics of convex and concave cylindrical LSs.

2 BENT LS: CONVEX AND CONCAVE

The issues of convex and concave cylindrical LS are summarized schematically in Fig.1. The illustration shows a standard method for plane LS. The DOF of LMD, the change of inclination angles of the emitted rays on the cylindrical LS, viewed from the lower part and the upper part of the LMD's lens, and the optimized measurement distance for each DUT radius, are outlined in the figure as well as in the following references [1] to [5]. As shown in Figs.2 and 3, the lateral scanning, i.e., an LMD rotates around DUT in parallel to LS surface, and the directional scanning, i.e., an LMD rotates around the DUT (device under test) by fixing the measurement field on LS, are used to measure the luminance, the luminance variation, the chromaticity, the chromaticity variation, and the luminous intensity distribution. These characteristics change seriously with decreasing radius of cylindrical LS.

The DOF of a digital imaging device is shown in Fig.4. The DOF of a lens is its ability to maintain a desired amount of image quality (spatial frequency at a specified contrast), without refocusing. An LMD should have a long enough depth-of-field to cover the DUT size in a measurement. On the other hand the imaging device is required to have enough depth-of-focus and pixel size to capture the DUT in small solid angles. The following equation gives an estimations for front and rear DOFs in the LMD.

$DOF=\Delta L_f+\Delta L_r$ ………………... (1)

$\Delta L_f=+\{l_0-1/[1/f-(1-c/a)/l_i]\}$ ……. (2)

$\Delta L_r=-\{l_0-1/[1/f-(1+c/a)/l_i]\}$ ……. (3)

f: focal length, l_i: rear depth of focus, l_o: front depth of focus, a: aperture of the lens, c: circle of confusion at a distance of l_i

3 BENT LS AND OPTICAL CHARACTERISTICS

In near field measurement an imaging system is used to measure the light source. The measurement distance is shorter than that of the conventional goniometric method, i.e., about 10 times of the DUT size. In this method a NPLS is mounted on a two-axis goniometer (θ,ϕ), and a stationary imaging, e.g. a colorimeter (CCD system) is placed directly in NF views of the NPLS (DUT). The luminous intensity, $I_v(\theta,\phi)$, luminous flux, (Φ_v), in a given direction per unit area, i.e., the luminance L_v (x,y,z,θ,ϕ), as well as the spectrum of a NPLS, are acquired as a function of the ray angles. The data obtained from NF goniometric measurements are (1) ray data, i.e., the luminance distribution $L_v(x,y,z,\theta,\phi)$ which is discrete and position resolved, and (2) the integral quantities, e.g. the luminous intensity distribution $I_v(\theta,\phi)$ and the total luminous flux Φ_v.

In a NF model, the LS luminance and chromaticity versus ray angle are achieved. The acquired data is used for modeling light source, in which a ray tracing is used to yield far field (FF) intensity data at any intended distance [7-9].

The illuminance distributions, $E_v(\theta,\phi)$, at any distance including FF can be accurately simulated using the acquired data in a ray tracing optical software. The intensity distribution at FF regions is obtained by tracing the rays to infinity, and summing the luminance across the projected area. In addition, the acquired data contains color variation and appearance of the NPLS with ray angle. To extend the data to spectral information with ray angle, a spectrometer can also be attached to the imaging colorimeter.

4 CYLINDRICAL OLED

We use an OLED panel as a NPLS in our study. An OLED panel consists of very thin layers on the substrate [1-6]. Few organic stacked layers are sandwiched between cathode and anode. The thicknesses of the organic layers are 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, an OLED can be bent or can be a flexible in case of a thin substrate plastic foil [2,3]. A bending in substrate or superstrate of OLED results in the internal structure change, or geometry change and as a result the change in optical characteristics [1-6]. In case of convex, the higher order emitted light rays, that is, rays with large emission angle with respect to the surface normal, cannot be extracted [6]. Therefore, the light radiation pattern changes that can be presented by power (p) of a cosine with p>1 ($\cos^p(\theta)$: zenith angle, θ, i.e., an angle with respect to the surface normal) in Lambert law. In case of concave cylindrically bent, the power of the cosine reduces, i.e., p<1 [1-6]. In both cases the result is the reduction in emitted luminous flux on the bent OLED.

A light source with a Lambertian emission can be measured with less error than that the light source with a non-Lambertian ($p\neq1$) as mentioned above.

5 EXPERIMENT RESULTS

5.1 OLED panel, fixtures, experiment conditions

To measure the effect of single radius (cylindrical OLED) on a NPLS we prepared an OLED panel. The panel was an integration of a reflective substrate and a diffusive film on the front surface. The length, width, and thickness were L_p=200 mm, W_p=50 mm, and T_p=0.41 mm, respectively, with a light emission area of 189×39 mm^2. The flux of the OLED is 75 lm at a current of 175 mA, and a voltage of 8.2 V (consumption power 1.44 W). The correlated color temperature is CCT: 3000±200 K.

Two fixtures were fabricated using 3D printer, one was flat and the other one was curved. The materials of the fixture was ABS (Acrylonitrile Butadiene Styrene) with white color. The curved fixture had a radius of R_f=100 mm. Both fixtures had lengths of L_f=314 mm (a length of half a circle) and widths of W_f=50 mm and thicknesses of T_f=2 mm.

The measurement room was dark having a temperature of T_c=25±1 °C and a relative humidity of RH=50±5 %.

5.2 Measurement and Results

The OLED fixed on a convex fixture of radius 100 mm. The outer surface of the fixture was used to measure the OLED in convex state and the inner surface was used to measure in concave state. The 2D luminance images of the OLED were captured along the azimuth and zenith angles.

The luminance images of the OLED panel in convex state are shown in Fig.5 along azimuth angle ϕ=0°-360° (angular interval: 45°), at the zenith angle of θ=50°. The luminous intensity, $I_v(\theta,\phi)$, of the OLED in convex state was measured along the azimuth angle by rotating the DUT and fixing the position of the LMD. The intensity distribution is plotted in Fig.6. The NF ray information was used in a dedicated ray tracing software to calculate the corresponding FF luminous intensity distribution as shown in Fig.7. The FF luminous intensity, $I_v(\theta,\phi)$, is plotted for zenith angles of θ=0° to 90° with an angular interval of 10 degrees.

The variation chromaticity (C_x, C_y) and the correlated color temperature (CCT) of the convex OLED were measured along the azimuth and zenith angles as shown in Fig.8.

The experiment continued using the planar fixture to measure the OLED for comparison with those of the convex and concave cylindrical states' results. Finally the OLED fixed on the inner surface of the curved fixture (R=98 mm, i.e., 2 mm less than the convex due to thickness of the fixture). Because, there is lack of space in this paper the results will be presented at the virtual conference.

6 DISCUSSION

In this paper the characteristics of an OLED light source which was in cylindrically bent form were evaluated. The near field goniometer measurement method was employed, because the space required for the measurement is small and the method is accurate. Almost all required information for the FF luminous intensity distribution were acquired in a single spherically scanning on an imaginary sphere around the LS. The measurement of the OLED in planar, convex and concave cylindrical states were performed.

Using a light source in cylindrical bent state causes changes in optical characteristics of the OLED. The differences between the planar and cylindrically bent characteristics are revealed in this paper. As a result of ray tracing the FF luminous intensity, $I_v(\theta,\phi)$, were obtained for three cases of planar, convex and concave states.

Since the light distribution changes with the bent (p<1 or P>1) the changes in the light emission of the OLED is of great concern. The light emission distribution should be the same when comparing the planar and the bent OLED. Therefore, the issue of Lambertian emission on planar OLED and non-planar on bent OLED should be considered in our future work.

7 CONCLUSION

An imaging system, i.e., the near field goniometric measurement method, was used to measure the panel instead of spot detector. Here, the measurement field on the OLED panel has not been considered as point source. The measurement was performed at shorter distance rather than standard far field goniometric. The luminance, the luminous intensity, the flux, and the spectra of the panel in the planar, the convex and the concave states were measured. The near field ray information was used to trace the FFs and to calculate the luminous intensity distribution pattern at other positions in the space around the panel.

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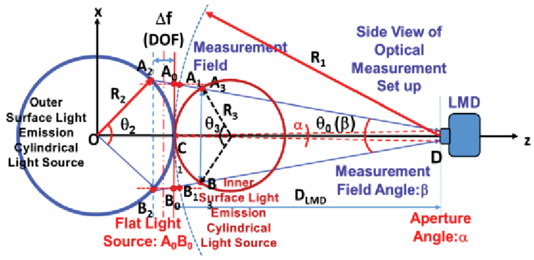


Figure 1 Measurement set up for planar, convex and concave light sources

Cross sections of flat (A_0CB_0), convex (R_2, arc: A_2CB_2), and concave (R_3, arc: A_3CB_3) cylindrical light sources (NPLS) in a conventional measurement system. The depth-of-field, the inclination ray angles of the light sources (non-Lambertian) are the issues.

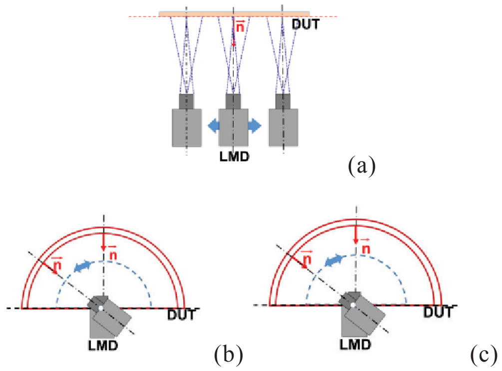


Figure 2 Lateral scanning measurement method

(a) Lateral scanning of a planar LS, (b) Convex cylindrical LS, and (c) Concave cylindrical LS.

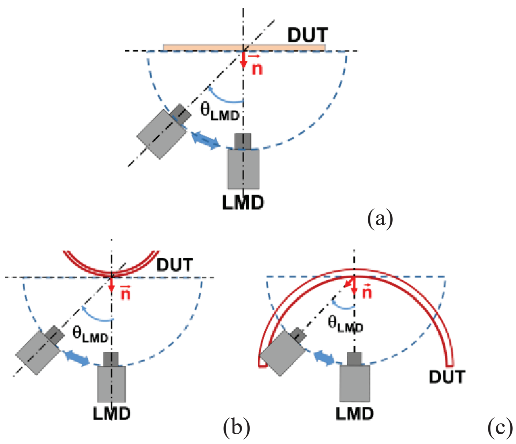


Figure 3 Directional scanning measuremnt method

Directional optical characteristics of a planar LS, (b) a convex cylindrical LS, and (c) a concave cylindrical LS.

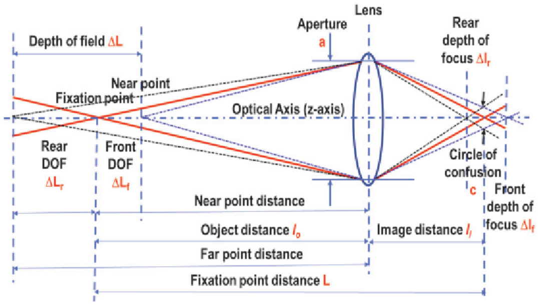


Figure 4 Optics of photography
Pictorial definitions of depth-of-field, depth-of-focus and circle of confusion for an LMD.

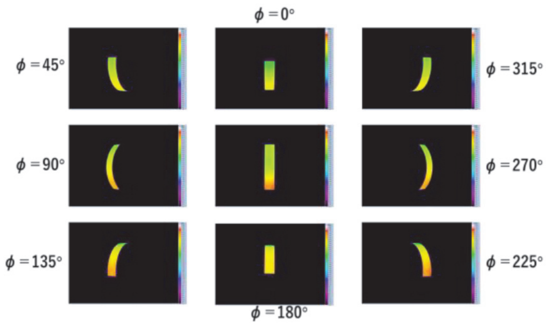
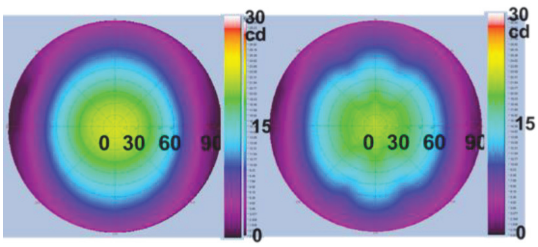


Figure 5 Luminance images
Luminance images of a lit OLED in <u>convex</u> cylindrical <u>state</u>, captured by the imaging LMD, The images were captured at zenith angle of θ=50° along the azimuth angles (ϕ=0°-360°), @ a distance of 952 mm.



(a) (b)

Figure 6 NF and FF luminous intensity patterns
(a) NF luminous intensity pattern, $I_v(\theta,\phi)$, of the OLED panel in <u>convex cylindrical state</u> (@ a distance of 952 mm), and (b) FF luminous intensity pattern of the cylindrical OLED panel. The NF luminous intensity of the OLED was used to calculate the FF luminous

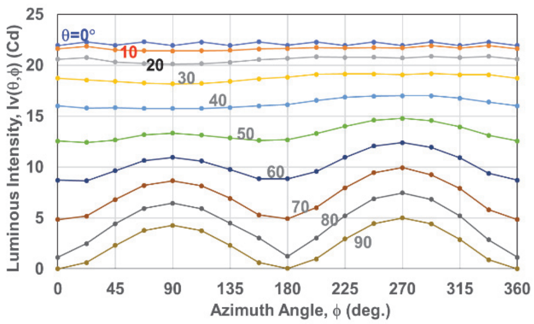
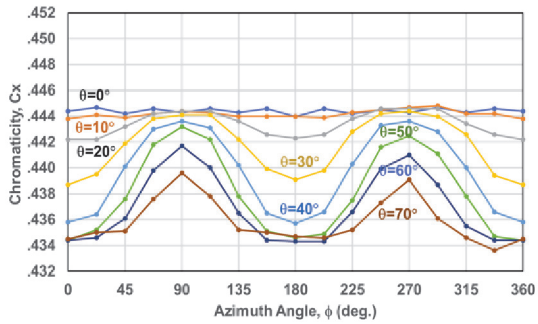
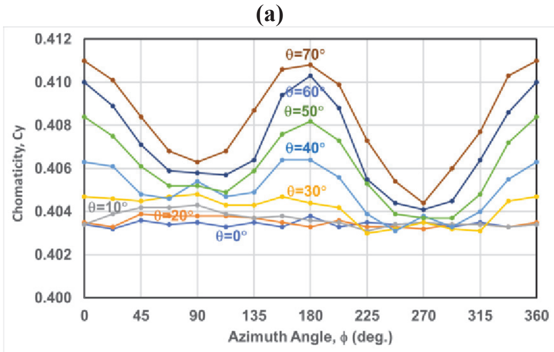


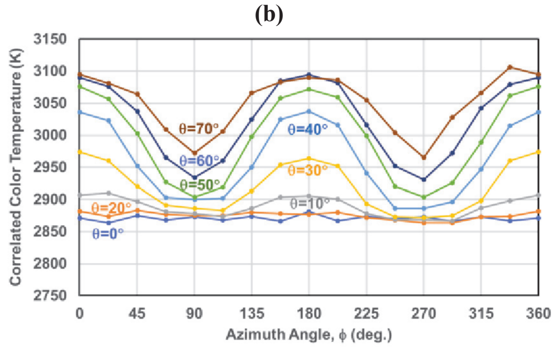
Figure 7 Luminous intensity along (θ, ϕ)
NF goniometric measurement method used to obtain the luminous intensity, $I_v(\theta,\phi)$, of the OLED panel in <u>convex cylindrical state</u>, along azimuth angles (ϕ=0°-360°) and zenith (θ=0°-90°, angular interval Δθ=10°) and @ a distance of 952 mm (near field). The Figure 6(a) was used to plot the Figure 7.



(a)



(b)



(c)

Figure 8 Chromaticity (C_x,C_y), and CCT
NF goniometric measurement method used to obtain, (a) chromaticity C_x, (b) chromaticity C_y, and (c) the correlated color temperature (CCT) of the convex cylindrical OLED at NF. The chromaticity C_x, C_y, and CCT are along azimuth angles (ϕ=0°-360°) and zenith (θ=0°-90°, angular interval Δθ=10°) and @ a distance of 952 mm (near field).