Improve Electroluminescence Morphology and Operating Lifetime of QLED Device by Modified ZnMgO

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Abstract

In this work, we developed a modified method by further heating to ZnMgO for the application of quantum dot light emitting diodes (QLED). Compared to the original ZnMgO, this modified ZnMgO can largely improve the electroluminescence morphology, especially at low brightness. Besides, the modified ZnMgO can also lower the turn-on voltages and increase the device's operating lifetime. All these advantages will help the QLED performance in the display application.

Author Keywords

QLED, ZnMgO, electroluminescence morphology, positive aging

1. Introduction

Since their discovery in the 1980s, quantum dots (QDs) have received much academic and industrial attention for applications in lighting, displays, photovoltaics, photosynthesis, and biosensing.[1, 2] Compared to conventional technologies, QDs-based LED and display offer several advantages such as narrow emission wavelength for a high color gamut, tunable bandgap through size and composition changes, use of inorganic core materials for enhanced stability, and cost reduction through solution preparation processes.[3] The QDs display by the photoluminescent (PL) model has been commercialized for several years, where the display backlight is applied and QDs work as a color-converting film or patterned color-converting layer.[4] Furthermore, the active luminescence by the separated injection of electron and hole to QDs which is called QD-LED or QLED is supposed to be one of the next generations of device technology.[3, 5]

After recent years of development, QLED devices have made breakthroughs in performance. Many researchers have found that positive aging strongly correlates with the performance of QLED devices, which can significantly improve the performance of devices in terms of external quantum efficiency and operating lifetime.[6] More and more research groups have begun to focus on the internal mechanism of this unique optical phenomenon. So far, the researchers have found that positive aging is observed in QLED devices when the device is encapsulated with acids-based UV encapsulation resins and ZnO is used as the electron transport layer.[7, 8] Although the performance of QLED devices can be rapidly improved, many problems and phenomena exposed during the operation of QLED devices have still not been solved and explained.[9]

Although high efficiency can be obtained by the acids that assist positive aging, some research shows that the luminous morphology may not be good after the positive aging process, with bright/dark spots, black holes, and even incomplete luminous regions. This phenomenon is more obvious after long-term operating or storage, leading to the lack of stability and reproducibility of the device.[10] Such inhomogeneous luminescence morphology could cause uneven overall luminescence and cannot be ignored in a display panel.

Since the positive aging process mainly occurred between acids-based UV encapsulation resins and the QLED electron transfer layer ZnO (or ZnMgO), we focus on modifying the ZnMgO to increase the luminous morphology. In this work, we applied an additional heating process after the synthesis of ZnMgO to increase the stability of the QLED electron transfer layer ZnMgO. After fabricating the QLED device, it was noticed that the modified ZnMgO can increase the luminescence morphology, especially at low brightness. Besides, the modified ZnMgO can also lower the turn-on voltages and increase the device's operating lifetime. All these advantages will help the QLED performance in the display application.

2. Results and discuss

The absorption spectrum of ZnMgO before and after heating was first tested using an ultraviolet absorption spectrometer. Original ZnMgO is synthesized without an additional heating process, with an absorption peak around 310 nm. When the additional heating rises gradually to T6, it can be seen an obvious redshift to 340 nm. Since the elemental analysis proved that the Mg doping content did not change significantly during the heating process, the redshift of the absorption spectrum was due to the increase of ZnMgO size according to the quantum confined effect.

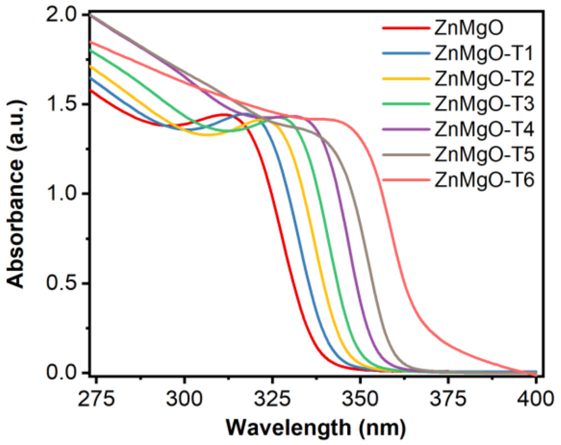

Figure 1. The absorption spectrum of original ZnMgO and modified ZnMgO with increasing temperature from T1 to T6

The TEM (Transmission Electron Microscopy) was then tested to further confirm the change in size of the modified ZnMgO. More than 50 ZnMgO nanoparticles were selected from TEM images and analyzed the particle size. It can be seen from the statistics result of the following TEM images, the diameter of

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ZnMgO increases after heating. Then, we made statistics on particle size the result is shown in Figures 2b and 2d. After heating, the diameter of ZnMgO increases from an average of 3.9 nm to 5.2 nm. In addition, further agglomeration of ZnMgO particles can be seen in the TEM images.

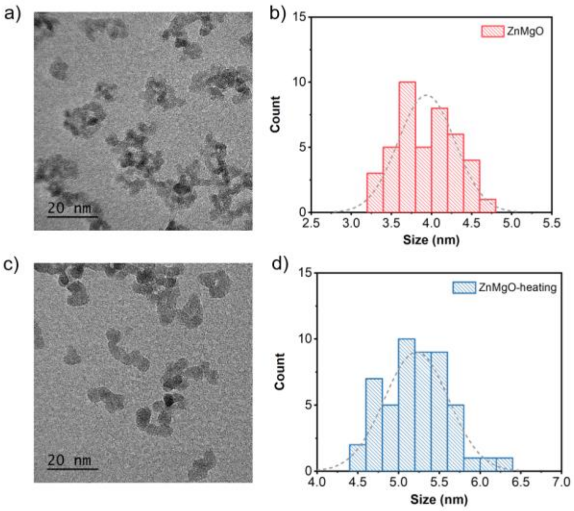

Figure 2. TEM image (a, c) and statistical size distribution (b, d) of original ZnMgO and modified ZnMgO after heating.

After obtaining the different ZnMgO, we fabricated bottom-emitting QLEDs device with the following conventional architecture of ITO/PEDOT:PSS/TFB/QDs/ZnMgO/Al (Fig. 3). Among them, we select PEDOT:PSS as the hole injection layer and TFB as the hole transport layer. Cd based RQD is used as the emission layer, and metal Al electrode is the cathode. ZnMgO and ZnMgO-heating were used as the QLED electron transfer layer. PEDOT:PSS, TFB, QDs, and ZnMgO solutions were spin-coated onto ITO substrates at 3000 rpm for 40 s in turn, and the ITO substrates were treated by oxygen plasma for 10min before. PEDOT:PSS coating process was done in air and all other functional solution coating processes were done in N_2 glove box. Then 100 nm Al was evaporated in a vacuum chamber. Finally, the device was encapsulated using cover glass with acids-based UV encapsulation resins. Here Cd-based red QDs obtained from Mesolight with PLQY > 95% are used here. PEDOT:PSS and TFB were obtained from commercial purchases.

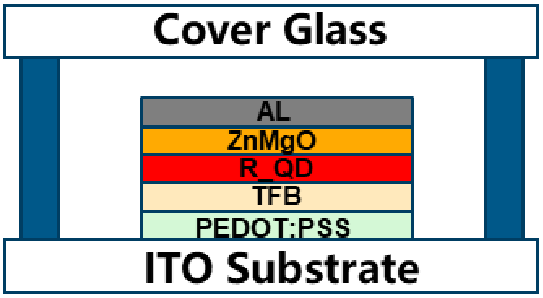

Figure 3. Device structure including ITO substrate, PEDOT:PSS Film, TFB Film, R_QD Film, ZnMgO Film, AL Film, and cover glass.

Besides the general current density–voltage-luminescence test, we also monitored the luminescence morphology, and the image was captured by an optical microscope under a relatively low brightness, typically below 1000 cd/m^2. The low luminescence for the image capture is considered as these two following aspects. First, we notice that if the brightness is high, the uneven luminescence morphology is difficult to observe as the limitation of the CCD used in optical microscopes. Second, in the real display application, the brightness of QLED emission most of the time is not very high. In Figure 4, we can see that after the device fabrication, the luminescence morphology of the device is not very good, which means the acids-based UV encapsulation resins have already affected the device. While for the ZnMgO synthesized by additional heating in solution, the luminescence morphology can be gradually improved by the increase of the heating temperature. Fig 4b shows the device of modified ZnMgO has a uniform and even luminescence morphology without bright/dark spots or black holes. Good luminescence morphology can provide a key guarantee for the preparation of high-efficiency devices.

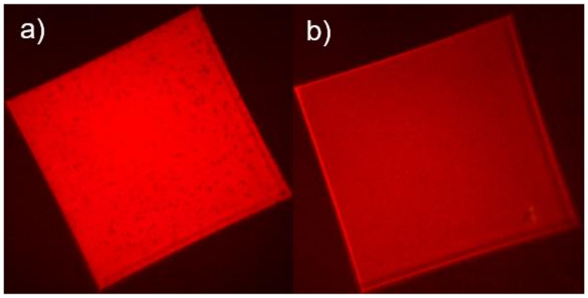

Figure 4. Electroluminescence from QLED device fabricated by original ZnMgO (a) and modified ZnMgO (b) after heating.

The current density–voltage-luminescence by QLED device from different ZnMgO was also tested. The efficiency of the QLED device does not have an obvious difference, the EQE of both the original ZnMgO and the modified ZnMgO are around 20%, which shows good electron and hole injection as well as excitation radiative recombination in QDs. However, we notice that the turn-on voltages are decreased by the additional heating ZnMgO. Compared to the original ZnMgO that needs 2.2 V to obtain a brightness with 100 cd/m^2, the voltage to get similar brightness for modified ZnMgO deceases by 0.2 V. The lower drive voltages will increase the power efficiency in the QLED device, which can benefit the QLED display application.

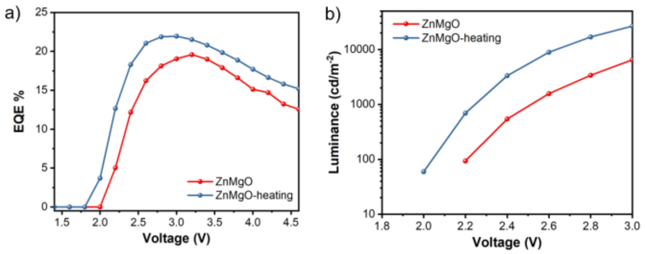

Figure 5. a) EQE and b) brightness of the devices by different ZnMgO.

We also tested the QLED stability for the ZnMgO and modified ZnMgO by heating. Such comparison was performed in two aspects. First is the long-time storage. After storing the device in the atmospheric environment for three weeks, it can be seen that the luminescence morphology was largely destroyed, while for the modified ZnMgO the luminescence morphology was kept to a certain extent. It shows that the additional heating process for ZnMgO plays a key role in the storage stability of the device's luminescence morphology. It will be beneficial for the enhancement of device's lifetime.

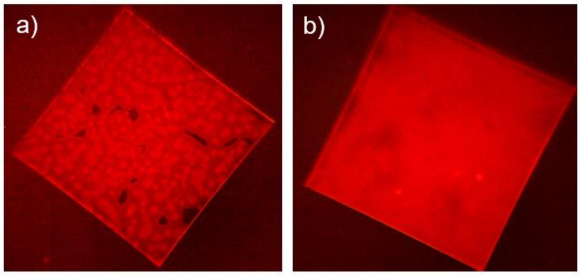

Figure 6. Electroluminescence from QLED device after 21 days storage fabricated by original ZnMgO (a) and modified ZnMgO (b) after heating.

Then the operating stability was also tested. The results show that the device lifetime for modified ZnMgO was increased. The T95 (time duration for the brightness to decrease to 95% of the initial value) is 133h under the luminescence of 11100 cd/m^2, which is equal to 13300 h for T95@1000nit (using the acceleration factors = 1.8). The result is calculated according to the following formula:

$$L_0^n \times \mathrm{T} = Const$$

Where Z is the initial brightness of QLED at the beginning of the lifetime test, n is the acceleration factor, k is a constant and T is the lifetime. Nevertheless, for the original ZnMgO, the T95 is 5160 h under the luminescence of 1000 cd/m^2. Compared with control devices, the device for modified ZnMgO has a 2.6 times higher lifetime.

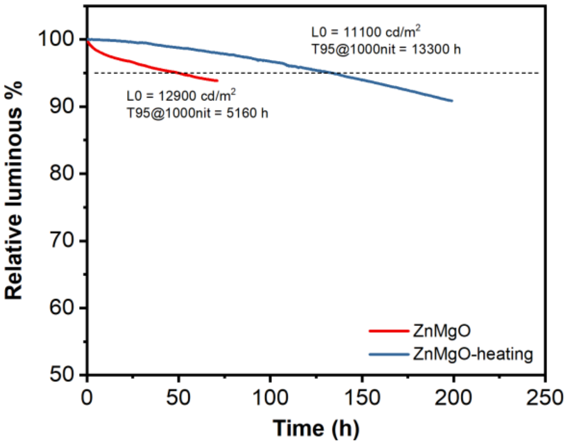

Figure 7. T95 operational lifetime tests of QLED by original ZnMgO and modified ZnMgO after heating.

3. Conclusion

In this work, we developed a modified method for ZnMgO to increase the luminescence morphology and device stability for QLED. After storing the device in the atmospheric environment for three weeks, it was able to keep the uniform luminescence morphology of the modified ZnMgO device. At the same time, it can increase the lifetime of the device to 2.7 times compared with control devices**.** We believe this simple method can help the further QLED display application.

4. Acknowledgement

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5. References

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