Efficient and Stable OLEDs Employing Square Planar Metal Complexes and Inorganic Nanoparticles

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Progress of Excimer-based WOLEDs

For Pt-16 WOLED, power efficiency exceeds 50 lm/W (no n/p-doping and enhanced Förster coupling), CIE (0.33, 0.32), CRI >= 80, showing promise for lighting applications.

Power efficiency is 29 lm/W at 1000 cd/m²

Pt7O7 - Both Efficient Monomer and Excimer Emission

ITO/HATCN(10nm)/NPD(30nm)/TAPc(10nm)/x%Pt7O7:mCBP(25nm)/DPPS(10nm)/BmPyPB(40nm)/LiF/Al.

Our Pt7O7 data suggest that both monomer and excimer can have PL quantum efficiency of close to 100%.

Recent Update of Excimer-Based WOLED

1) maximum efficacy @ 50 lm/W,

2) CRI ~70, EQE > 17% and LT_{50} >1000 hrs @1000 cd/m^2 on a standard glass substrate.
Material Design for Blue Emitters Based on Pt Complexes

Add electron withdrawing groups to lower HOMO

Replace pyridine with azole groups to raise LUMO

Break conjugation with 6-membered chelating rings

blue emitters with green triplet energy (MADF material concept)
Blue Emitting Pt vs. Ir Complexes

With such molecular design principle, PtON7 shows a better photophysical properties than its Pt analogs and Ir analogs;

A deep blue OLED with a maximum EQE of 22% and CIE coordinates of (0.14, 0.15) was fabricated using PtON7.


<table>
<thead>
<tr>
<th>Complex</th>
<th>$\lambda_{\text{max}}$ (nm)</th>
<th>$\Phi$ (%)</th>
<th>$\tau$ (μs)</th>
<th>$k_r$ ($\times 10^4$ s$^{-1}$)</th>
<th>$k_{nr}$ ($\times 10^4$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PtON7</td>
<td>452</td>
<td>89</td>
<td>4.1</td>
<td>21</td>
<td>2.6</td>
</tr>
<tr>
<td>PtOO7</td>
<td>442</td>
<td>58</td>
<td>2.5</td>
<td>23</td>
<td>17</td>
</tr>
<tr>
<td>Pt-16$^{[9b]}$</td>
<td>450</td>
<td>32</td>
<td>5.1</td>
<td>6.3</td>
<td>13.3</td>
</tr>
<tr>
<td>Pt(MePmi)$^{[9a]}$</td>
<td>419</td>
<td>20</td>
<td>25</td>
<td>0.8</td>
<td>3.2</td>
</tr>
<tr>
<td>Ir(cnamic)$_3$$^{[7b]}$</td>
<td>425(sh), 450</td>
<td>78</td>
<td>19.5</td>
<td>4</td>
<td>1.1</td>
</tr>
<tr>
<td>Ir(dbfmi)$^{[7a]}$</td>
<td>445</td>
<td>70$^a$</td>
<td>19.6</td>
<td>3.6</td>
<td>1.5</td>
</tr>
<tr>
<td>PtON1</td>
<td>449</td>
<td>85</td>
<td>4.5</td>
<td>19</td>
<td>3.3</td>
</tr>
</tbody>
</table>

ITO/PEDOT:PSS/NPD(30 nm)/TAPC(10 nm)/2% emitter:26mCPy(25 nm)/PO15(40 nm)/LiF/Al.
RGB Narrowband Phosphorescent Emitters

Metal-Assisted Delay Fluorescent Emitters

Blue-emitting MADF emitter with green triplet energy could be most energetically favorable.


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Operational Stability of Pt Complexes

ITO/HATCN(10 nm)/NPD(40 nm)/EML(25 nm)/BAIq(10 nm)/BPtyP(40 nm)/LiF/Al.

Figure 4. (a) EQE vs luminance and EL spectra (inset); (b) relative luminance vs operation time at constant current of 20 mA/cm² for different concentrations of PtN3N-ptb doped in Beq3 in Structure 3: ITO/HATCN/NPD/TrisPCz/x% PtN3N-ptb:Beq3/BAlq/BPtyP/LiF/Al, where x = 2, 6, or 10.

Horizontally Aligning Pt Complexes for Improved Light Extraction

Standard OLED EQE could be improved to 45% if 100% horizontally oriented emitting dipoles. Square planar metal complexes with in-plane emitting dipoles could have a better control of molecular orientation. Such molecular orientation approach adds zero cost to OLED fabrication.


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Narrowband vs Broadband Emitters in Tuned MCOLEDs

Narrowband phosphorescent emitter makes MCOLEDs an effective approach for light extraction enhancement purpose.

Ecton et al. *In preparation.*
100% horizontally oriented narrowband phosphorescent emitters in the microcavity OLED with external extraction layer will enable the EQE of monochromic OLED over 70% (suitable for signage and taillight applications).

100% horizontally oriented blue narrowband phosphorescent emitters in the microcavity OLED with external extraction layer will enable the EQE of white OLED over 70% (suitable for general illumination applications).
Semiconductor Colloidal Quantum Dots

- Size- and composition-dependent tunable emission through visible spectrum (quantum confinement effect)
- Narrow emission peaks (minimum width ~20 nm)
- High luminescence quantum yield (~90%)
- Solution processible; good stability

Versatile for solid-state lighting; potential for high CRI and high efficacy

CRI=90, LER= 360 lm/W
Solution-Processed QD-LEDs

<table>
<thead>
<tr>
<th>Color</th>
<th>( \lambda_{\text{max}} ) (nm)</th>
<th>FWHM (nm)</th>
<th>Max. Lum. (cd/m(^2))</th>
<th>( \eta_{\text{EQE}} ) (%)</th>
<th>( \eta_p ) (lm/W)</th>
<th>( \eta_A ) (cd/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>455</td>
<td>20</td>
<td>4,000</td>
<td>10.3</td>
<td>2.7</td>
<td>4.3</td>
</tr>
<tr>
<td>Green</td>
<td>537</td>
<td>29</td>
<td>14,000</td>
<td>14.3</td>
<td>58</td>
<td>62</td>
</tr>
<tr>
<td>Red*</td>
<td>625</td>
<td>28</td>
<td>21,000</td>
<td>12.0</td>
<td>17.4</td>
<td>15</td>
</tr>
</tbody>
</table>

- EQE > 10% achieved in QLEDs for all three colors
- QLEDs operate more efficiently at high luminances
- Low operation voltage \( \Rightarrow \) good lm/W efficiency
- Possible lifetime improvement (PEDOT:PSS, HTL, etc.)


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Future Outlooks

• The development of stable blue emitters is key;
• The choice of excimers should include phosphorescent materials, thermal activated delayed fluorescent (TADF) materials and metal-assisted delayed fluorescent (MADF) materials;
• Square planar metal complexes could play a role of improving light extraction efficiency of OLEDs;
• The recent progress of QLEDs has demonstrated enough promise as a future solution for solution processed organic solid state lighting devices.