Supporting Information

Extremely Low-Index Photonic Crystal Layer for Enhanced Light Extraction from Organic Light-Emitting Diodes

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1. Fabrication of photoresist

Because the indium tin oxide (ITO) layer is accumulated over the photoresist (PR), the PR morphology is carefully considered for electrical stability. If the PR is formed into the undercut profile (not smooth) or has too much height, cracks are generated at each angled corner of the ITO, causing the sheet resistance of the corrugated ITO to be unintentionally raised 10 times higher than that of flat ITO. There are two adjustable ways to avoid this side effect.

1.1. Photoresist Profile

The total amount of exposed laser energy affects the PR shape. When the energy was below 25 mJ, more etching occurs at the bottom side of the PR with increased developing time, which makes the PR shape into an undercut profile. In contrast, a tapered PR profile for the smooth ITO surface can be obtained with at least 35 mJ, but the etching is not performed with balance at more than 60 mJ.

Thus, the adequate energy is found to be between 35 mJ and 50 mJ. Additionally, the post bake process (reflow) helps to obtain a more rounded PR shape. Figure S1 shows scanning electron microscope (SEM) images of the PR in accordance with two conditions.

Condition A. Exposure energy: 15 mJ; no post bake

Condition B. Exposure energy: 35 mJ; post bake at 150 °C for 5 min

Only after a few cycles of the developing process, the PR is patterned in a square shape as in Figure S1-(a). However, with more developing, the PRs are differently etched depending on the above conditions as in Figure S1-(b) and S1-(c). As a result, the desired shape of the PR for the low-index photonic crystal (LIPC) layer could be produced by appropriate hardening and annealing processes.

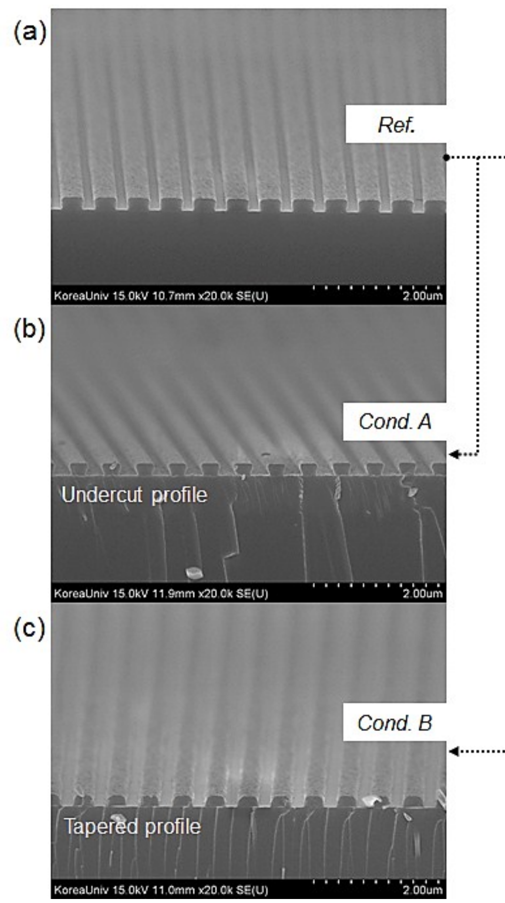

Figure S1. SEM images of nanopatterned PR: (a) The reference conducted with only a few developing cycles, (b) undercut profile PR applying condition A, and (c) tapered profile PR applying condition B.

1.2. Height of Photoresist

When the spin-rate is fixed at 4000 rpm, the PR height, which becomes the depth of the LIPC layer, depends on the diluted ratio of the solution composed of the PR (AR-N 4240, Allresist Co., Ltd.) and thinner (AR 300-12, Allresist Co., Ltd.) as shown in Figure S2. From this, we can find the maximum LIPC height of which can also maintain the electrical stability.

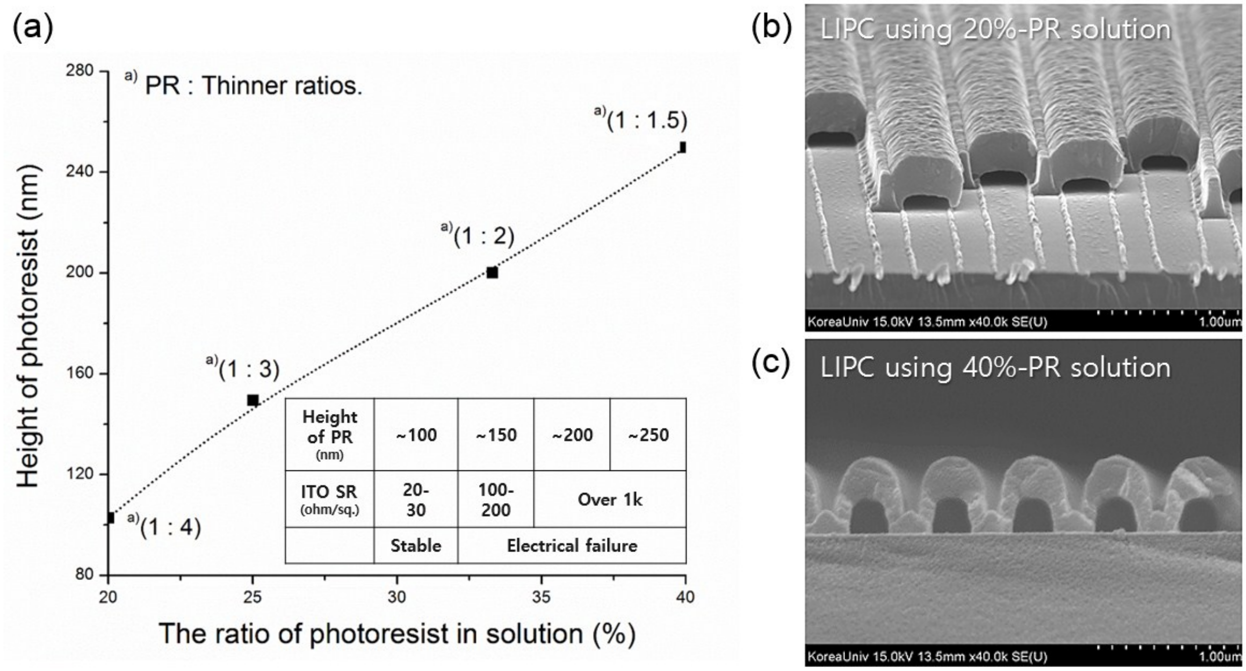

Figure S2. (a) Height of photoresist as a function of the ratio of photoresist in solution. The inset shows the electrical sheet resistance (SR) of ITO according to the height of PR. SEM images of LIPC layers produced by the ratio of (b) 20% PR (1:4) and (c) 40% PR (1:1.5).

2. Enhancement Factor According to the Refractive Index Difference (n_{diff}) of the PC Layer

Figure S3 involves the plot of spectral enhancement per pitch of LIPC. The peaked emission wavelength is not seriously enhanced by the change of n_{diff}; on the other hand, the intensity is clearly increased. It can be seen that the spectral enhanced line reflecting Bragg's diffraction equation becomes more pronounced, which means the extremely LIPC is the most effective way to improve light extraction by photonic crystal.

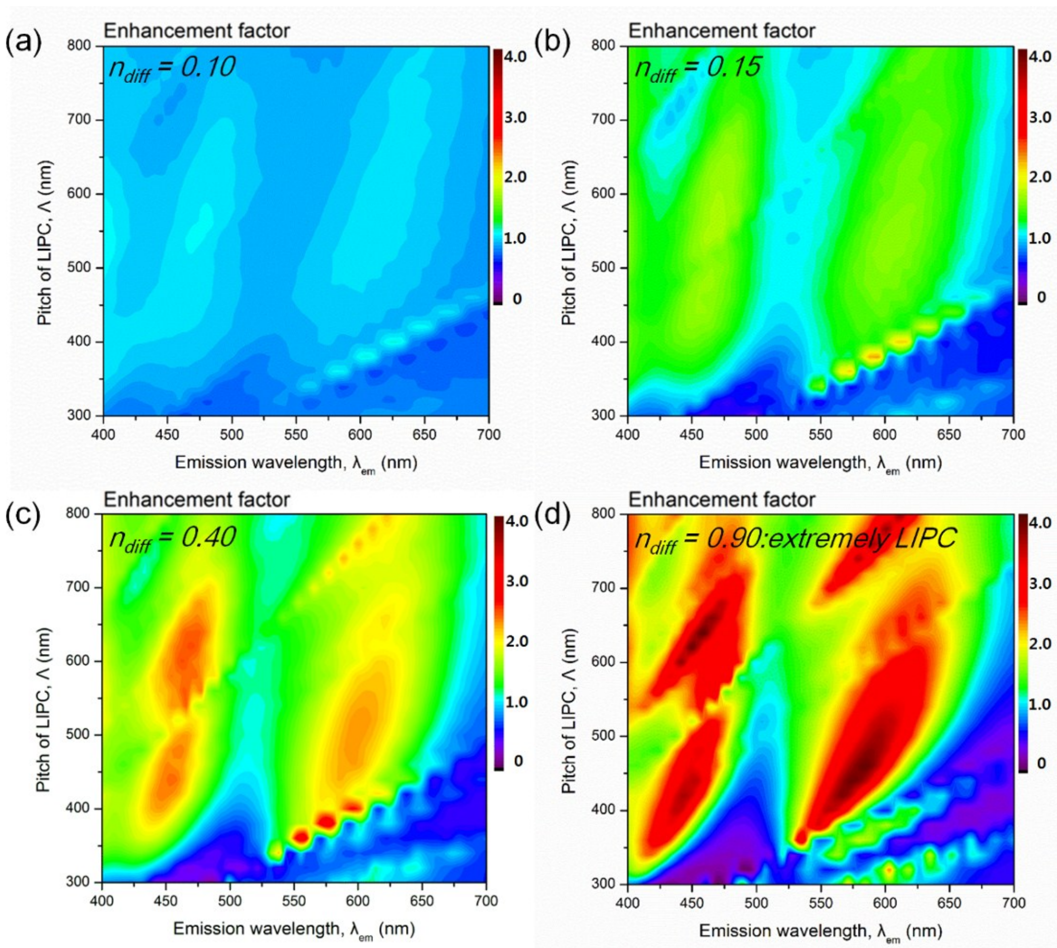

Figure S3. Calculated enhancement factor as a function of emission wavelength (λ_{em}) and pitch of LIPC (Λ). Each plot indicates the condition of (a) n_{diff} = 0.1, (b) n_{diff} = 0.15, (c) n_{diff} = 0.40, and (d) n_{diff} = 0.90, which means an extremely LIPC.