Electronic Supplementary Information

Novel Microlens Arrays with Embedded Al₂O₃ Nanoparticles for Enhancing Efficiency and Stability of Flexible Polymer Light-emitting Diodes

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Experimental Method

For the photoluminescence (PL) measurement, an anode (PEDOT:PSS, Clevios PH1000), a hole-transporting layer (PEDOT:PSS, Clevios AI4083), and a blue light-emitting layer (SPB-02T, Merck) were deposited on a PEN substrate by the same preparation methods and conditions used in the fabrication of the polymer light-emitting diodes (PLED). The PL spectra were obtained by fluorospectrometer (ISS PC1 Photon Counter Meter). The samples were excited at 300 nm light generated by a xenon arc lamp attached to a monochromator. Flexible yellow PLEDs were fabricated via the same procedure used for SPB-02T-based devices except a deposition of a yellow light-emitting layer. The yellow light-emitting polymer (PDY-132, Merck) was dissolved in chlorobenzene by a concentration of 7 mg/ml. PDY-132 solution was deposited on atop of the AI4083 layer by spin-coating at 3000 rpm for 60 seconds followed by thermal annealing at 115 °C for 20 minutes. The water-vapor transmission rates (WVTR) were assessed by AQUATRAN Model 1 (MOCON) following ASTM protocol F1249.
Photoluminescence measurement

**Figure S1.** PL spectra of SPB-02T-based films fabricated on bare PEN, on a microlens array, and on the microlens arrays with Al₂O₃ nanoparticles.

**Figure S2.** Relative PL intensities of samples fabricated on bared PEN, with microlens only, and microlens embedded with Al₂O₃ nanoparticles having different concentrations.
Voltage-current density curves for the SPB-02T-based devices

Figure S3. Current density versus applied bias for the flexible, blue PLEDs.
Water-vapor transmission rates of PEN films

Figure S4. Water-vapor transmission rates of PEN films without and with silica hybrid sol

Figure S5. Water-vapor transmission rate of the samples over time.
Performances of yellow PLEDs with and without microlens array

**Figure S6.** a) Luminance and b) current efficiency of devices as a function of current density.

The structure of PLED fabricated in this experiment is shown in the inset image.
Table S1. Luminance and efficiencies of PDY-132-based devices with and without a microlens array

<table>
<thead>
<tr>
<th></th>
<th>L ‡</th>
<th>Max. PE ‡</th>
<th>Max. CE ‡</th>
<th>R_{\text{Max.CE}} ‡</th>
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<tr>
<td></td>
<td>(cd/m²)</td>
<td>(lm/W)</td>
<td>(cd/A)</td>
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<td>Reference</td>
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<td>4.61</td>
<td>6.93</td>
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<tr>
<td>Regular microlens array</td>
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<td>6.08</td>
<td>8.60</td>
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<td>Regular microlens array + Al₂O₃ 2.6 %</td>
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<td>7.54</td>
<td>9.59</td>
<td>1.38</td>
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</table>

‡ L: Luminance at 20 mA/cm², Max. PE: Maximum power efficiency, Max. CE: Maximum current efficiency, R_{\text{Max.CE}}: Relative maximum current efficiency