Electronic Supplementary Material (ESI) for Nanoscale.

High-efficiency inverted quantum dot light emitting diodes with enhanced hole injection

Lishuang Wang,[a,b] Ying Lv,[a] Jie Lin,*[a] Yi Fan,[a] Jialong Zhao,*[c] Yunjun Wang,[d] Xingyuan Liu*[a]

[a]State Key Laboratory of Luminescence and Applications, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun 130033, China.

[b]University of Chinese Academy of Sciences, Beijing 100049, China

[c]Key Laboratory of Functional Materials Physics and Chemistry of the Ministry of Education, Jilin Normal University, Siping 136000, China.

[d]Suzhou Xingshuo Nanotech Co., Ltd.(Mesolight),Suzhou 215123, China

*Email address: linj@ciomp.ac.cn; zhaojl@ciomp.ac.cn; liuxy@ciomp.ac.cn

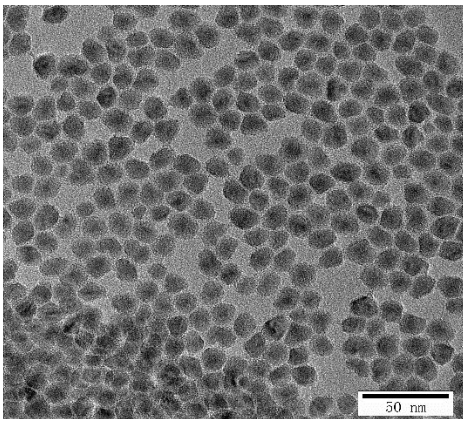

Fig. S1 TEM image of green QDs.

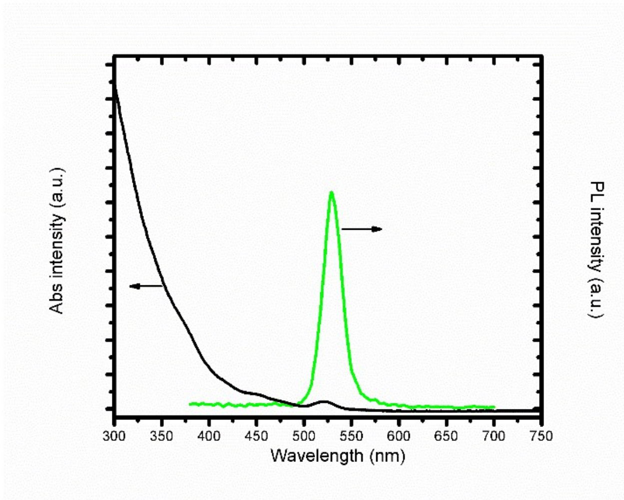

Fig. S2 Ultraviolet-Visible absorption and PL emission spectra of green QD solution.

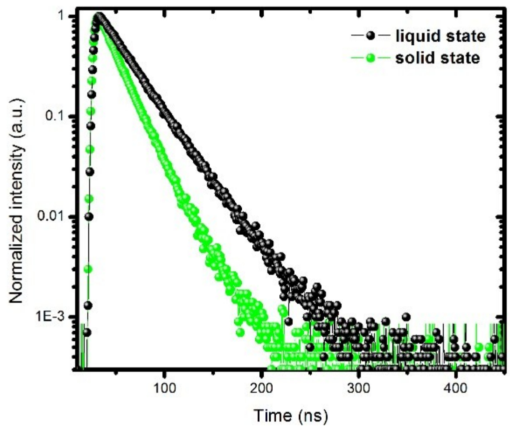

Fig. S3 PL decay curves of QDs in liquid and solid states.

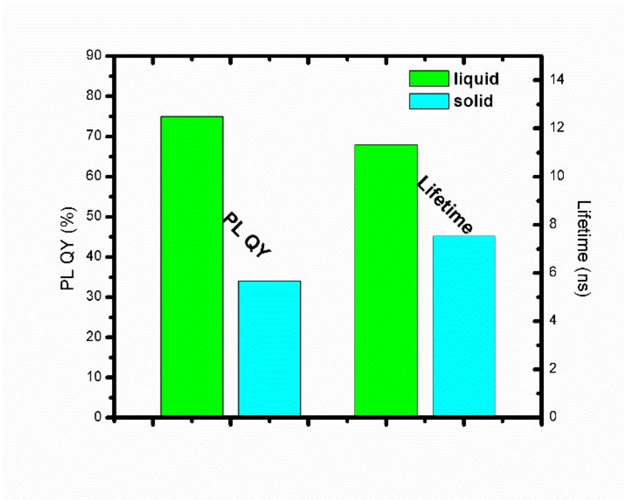

Fig. S4 Comparison of PL QY and fluorescence lifetime of QDs in liquid and solid (film) states.

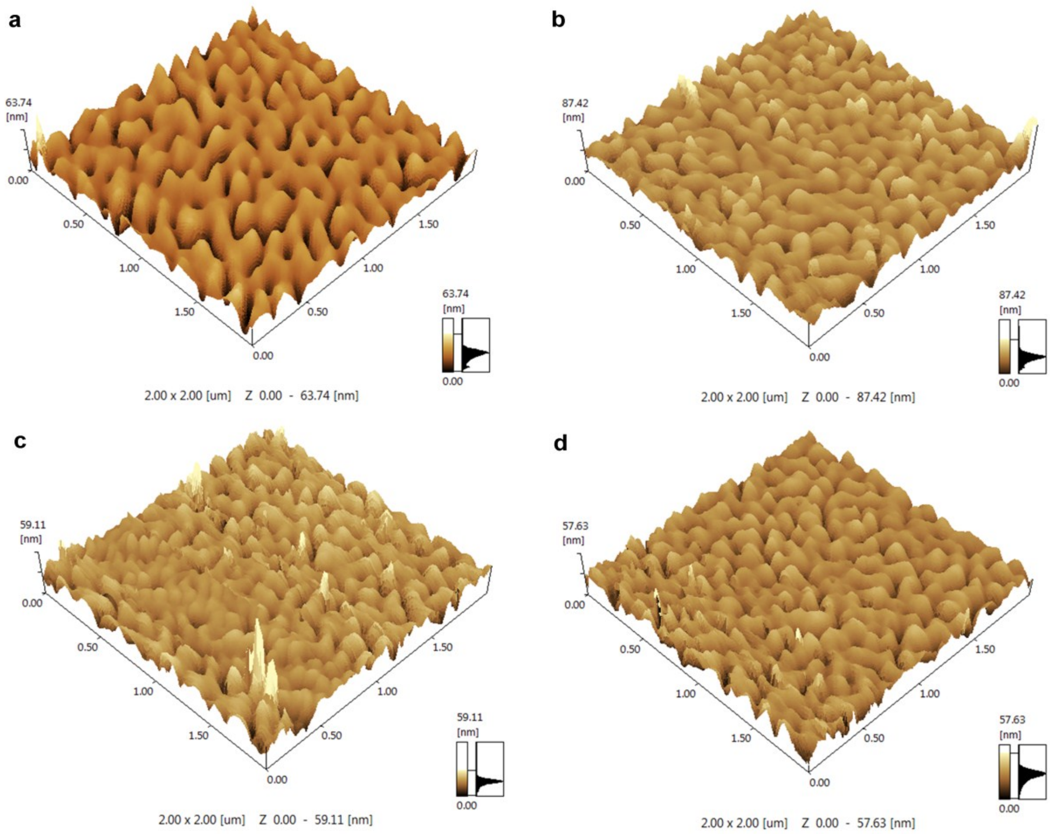

Fig. S5 Surface morphologies of CBP layer as a function of MoO_3 overlayer thickness of 0−2.5 nm. (a) 0 nm. (b) 0.5 nm. (c) 1.5 nm. (d) 2.5 nm.

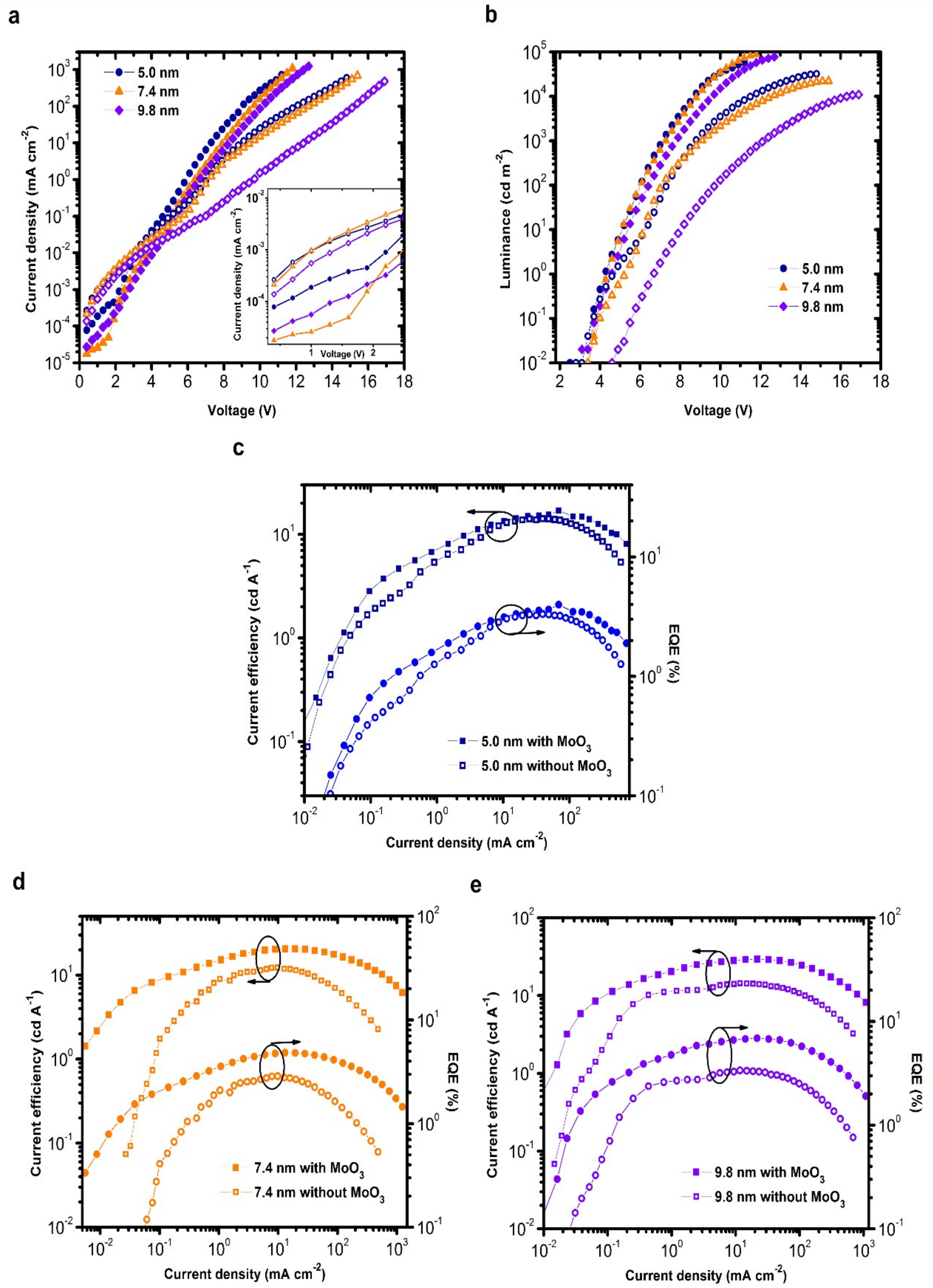

Fig. 6 EL performance of QLEDs with different thickness HAT-CN layer. Devices that have 1.5 nm MoO_3 layer or not are represented by solid sign and hollow sign, respectively. (a) J-V characteristics. Inset: J-V curves at low bias voltage range. (b)

Luminance-voltage curves. CE and EQE as a function of current density of devices with or without MoO_3 layer. (c) 5.0 nm HAT-CN device. (d) 7.4 nm HAT-CN device. (e) 9.8 nm HAT-CN device.

Table S1. Summary of EL characteristics of optimized QLEDs with different thickness HAT-CN layer.

Device (1.5 nm MoO_3/X nm HAT-CN)		V_{on} (V)	L_{max} (cd m^{-2})	CE (cd A^{-1})		EQE (%)	
				CE_{max}	1000 cd m^{-2}	EQE_{max}	1000 cd m^{-2}
5.0 nm	With MoO_3	2.5	62000	17	13.5	3.98	3.13
	Without MoO_3	2.8	32300	14.2	12.1	3.32	2.83
7.4 nm	With MoO_3	2.8	88100	29.5	27.2	6.89	6.39
	Without MoO_3	3.4	22300	14.3	13.9	3.34	3.24
9.8 nm	With MoO_3	3.1	77200	20.6	19.8	4.83	4.63
	Without MoO_3	4.3	11900	12.3	12.2	2.86	2.85

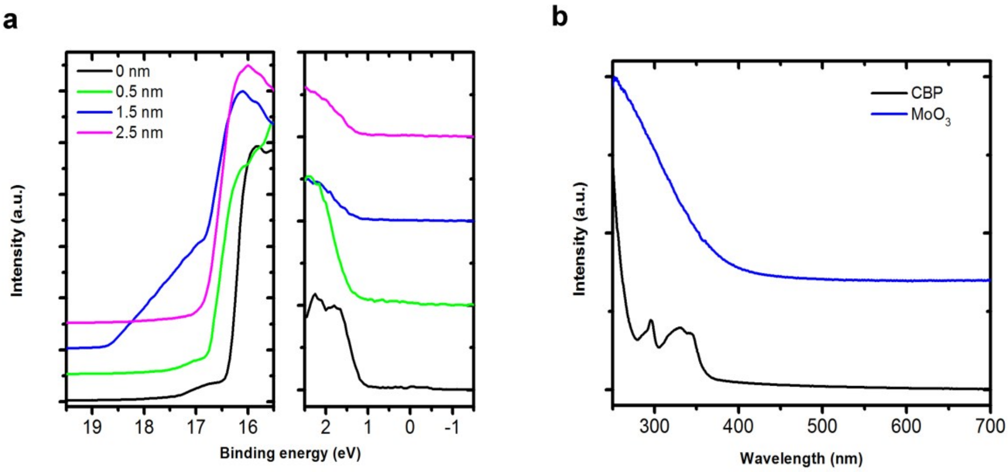

Fig. S7 (a) UPS spectra of the CBP layer as a function of MoO_3 overlayer thickness of 0−2.5 nm. (b) Ultraviolet-Visible absorption spectra of CBP and MoO_3 layer.

The HOMO of CBP is 6.0 eV which shows similar result in literature[1]. VBs of MoO_3 are 5.7 eV, 5.5 eV, and 5.7eV for CBP covered with 0.5 nm, 1.5 nm and 2.5 nm MoO_3, respectively.

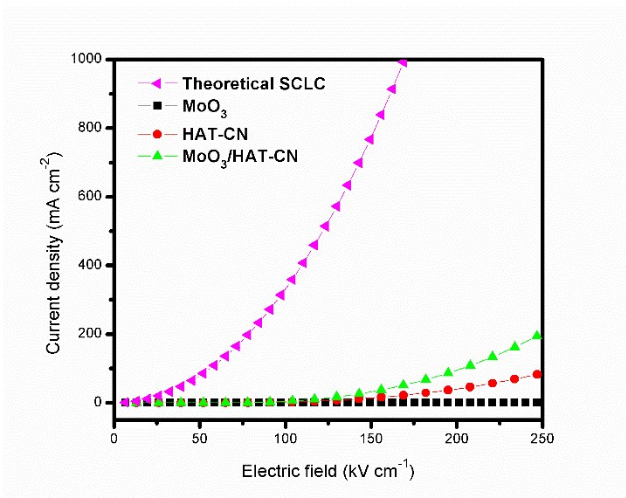

Fig.S8 Current density-voltage (J-V) characteristics of hole-only device with different HIL.

Calculation of J_{SCL}

Ideally, if an organic material is under condition of Ohmic injection contact as well as trap-free, the steady-state current should follow the space-charge-limited current (SCLC) (J_{SCL})[2, 3]:

$$J_{SCL} = \frac{9}{8}\mu_0\varepsilon_0\varepsilon_r \exp(0.89\beta\sqrt{F})\frac{F^2}{d} \qquad (1)$$

Here μ_0 is the mobility at zero electric field, β is the Poole−Frenkel factor that represents the slope of the field dependence of the mobility, ε_0 is the permittivity in free space, ε_r is the dielectric constant (approximate3 for organic materials), F is the applied electric field strength and d is the thickness of organic layer, respectively. Both μ_0=1.46×10^{-3} cm^2 V^{-1}s^{-1} and β=5.67×10^{-4} cm$^{-1/2}$ V$^{-1/2}$ can be obtained from independent time-of-flight measurement in literature[4].

References

1. M. Kröger, S. Hamwi, J. Meyer, T. Riedl, W. Kowalsky and A. Kahn, *Org. Electron.*, 2009, **10**, 932-938.
2. P. Murgatroyd, *Journal of Physics D: Applied Physics*, 1970, **3**, 151.
3. C. H. Cheung, W. J. Song and S. K. So, *Org. Electron.*, 2010, **11**, 89-94.
4. C. Li, L. Duan, Y. Sun, H. Li and Y. Qiu, *The Journal of Physical Chemistry C*, 2012, **116**, 19748-19754.