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

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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.

<table>
<thead>
<tr>
<th>Device</th>
<th>$V_{on}$ (V)</th>
<th>$I_{max}$ (cd m$^{-2}$)</th>
<th>CE (cd A$^{-1}$)</th>
<th>EQE (%)</th>
</tr>
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<tbody>
<tr>
<td>(1.5 nm MoO$_3$/X nm HAT-CN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0 nm</td>
<td>With MoO$_3$</td>
<td>2.5</td>
<td>62000</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Without MoO$_3$</td>
<td>2.8</td>
<td>32300</td>
<td>14.2</td>
</tr>
<tr>
<td>7.4 nm</td>
<td>With MoO$_3$</td>
<td>2.8</td>
<td>88100</td>
<td>29.5</td>
</tr>
<tr>
<td></td>
<td>Without MoO$_3$</td>
<td>3.4</td>
<td>22300</td>
<td>14.3</td>
</tr>
<tr>
<td>9.8 nm</td>
<td>With MoO$_3$</td>
<td>3.1</td>
<td>77200</td>
<td>20.6</td>
</tr>
<tr>
<td></td>
<td>Without MoO$_3$</td>
<td>4.3</td>
<td>11900</td>
<td>12.3</td>
</tr>
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</table>
**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 5.7 eV 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) $(J_{SCL})^2$: 

$$J_{SCL} = \frac{9}{8} \mu_0 \epsilon_0 \epsilon_r \exp(0.89 \beta \sqrt{F}) \frac{F^2}{d}$$  \hspace{1cm} (1)

Here $\mu_0$ is the mobility at zero electric field, $\beta$ is the Poole–Frenkel factor that represents the slope of the field dependence of the mobility, $\epsilon_0$ is the permittivity in free space, $\epsilon_r$ is the dielectric constant (approximate for organic materials), $F$ is the applied electric field strength and $d$ is the thickness of organic layer, respectively. Both $\mu_0=1.46 \times 10^{-3}$ cm$^2$ V$^{-1}$ s$^{-1}$ and $\beta=5.67 \times 10^{-4}$ cm$^{-1/2}$ V$^{-1/2}$ can be obtained from independent time-of-flight measurement in literature.

References