# Wide Color Gamut Display Solution Using Hybrid-typed Perovskite Quantum Dots White LEDs

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## ABSTRACT

***This study presents that hybrid-typed Perovskite WLED has higher luminous efficiency (85 lm/W) compared to solid-typed and good wide color gamut performance (123 % of NTSC and 92 % of Rec. 2020). Lower operation temperature and better reliability (over 500 hours) result have also been demonstrated under this design.***

## 1. INTRODUCTION

The main advantage of quantum dots-based white light emitting diodes (QDs-based WLEDs) over conventional WLED is high color purity with low cost production. Although there are several ways like QLEDs, QD film in liquid crystal display (LCD) to apply QDs for next generation display, QDs-based WLEDs still have several superior potentials [1]. Compared to QLEDs, they have higher efficiency and better reliability. This design requires fewer quantities of QDs to reach target color point which attributes to cost reduction hugely. Despite of great interest in QDs-based WLEDs, the major two issues that limit the practical applications are their instability and anion-exchange reaction when different QDs mixing together [2]. It is important to develop a suitable packaging type to overcome the anion-exchange reaction in order to get long term stability. In previous study [3], we proposed a hybrid-typed structure which owned high efficiency (51 lm/W) for perovskite quantum dot (PQD) WLEDs. It showed outstanding color gamut that can be reached to 122 % of NTSC standard and 91 % of Rec. 2020 at a correlated color temperature (CCT) of 5516 K. The thermal resistance of hybrid-typed structure is better than the solid type structure. This characteristic resulted to better reliability performance at 200 hrs. However, the luminous efficiency and reliability performance is still not good enough to catch up conventional WLEDs' specifications. We found that the drop of light intensity comes from the red QD. Thus, in this study, we replaced the red QD to $K_2SiF_6:Mn^{4+}$ (KSF) for hybrid-typed structure in order to get higher efficiency and reliability without the decrease of color gamut.

## 2. EXPERIMENTS

The process flow and structure of solid-typed and hybrid-typed WLEDs are shown in Fig. 1 (a) and (b), respectively. For solid-typed WLED shown in Fig. 1 (a), we prepared solid films of green PQD first. We injected green PQDs into a glass box and after that the UV glue was added to it and then kept it for 30 second under UV light of 365 nm wavelength for curing. Then, we mixed KSF and adhesive and injected them into the 3030-package (3.0 x 3.0 mm) with 450 nm blue chip inside. After we attached green-PQD films on the top of package, the solid-typed PQDs device has been finished. The hybrid-typed PQDs structure is shown in Fig. 1 (b). We first prepared a 3030-package with KSF and blue chip inside as mentioned above in solid-typed device structure. After that, liquid green PQDs were poured into a glass box. Finally, we attached the glass box on the top of package and finished the process of hybrid-typed PQDs device.

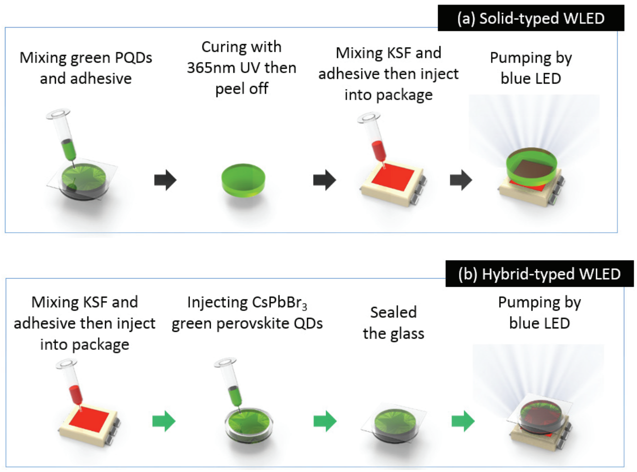


Fig. 1. (a) The process flows and structure of solid-typed WLED and (b) of hybrid-typed WLED.

The optical measurements were performed using a spectrometer CAS 140CT (Instrument System GmbH, Munich, Germany), with a 50-cm integrating sphere and 0.5-nm resolution. The thermal images for both solid and hybrid-typed device structure were recorded by using Testo

875 having tunable lenses, with high temperature measurement (up to 550 degrees).

## 3. RESULTS AND DISCUSSION

The spectrum of WLED with PQD and KSF is shown in Fig. 2. The peak wavelength of blue chip, green PQDs, and KSF phosphor of hybrid type and solid type are 450 nm, 528 nm, and 630 nm, respectively. The full width half wavelength (FWHM) of blue chip, green PQDs, and KSF phosphor of hybrid type and solid type are 16 nm, 30 nm, and 5 nm, respectively. The NTSC simulations are shown in Fig. 3. It shows 123 % of NTSC and 92 % of Rec. 2020 for hybrid-typed and solid-typed PQD WLEDs. Because the spectrum of hybrid-typed and solid-typed PQD WLEDs are the same, their value of NTSC and Rec. 2020 are the same. It can be observed that the blue point and red point of device are very close to the standard of NTSC and Rec. 2020, but the cie point of green PQD is still needed to be improved.

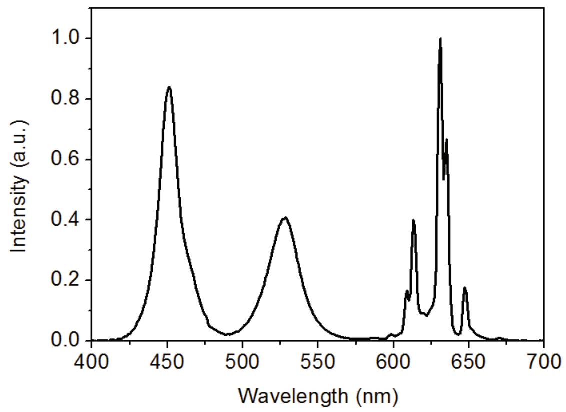


Fig. 2. The spectrum of WLED with green PQD and KSF.

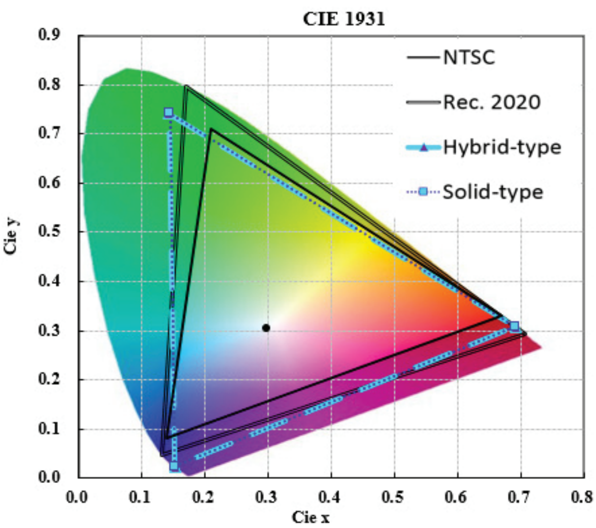


Fig. 3. The NTSC simulations. It shows 123 % of NTSC and 92 % of Rec. 2020 for hybrid-typed and solid-typed PQD WLEDs.

The light performances of hybrid type and solid type are measured and shown in Fig. 4. It can be observed that the luminous efficiency of hybrid type is better than solid type by 16 %. For hybrid type structure, the luminous efficiency can reach to 85 lm/W at 10 mA driving, but for solid-typed structure, the luminous efficiency can only be 73 lm/W. The reason of reduction in efficiency not only depends on packaging type, but also the aggregated QDs in solid-typed that are enclosed in silicone resin might cause the scattering and re-absorption [3-5]. As a result, this would lead the low efficiency in solid-typed structure.

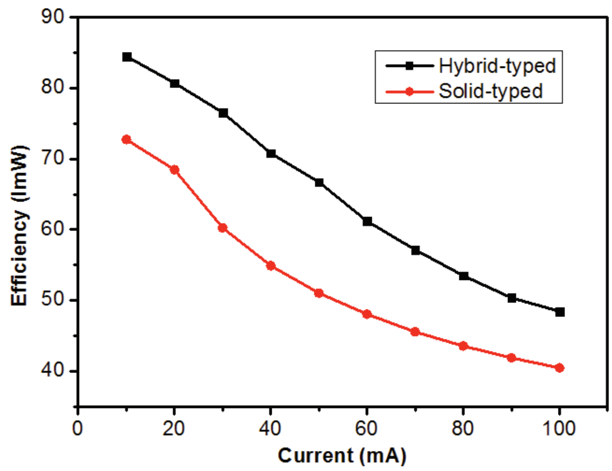


Fig. 4. The plot of luminous efficiency vs current of hybrid-typed and solid-typed PQD WLEDs.

The plot of device temperature vs current was measured in Fig. 5 (a). Fig. 5 (b) and (c) represent the thermal images for solid- and hybrid-typed devices under the typical operating current 100 mA with the maximum surface temperature about 43.2 ℃ and 28.8 ℃, respectively. The temperature gap between hybrid-typed and solid-typed PQD WLEDs is very big, which is about 15 ℃. It shows that for hybrid-typed PQD WLED, the operating temperature will not increase too much with current increasing. With driving current increasing from 10 mA to 100 mA, the increase of device temperature is less than 3 ℃. For solid-type PQD WLED, the temperature goes up to 43.2 ℃ with driving current increasing to 100 mA. This high value of temperature on the surface is attributed to the non-radiative relaxation energy [3]. As a result, the solid-typed device suffers the reduction in efficiency and reliability. On the other hand, hybrid-typed PQD WLED possesses low temperature on the surface, which makes the device more reliable towards its performance and efficiency. Besides, the glass sealed structure for liquid type QD made it less influenced by thermal effect.

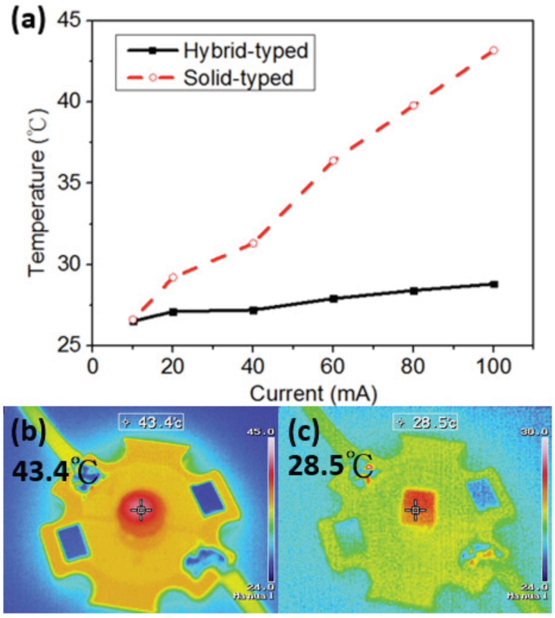


Fig. 5. (a) The plot of device temperature vs current for solid-typed and hybrid-typed PQD WLEDs. (b) The operating temperature of solid-typed PQD WLED. (c) The operating temperature of hybrid-typed PQD WLED.

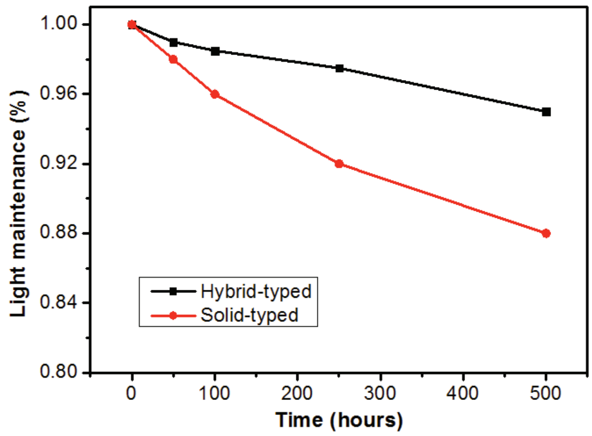


Fig. 6. Long-term stability of solid- and hybrid-typed WLEDs.

Finally, the reliability results of two types of PQD WLEDs have been tested. For hybrid type, the light intensity only decays by 5 % at 500 hours, which is much better than previous work with 12 % decay at 200 hours [3]. This result might be due to two reason. One is the lower device temperature for hybrid-typed PQD WLED shown in Fig. 5. The other is the red phosphor replacement. The stability of KSF is better than that of red QD. In this study, we demonstrate that the hybrid-typed PQD WLED has the higher luminous efficiency (85 lm/W) compared to the solid-typed structure and good wide color gamut performance (123 % of NTSC and 92 % of Rec. 2020) and better reliability result show that hybrid-typed structure is one of the solution for PQD WLED.

## 4. CONCLUSIONS

In previous work [3], we proposed a hybrid-typed structure which owned high efficiency (51 lm/W) for PQD LEDs. It also showed outstanding color gamut that can be reached to 122 % of NTSC standard and 91 % of Rec. 2020. However, the luminous efficiency and reliability performance is still not good enough compared to the conventional WLEDs. In addition, we found that the drop of light intensity in reliability test mainly comes from the red QD. In this study, we changed the red QD to KSF for hybrid-typed structure and demonstrate that the hybrid-typed PQD WLED has the high luminous efficiency (85 lm/W) and good wide color gamut performance (123 % of NTSC and 92 % of Rec. 2020). Lower operation temperature makes the better reliability result (5 % decay at 500 hours), which shows that hybrid type structure for PQD WLED is one of the choice for next generation display.

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