Electronic Supplementary Information for

Highly Efficient White Light-Emitting Diodes with a bi-Component Emitting Layer based on a Blue and Yellow Thermally Activated Delayed Fluorescence Emitters

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EXPERIMENTAL SECTION

Materials. $o,o'$-NPh$_2$ and 4-phenyl-4'$'$-carbazole-9-H-thioxanthen-9-one-10,10-dioxide (TXO-PhCz$_4$) was synthesized according to the reported procedure.$^{S1,S2}$ All of other materials used in the devices were purchased and the purities of them were higher than 99%. The hole injection material of poly(styrene sulfonic acid)-doped poly(3,4-ethylendioxythiphene) (PEDOT:PSS, Baytron PVP A4083) was purchased from Heraeus Holding GmbH. Dipyrazino[2,3-f:2',3'-h]quinoxaline-2,3,6,7,10,11-hexacarbonitrile (HATCN), 1,1-bis[4-[N,N'-di(p-tolyl)amino]phenyl]cyclohexane (TAPC), 1,3-bis(carbazol-9-yl)benzene (mCP), 1,3,5-tri(m-pyrid-3-yl-phenyl)benzene (TmPyPB) and 2,2',2''-(1,3,5-benzenetriyl)-tris(1-phenyl-1-H-benzimidazole) (TPBi) were purchased from Jilin Optical and Electronic Materials Co. Ltd. Besides, bis(2-(diphenylphosphino)phenyl)ether oxide (DPEPO) and N,N'-bis(naphthalen-1-yl)-N,N'-bis(phenyl)-2,2'-dimethylbenzidine ($\alpha$-NPD) were purchased from Luminescence Technology Corp.

Device Fabrication. Organic light-emitting devices were fabricated on glass substrates precoated with 150 nm ITO. The substrates should be cleaned with detergent, ultrasonicated in water, acetone and ethyl alcohol firstly, and subsequently dried at 75 °C (15 min) in an oven. Afterwards the substrates were exposed to oxygen plasma (10 min) in order to remove organic residues and improve the work function of ITO. The PEDOT:PSS aqueous solution was spin-coated onto the precleaned substrates and then annealed at 120 °C for 30 min under nitrogen environment. Then the substrates were transferred to a thermal evaporation chamber with a pressure lower than $4 \times 10^{-4}$ Pa for organic semiconductor layers and metal cathode deposition.

PL Characterization and Device Measurement. The ultraviolet-visible (UV-vis) spectra and fluorescence spectra were obtained with Hitachi U-3900 and F-4600 spectrophotometers, respectively. The phosphorescence spectra were measured in 2-MeTHF glass matrix at 77 K using a Hitachi F-4600 fluorescence spectrometer. The absolute fluorescence quantum yields of the solid films were measured with an integrating sphere. The transient PL decay characteristics were measured using an
Edinburgh Instruments FLS920 spectrometer. The electroluminescence (EL) spectra were measured by a Spectra scan PR655 photometer. The current–voltage–brightness characteristics were measured by using a computer-controlled Keithley source measurement unit (Keithley 2400) with a Konica Minolta CS-200 luminance-meter under dark and ambient atmosphere. External quantum efficiencies (EQE, %), current efficiencies (cd/A) and power efficiencies (lm/W) were calculated from the electrical and optical properties. For this calculation we assumed Lambertian light distribution.
**Figure S1.** Normalized absorption (a) and PL spectra (b) of \( o,o' \)-NPh\(_2\) in different solvents.

**Figure S2.** Highest occupied NTO and lowest unoccupied NTO according to the results of time-dependent DFT for the \( S_1 \) state of \( o,o' \)-NPh\(_2\) using the optimized structure of the \( S_0 \) state.

**Figure S3.** (a) The overlap between absorption spectrum of TXO-PhCz4 and PL spectrum of \( o,o' \)-NPh\(_2\). (b) The phosphorescence spectrum of \( o,o' \)-NPh\(_2\) and fluorescence spectrum of TXO-PhCz4.
Figure S4. (a) The PL spectra of $o,o'$-NPh$_2$:TXO-PhCz4 film with different doping concentration. (b) The CIE coordinates variation of TXO-PhCz4 doped in PMMA (dashed) and $o,o'$-NPh$_2$ (solid).
**Figure S5.** Molecular structures and energy levels of WOLEDs based on bi-component TADF EML with simple structure.

**Figure S6.** EL spectra of WOLED without the TSPO1 buffer layer at different luminance.
### Table S1. Photophysical data extracted from the transient PL spectra of DPEPO: 10 wt% \( o,o'-\text{NPh}_2 \) at room temperature.

<table>
<thead>
<tr>
<th>( \phi_{\text{total}} ) (%)</th>
<th>( \phi_p ) (%)</th>
<th>( \phi_d ) (%)</th>
<th>( \tau_p ) (ns)</th>
<th>( \tau_d ) (μs)</th>
<th>( k_p \left( \times 10^7 \text{s}^{-1} \right) )</th>
<th>( k_d \left( \times 10^3 \text{s}^{-1} \right) )</th>
<th>( k_{RISC} \left( \times 10^3 \text{s}^{-1} \right) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.5</td>
<td>33.7</td>
<td>0.8</td>
<td>9.17</td>
<td>1.57</td>
<td>3.7</td>
<td>5.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>

\(^a\)Calculated according to the reported method.\(^{S3}\)

### Table S2. Summary of the performance of WOLEDs based on TADF emitters and on bi-component EML.

<table>
<thead>
<tr>
<th>Type</th>
<th>EML</th>
<th>( V_{\text{on}} ) (V)</th>
<th>( \text{EQE}_{\text{max}} ) (%)</th>
<th>( \text{CFE}_{\text{max}} ) (cd/A)</th>
<th>( \text{PE}_{\text{max}} ) (lm/W)</th>
<th>CIE(x, y)</th>
<th>CRI</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>bi-Component Emitting Layer system</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( o,o'-\text{NPh}_2:1 \text{ wt% TXO-PhCz4} )</td>
<td>3.5</td>
<td>12.5</td>
<td>30.2</td>
<td>27.1</td>
<td>(0.38, 0.40)</td>
<td>71</td>
<td>This work</td>
<td></td>
</tr>
<tr>
<td>4P-NPD:2 \text{ wt% Ir(dhfpy)}_2(\text{acac})</td>
<td>–</td>
<td>5.5</td>
<td>–</td>
<td>10.5</td>
<td>(0.45, 0.43)</td>
<td>38</td>
<td>S4</td>
<td></td>
</tr>
<tr>
<td>CPhBzIm:0.1 \text{ wt% (pbi)}_2Ir(\text{acac})</td>
<td>2.5</td>
<td>7.0</td>
<td>15.5</td>
<td>12.8</td>
<td>(0.31, 0.33)</td>
<td>–</td>
<td>S5</td>
<td></td>
</tr>
<tr>
<td>DADBT:0.1 \text{ wt% Ir(2-phq)}_3</td>
<td>2.4</td>
<td>26.6</td>
<td>53.5</td>
<td>67.2</td>
<td>(0.41, 0.43)</td>
<td>–</td>
<td>S6</td>
<td></td>
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<tr>
<td>4P-NPD:8 \text{ wt% FPtOPhND}</td>
<td>4.0</td>
<td>7.4</td>
<td>13.0</td>
<td>6.7</td>
<td>(0.36, 0.28)</td>
<td>81</td>
<td>S7</td>
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<tr>
<td>Bepp(_2):0.1 \text{ wt% (fbi)}_2Ir(\text{acac})</td>
<td>–</td>
<td>–</td>
<td>4.8</td>
<td>5.0</td>
<td>(0.27, 0.25)</td>
<td>88</td>
<td>S8</td>
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<tr>
<td>Bepp(_2):1.0 \text{ wt% (fbi)}_2Ir(\text{acac})</td>
<td>–</td>
<td>–</td>
<td>37.6</td>
<td>44.9</td>
<td>(0.47, 0.48)</td>
<td>39</td>
<td>S8</td>
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<tr>
<td>TPA-SO2:0.5 \text{ wt% PO-01}</td>
<td>2.5</td>
<td>13.2</td>
<td>39.6</td>
<td>43.0</td>
<td>(0.42, 0.46)</td>
<td>–</td>
<td>S9</td>
<td></td>
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<tr>
<td>BBPI:1.0 \text{ wt% Ir(2-phq)}_3</td>
<td>2.6</td>
<td>23.8</td>
<td>56.1</td>
<td>62.9</td>
<td>(0.49, 0.41)</td>
<td>–</td>
<td>S10</td>
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<tr>
<td>BBPI:0.4 \text{ wt% PO-01}</td>
<td>2.6</td>
<td>12.9</td>
<td>36.8</td>
<td>38.6</td>
<td>(0.44, 0.48)</td>
<td>–</td>
<td>S11</td>
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<tr>
<td>DMAC-DPS:0.6 \text{ wt% Rubrene}</td>
<td>2.5</td>
<td>7.4</td>
<td>20.2</td>
<td>15.9</td>
<td>(0.36, 0.44)</td>
<td>–</td>
<td>S12</td>
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<tr>
<td>1,8-D:17 \text{ wt% T4AC}</td>
<td>5.5</td>
<td>–</td>
<td>3.91</td>
<td>2.05</td>
<td>(0.30, 0.43)</td>
<td>56</td>
<td>S13</td>
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<tr>
<td>5CzOXD:4CzPNPh</td>
<td>2.4</td>
<td>7.2</td>
<td>21.6</td>
<td>26.1</td>
<td>(0.35, 0.44)</td>
<td>62</td>
<td>S14</td>
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<tr>
<td>DMAC-DPS:0.2 \text{ wt% TBRb}</td>
<td>2.8</td>
<td>14.0</td>
<td>45.1</td>
<td>48.0</td>
<td>(0.37, 0.48)</td>
<td>–</td>
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<tr>
<td>TADF-based Emitting Layer system</td>
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<td></td>
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<tr>
<td>DPEPO:DMAC-DPS:0.2 \text{ wt% TBRb}</td>
<td>2.8</td>
<td>14.6</td>
<td>44.4</td>
<td>51.6</td>
<td>(0.34, 0.47)</td>
<td>–</td>
<td>S15</td>
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<tr>
<td>CzAcSF:TBP:0.2 \text{ wt% TBRb}</td>
<td>&lt; 3</td>
<td>15.2</td>
<td>–</td>
<td>–</td>
<td>(0.23, 0.30)</td>
<td>–</td>
<td>S16</td>
<td></td>
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<tr>
<td>DPEPO:50 \text{ wt% DMAC-DPS:0.03 \text{ wt% TBRb}}</td>
<td>&lt; 3</td>
<td>17.6</td>
<td>39.3</td>
<td>41.0</td>
<td>(0.23, 0.31)</td>
<td>44.7</td>
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<tr>
<td>DPEPO:50 \text{ wt% DMAC-DPS:0.05 \text{ wt% TBRb}}</td>
<td>&lt; 3</td>
<td>15.5</td>
<td>38.4</td>
<td>39.3</td>
<td>(0.28, 0.35)</td>
<td>58.6</td>
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<tr>
<td>CDBP:PO-T2T:7.5 \text{ wt% 2CzPN:0.6 \text{ wt% AnbCz}}</td>
<td>2.3</td>
<td>19.0</td>
<td>50.1</td>
<td>63.0</td>
<td>(0.34, 0.44)</td>
<td>63</td>
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<tr>
<td>mCP:20 \text{ wt% 2CzPN: 0.2 \text{ wt% PO-01}}</td>
<td>–</td>
<td>19.6</td>
<td>–</td>
<td>50.2</td>
<td>(0.42, 0.48)</td>
<td>53</td>
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<td>PPF:6\text{ wt% CC2BP:mCPB:18 \text{ wt% Px2BBP}}</td>
<td>5.0</td>
<td>6.7</td>
<td>16.4</td>
<td>–</td>
<td>(0.32, 0.39)</td>
<td>–</td>
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<tr>
<td>mCBP: 10 \text{ wt% 4CzPN/mCBP: 6 \text{ wt% 4CzPN:2}}</td>
<td>3.6</td>
<td>17.6</td>
<td>38.6</td>
<td>30.3</td>
<td>(0.26, 0.38)</td>
<td>–</td>
<td>S21</td>
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wt% 4CzTPN-Ph/PPT: 10 wt% 3CzTRZ

<table>
<thead>
<tr>
<th>Compound</th>
<th>wt% DBP</th>
<th>wt% TPTA/mCP/DMAC-DPS</th>
<th>TPTA/DMAC-DPS</th>
<th>7.2</th>
<th>12.3</th>
<th>18.9</th>
<th>(0.23, 0.30)</th>
<th>82</th>
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<tbody>
<tr>
<td>mCP:1 wt% DBP:15 wt% TPTA/mCP/DMAC-DPS</td>
<td>3.2</td>
<td></td>
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<td></td>
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<tr>
<td>mCP:5 wt% TXO-TPA/mCP: 2 wt% 4P-NPB</td>
<td>4.0</td>
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<tr>
<td>DMAC-DPS:0.5 wt% DBP/DMAC-DPS:1.0 wt% DBP:0.5 wt% TPTA/DMAC-DPS:0.2 wt% TPTA</td>
<td>2.8</td>
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<tr>
<td>CBP:7 wt% NI-1-PhTPA/CBP/CBP:3 wt% PXZDSO2/CBP:5 wt% PXZDSO2:0.3 wt% DBP/CBP:3 wt% PXZDSO2/CBP/CBP:7 wt% NI-1-PhTPA</td>
<td>3.4</td>
<td></td>
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<tr>
<td>CBP:6 wt% Ir(pq)2acac/4P-NPD/CBP:4 wt% 4CzIPN</td>
<td>–</td>
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Reference

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(S26) S. E. Lee, H. W. Lee, H. J. Baek, T. J. Yun, G. J. Yun, W. Y. Kim and Y. K. Kim, 