

Development of Long Lifetime and High Performance OLED Display with Wide Temperature Range

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ABSTRACT

We developed the long lifetime OLED display by optimizing each organic layer materials. In particular, the optimization of a hole-transport layer material improved the lifetime of the blue-OLED significantly at high temperature such as 85 °C. The developed OLED display would be useful for automotive application.

1 INTRODUCTION

Organic light-emitting diode (OLED) displays show great display performances such as high contrast ratio, wide viewing angle, wide color gamut, and etc. [1,2]. Furthermore, flexible, bendable, and rollable OLED displays are being actively developed in late years [3]. Hence the market of the OLED display has been rapidly growing for many applications such as smart phones, tablets, televisions, and head-mounted displays. Besides the fact, a demand for displays toward automotive application has also become large, and most of the automotive displays used recently are liquid crystal displays (LCDs). The LCDs, however, show low contrast ratio, narrow viewing angle, and slow response speed [4]. Moreover, the stability of the LC material at both high and low temperature is low in principle because nematic phase of the LC material is shifted to other phases. Therefore, the LCDs for the automotive application are limited. On the other hand, the stability of organic materials for the OLED is relatively stable in wide temperature range since phase transition does not take place in the temperature range between -40 °C and 100 °C. Thus, the OLED displays would be suitable for the automotive application from the standpoint of not only performances of OLED device (OLED) but also the stability of the organic materials against environmental temperature. However, it is known that lifetime of OLED at high temperature is relatively short [5]. Hence it is necessary to improve the lifetime in order to go into the market of the automotive field.

On the basis of the above background, we attempted to improve the lifetime of OLED, top-emission (TE) OLED shown in Fig.1, by optimizing the organic materials. For improvement of the lifetime, charge-carrier balance between hole- and electron-carriers in an emission layer (EML) was optimized. It is generally known that the hole-dominated OLED, especially blue OLED, shows

relatively long lifetime compared with the electron-dominated OLED [6,7]. Thus, we firstly optimized the materials for a hole-blocking and an electron-blocking layers (HBL and EBL), which are adjacent to the EML. Then, we also optimized a material for the hole-transport layer (HTL) for adjustment of the charge-carrier balance. Lastly, we attempted to evaluate the lifetimes of green- and red-OLEDs.

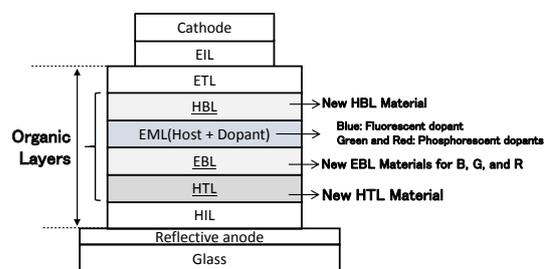


Fig. 1 Device structure of the TE-OLED used for this study.

2 IMPROVEMENT OF OLED LIFETIME

2.1 Fabrication of the OLEDs

The OLEDs with blue (B), green (G), and red (R) were each fabricated for the evaluation of the lifetimes. The organic layers were prepared with vacuum deposition technique under appropriate temperatures. The lifetimes of the OLEDs were evaluated under 50 mA/cm² for B- and R-OLEDs, and 30 mA/cm² for G-OLED at 25 °C, 70 °C, and 85 °C.

2.2 HBL and EBL Materials

The HBL and EBL materials were firstly optimized with using the B-OLED. We selected the HBL material with deeper LUMO level compared with the LUMO level of the EML in order to limiting electron-injection. In addition, the EBL material with relatively deep HOMO level was selected to improve the hole-injection into the EML. Finally, the lifetime of the B-OLED was improved more than three times compared with that of the reference (Ref)-OLED at 25 °C and 70 °C. The decay profiles of the B-OLED carrying the new HBL and EBL materials and Ref-OLED measured at 70 °C is presented in Fig.2.

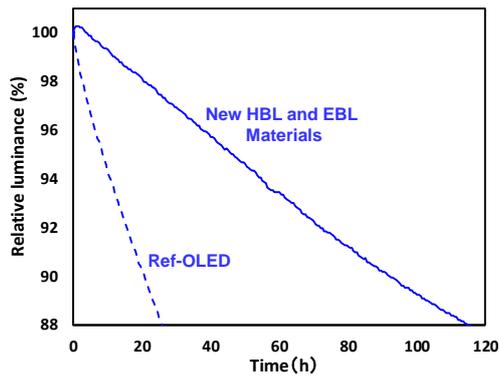


Fig. 2 Decay profiles of the B-OLED having new HBL and EBL materials at 70 °C.

2.3 HTL Material

For further improvement for the lifetime of B-OLED, charge-carrier balance between hole and electron was attempted to optimize with selecting new HTL material. For evaluation of the hole-transport property of the HTL material, hole-transport devices (HTDs) being constructed from anode/HIL/HTL/EBL/cathode were fabricated, and three HTL materials with almost same HOMO level (HTL-1, -2, and -3) were selected. The same HIL and EBL materials were used for the HTDs. Fig.3 shows the current-voltage characteristics (*I-V* curves) of the HTDs with different HTL materials measured at 25 °C. The slope of the *I-V* curve for the HTD carrying the HTL-1 shows larger than those carrying the HTL-2 and HTL-3, estimating that the hole-transport property of the HTL-1 was the largest among the HTL-1, -2 and -3. Therefore, the degree of the hole-transport would be increased for the B-OLED with using HTL-1 as the HTL material.

Fig.4 shows the decay profiles of the B-OLEDs with and without using HTL-1. With using HTL-1, further improvement of the lifetime was obtained. Hence, we confirmed that the charge-carrier balance of the B-OLED affects the lifetime, and the lifetime would be long with increasing a degree of the hole-transport.

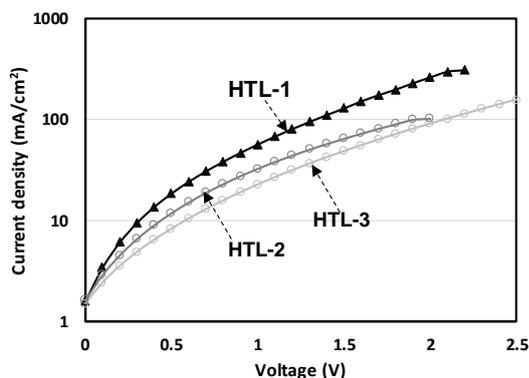


Fig. 3 *I-V* curves for the HTDs with different HTL materials at 25 °C.

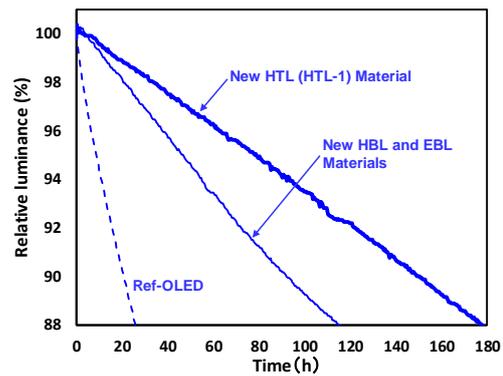


Fig. 4 Decay profiles of the B-OLEDs with and without using HTL-1 as the HTL material at 70 °C.

2.4 Lifetimes for B-, G-, and R-OLEDs at 85 °C

With using the new selected HBL, EBL, and HTL materials, G- and R-OLEDs were also fabricated. In the case of the HBL and HTL, the same materials with the B-OLED were used because the HBL and HTL are both the common layers. In contrast, the materials for the EBL were severally optimized for G- and R-OLEDs. The characteristics of each color OLEDs are listed in Table 1. The lifetimes at 85 °C were then evaluated in the similar manner to the B-OLED as described above. Decay profiles of the B-, G-, and R-OLEDs are shown in Fig.5. The results indicate that the significant improvement of the lifetimes for the B-, G-, and R-OLEDs were obtained by selecting the new materials. In particular, improvement of the lifetime for the B-OLED is prominent, anticipating that the lifetime of the B-OLED is notably affected by the charge-carrier balance between hole and electron compared with the G- and R-OLEDs.

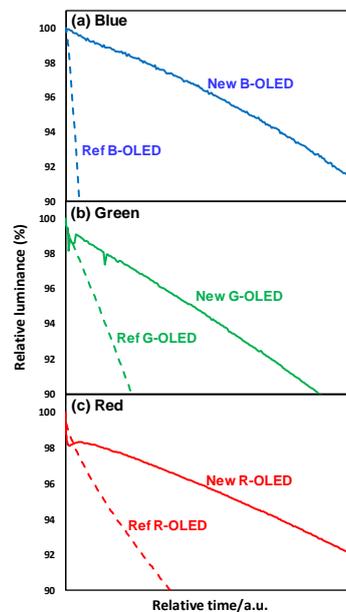


Fig. 5 Decay profiles of the (a) B-, (b) G-, and (c) R-OLEDs evaluated at 85 °C.

Table. 1 Characteristics of the B-, G-, and R-OLEDs under 10 mA/cm² at 25 °C.

	OLEDs (OLED devices)		
	Blue	Green	Red
cd/A	5.2	130	40
Chromaticity (x, y)	(0.14, 0.05)	(0.24, 0.72)	(0.70, 0.31)

2.5 Estimation of the Lifetime for Real Use

As described above, long lifetime at 85 °C is essential toward the automotive application. The lifetime for real use is defined in the following relation [8],

$$Lifetime_{(real)} = Lifetime_{(X)} \left(\frac{X}{A_{(real)}} \right)^k \quad (X = 50 \text{ or } 30)$$

where $Lifetime_{(real)}$ and $Lifetime_{(X)}$ indicate the lifetimes under current density of the real use and X (mA/cm²), respectively. $A_{(real)}$ indicates the current density for the real use (mA/cm²), and k indicates the accelerating factor. We attempted to estimate the $Lifetime_{(real)}$ for B-, G-, and R-OLEDs with using the above relation. As the real use, 600 cd/m² luminance of white color with the chromaticity (0.31, 0.32) was selected, and $A_{(real)}$ was calculated for B-, G-, and R-OLEDs with the assumption of the 167 ppi OLED panel. The k values were then determined with the similar manner described previously by our group [9]. We defined that the lifetime is the arrival time at 80 % against the initial luminance. The calculated lifetimes ($Lifetime_{(real)}$) for B-, G-, and R- OLEDs are summarized in Table 2. The results indicate that the lifetimes for the B-, G-, and R-OLEDs under the real use (600 cd/m² white luminance) show over 1,000 hours (hs). Thus, we can confirm that the OLEDs developed in this study show enough level of the lifetime under operation of 600 cd/m² white luminance at high temperature.

Table. 2 Calculated lifetimes of B-, G-, and R- OLEDs with white luminance of 600 cd/m² at 85 °C.

TE-OLED	Current density (mA/cm ²)	Lifetime ⁽¹⁾ (h)	Current density for 600 cd/m ² white ⁽²⁾ (mA/cm ²)	k ⁽³⁾	Lifetime for 600 cd/m ² white (h)
Blue	50	190	6.6	1.31	2.7×10^3
Green	30	170	6.3	1.42	1.5×10^3
Red	50	230	9.1	1.24	1.9×10^3

- (1) Lifetimes measured by the B-, G-, and R-OLEDs under current densities of 50 mA/cm² for B- and R-OLEDs and 30 mA/cm² for G-OLED.
- (2) Current densities of B-, G-, and R-OLEDs for white luminance of 600 cd/m² were determined under 167 ppi RGB TE-OLED panel.
- (3) Accelerating factor (k) was determined with the similar manner reported previously [9].

3 FABRICATION OF PROTOTYPE 12.3" ULTRAWIDE FLEXIBLE OLED DISPLAY

With using the new developed OLED materials as described in the previous section, we fabricated the 12.3" ultrawide flexible OLED display, as shown in Fig. 6. First of

all, the prototype OLED display showed an excellent brightness uniformity. The specifications are listed in Table 3. The fabricated OLED display could be operated in wide temperature range from -40 °C to 95 °C with enough level of reliability. In addition, since the OLED display shows high level of flexibility owing to the use of polyimide (PI) substrate, as shown in Fig. 6(a) and 6(b), it would be adjusted suitably in the case that it is attached inside automobiles. As another aspect, the flexible displays would be safer than the rigid displays because the flexible substrates would not be easy to get broken when they crash strongly. Thus, we can expect that the developed OLED display would be quite useful for the automotive application.

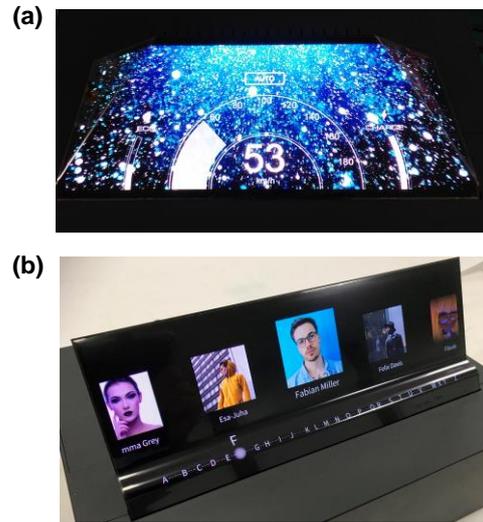


Fig. 6 Photographs of 12.3" flexible OLED displays, (a) bendable type and (b) "S"-character type.

Table. 3 Specifications of the fabricated 12.3" flexible OLED display.

Size	12.3 inch
Resolution	1920 x 720 x RGB (167 ppi)
OLED Type	Top Emission RGB Side-by-Side Type
Temperature Range	between -40 °C to 95 °C
Luminance	600 cd/m ²
Substrate	Polyimide

Viewing-angle property is also important for the automotive application. In Fig. 7, normalized luminance of white color is plotted as a function of the viewing-angle. The luminescent ratio is over 0.9 and 0.6 at the viewing angle of 10° and 50°, respectively, confirming that the enough level of viewing-angle property was obtained.

It is well-known that one of the most important factors for the automotive application is the reliability [4,9]. The

aging test with using the prototype 12.3" flexible OLED display fabricated for this work was performed under 200 cd/m² operation at 85 °C. As shown in Fig. 8, we could not observe obvious decrease of the relative luminance efficiency during 1,000 hs, indicating that the OLED display that we developed did not deteriorate under 200 cd/m² operation. We are now trying to perform another aging test under 600 cd/m² at 85 °C.

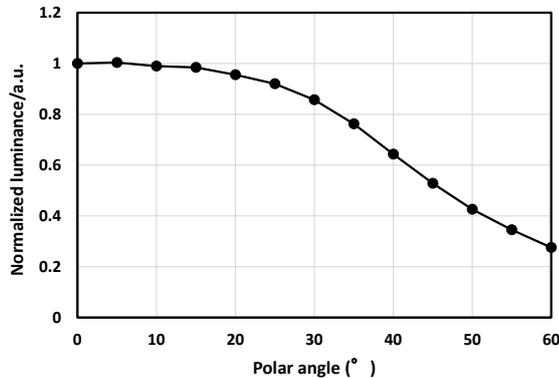


Fig. 7 Viewing angle-luminescence property of the 12.3" flexible OLED display.

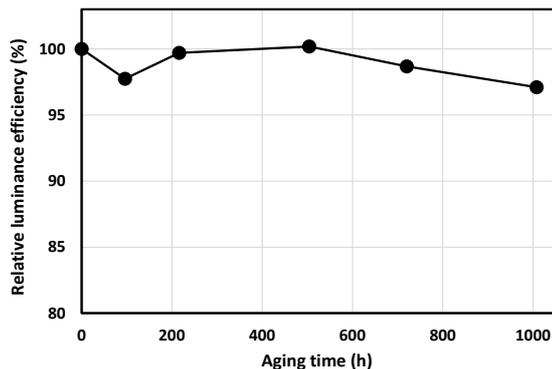


Fig. 8 Relative luminance efficiency of the 12.3" flexible OLED display as a function of aging time for 200 cd/m² operation at 85 °C.

4 CONCLUSIONS

We have developed the long lifetime OLED display at high temperature with the optimization of each organic layers. Charge-carrier balance between hole and electron inside the EML affects the lifetime of OLEDs, especially for blue-OLED. The lifetimes of the blue-, green-, and red-OLEDs developed in this work were achieved over 1,000 hs at 85 °C under the operation of 600 cd/m² white luminance. We fabricated the prototype 12.3" ultrawide flexible OLED display with using the new HBL, HTL and EBL materials. The aging test performed under 200 cd/m² operation at 85 °C shows no obvious decrease of the luminance efficiency for 1,000 hs. Hence, we believe that

the OLED display that we developed would be useful for the automotive application.

REFERENCES

- [1] S. Kawato, S. Inoue, Y. Kobayashi, and S. Mitsui, "Collimated flux deposition technology for RGB SBS OLED displays," *SID Symposium Digest of Technical Papers* 47, pp. 1005-1008 (2016).
- [2] T. Umeda, Y. Tsukamoto, B. Zhang, T. Jo, H. Imada, S. Kawato, and S. Mitsui, "Low-power-consumption flexible AMOLED display with highly efficient TE-type blue OLED," *SID Symposium Digest of Technical Papers* 50, pp. 54-57 (2019).
- [3] S. Eguchi, S. Kato, T. Kamada, Y. Suematsu, D. Nakamura, T. Nagata, T. Aoyama, N. Sugisawa, K. Toyotaka, H. Adachi, and S. Yamazaki, "A flexible OLED display with robustness and bendability," *SID Symposium Digest of Technical Papers* 50, pp. 632-635 (2019).
- [4] M. Mizusaki, H. Tsuchiya, K. Minoura, K. Ogawa, K. Taniike, and T. Fujihara, "High performance fringe field switching mode liquid crystal display with photo-alignment technology for vehicular application," *SID Symposium Digest of Technical Papers* 49, pp. 351-354 (2018).
- [5] B.-Y. Lin, P.-C. Tseng, M.-Z. Lee, Y.-Z. Hsiao, T.-L. Chiu, C.-F. Lin, J. Hsieh, S. Chen, and J.-H. Lee, "OLED lifetime improvement with exciplex sensitized triplet-triplet annihilation," *SID Symposium Digest of Technical Papers* 48, pp. 112-114 (2017).
- [6] E. Böhm, R. Anemian, A. Büsing, R. Forrte, H. Heil, J. Kaiser, J. Kröber, S. Leu, T. Mujica-Fernand, A. Parham, C. Pflumm, and F. Voges, "Novel transport materials for high-performance fluorescent and phosphorescent OLEDs," *J. Info. Disp.*, Vol. 12, pp. 141-144 (2011).
- [7] E. Böhm, C. Pflumm, F. Voges, M. Flammich, H. Heil, A. Büsing, A. Parham, R. Forrte, and T. Mujica, "Novel transport materials for high-performance OLEDs," *Proc. IDW'09*, Vol. 16, pp. 431-434 (2009).
- [8] C. Ferry, C. Racine, D. Vaufrey, H. Doyeux, and S. Cina, "Physical mechanism responsible for the stretched exponential decay behavior of aging organic light-emitting diodes," *Appl. Phys. Lett.*, Vol. 87, 213502 (2005).
- [9] M. Mizusaki, M. Shibasaki, H. Tsuchiya, Y. Tsukamoto, T. Umeda, K. Nakamura, T. Ohshita, and S. Shimada, "Long lifetime and high performance OLED display with wide temperature range for automotive application," *SID Symposium Digest of Technical Papers* 50, pp. 1400-1403 (2019).