Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary Information

High Performance Blue Quantum Light-Emitting Diodes by Attaching Diffraction Wrinkle Patterns

Hui Qi,[1] Shujie Wang,[1] Chenguang Li, Yaolong Zhao, Bo Xu, Xiaohong Jiang, Yan Fang, Aqiang Wang, Huaibin Shen, Zuliang Du*

Blue CdSe/ZnS QDs with emission peak of 470 nm was purchased from Xingshuo Nanotech Co., Ltd. (Suzhou, China), photoluminescent quantum yield (PL QY) @370 nm up to 70 %, PL peak emission wavelength is 465nm, full wave at half maximum is 25nm.

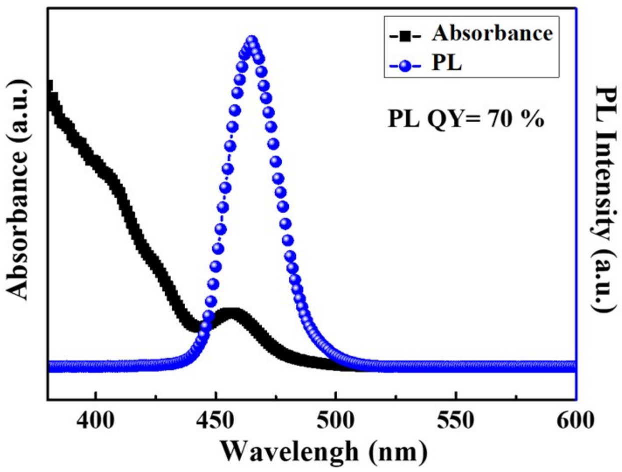

Fig. S1 Absorption and PL emission spectra of the CdSe/ZnS QDs

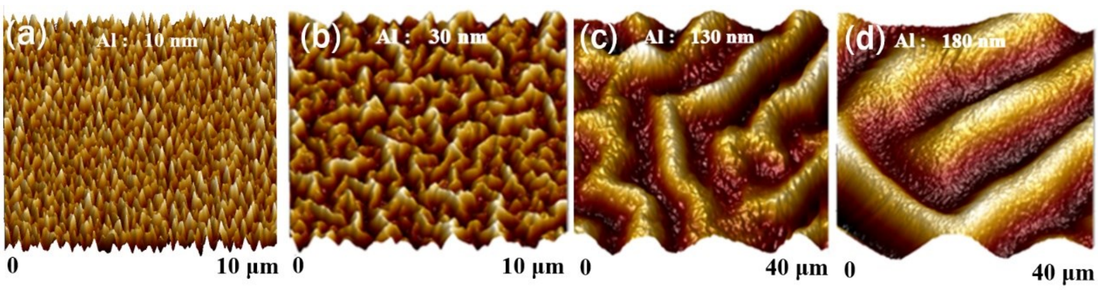

Fig. S2 The detailed evolutional behaviors of morphologies with different thickness of Al layer. AFM images measured on (a) 10, (b) 30, (c) 130, and (d) 180 nm Al layer deposited on PDMS substrate.

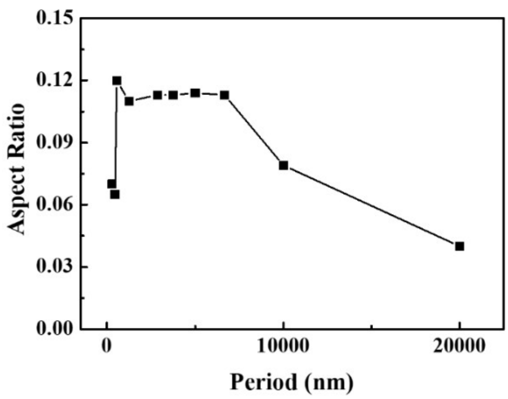

Fig. S3 The aspect ratio of wrinkles as a function of period

When the PDMS substrate cools down to the ambient temperature after deposition, the wrinkle pattern is formed due to the different Yang's modulus of the PDMS and Al. The surface wrinkle patterns are strongly dependent on the Al film thickness, and thus the quasi-period of the wrinkle patterns can be easily controlled by adjusting the thickness of Al layer deposited on PDMS. As shown in Fig. S2, the wrinkle patterns evolve gradually with the increase of the Al film thickness, and the aspect ratio of wrinkle patterns change obviously under different scopes, as shown in Fig. S3.

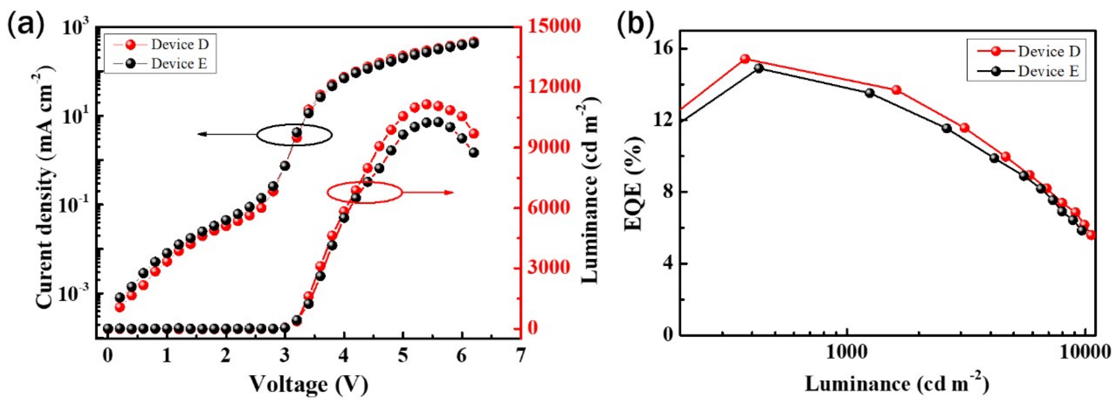

Fig. S4 The performances of the blue wrinkle QLEDs with different aspect ratios. (a) The *J–V–L* characteristics. (b) the EQE as a function of luminance for devices with different wrinkles.

The quasi-period of wrinkle patterns increases from 6.67 μm to 20 μm when the Al film thickness is from 100 nm to 180 nm, however, the aspect ratio reduces when Al film thickness is larger than 100nm. In order to investigate the influence of different aspect ratio on the properties of the devices, we applied wrinkles D, and E as external light extraction structures, the quasi-period and aspect ratio of wrinkles D, and E are (6.67 μm, 0.11), and (10 μm, 0.079), respectively. Fig. S4a shows the current density–voltage–luminance (*J*–*V*–*L*) curves of the blue devices with different wrinkle patterns, we can see that these devices show similar electrical properties. Fig. S4b shows EQE as a function of luminance for different devices, and the observed decrease in EQE of device E can be attributed to the decreased aspect ratio of the wrinkle structure. Moreover, the schematic illustration of light propagation inside the device is shown in Fig. S5. The circular wrinkle structure can effectively outcouple trapped light, for a given period of wrinkle pattern, light outcoupling efficiency increases with the aspect ratio of wrinkle pattern, the enhancement of light outcoupling efficiency reached the maximum as the aspect ratio approached 0.5,[1] which equals to that of a half sphere (Fig. S5c),[2] and it is regarded optimal for light outcoupling of trapped light.

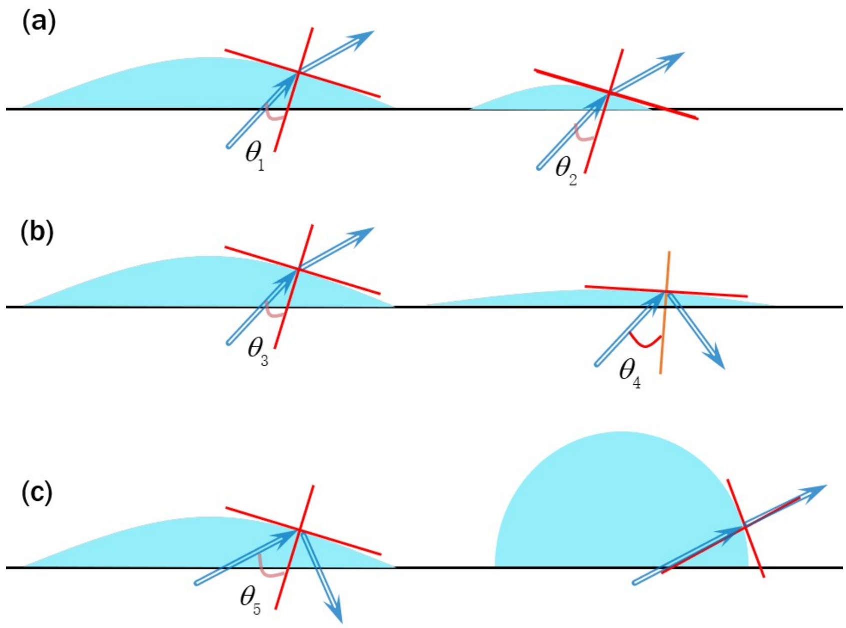

Fig. S5 Schematic illustration of light propagation inside wrinkle structures with the (a) same and (b) different aspect ratios, (c) the aspect ratio of 0.11 and 0.5.

The light outcoupling efficiency in QLEDs is obtained from the ratio of the amount of light output power (in air) and the amount of the generated power in the source. In a simulation done with the constant aspect ratio fixed to their actual values but with the periods of wrinkles varied, the enhancement ratio increases with the increase of quasi-periods first and then tends to be stable (Fig. S6). The simulation results show similar trend with our experimental data.

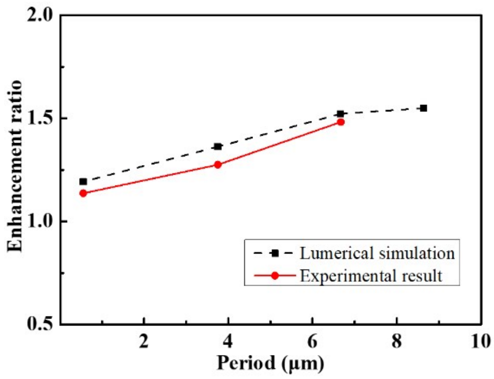

Fig. S6 The simulated light outcoupling enhancement ratio of QLEDs as variation of wrinkle period

References

1. J. Moon, E. Kim, S. K. Park, K. Lee, J.-W. Shin, D.-H. Cho, J. Lee, C. W. Joo, N. S. Cho, J.-H. Han, B.-G. Yu, S. Yoo and J.-I. Lee, *Org. Electron.*, 2015, **26**, 273-278.
2. Y. Sun and S. R. Forrest, *J. Appl. Phys.*, 2006, **100**, 073106.