Enhanced light emission from nanoimprinted photonic crystals via surface plasmon

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The cost reduction of organic LEDs and the improvement of their external efficiency are currently two of the critical research issues in optoelectronics. Here, we report on a method to enhance the light-emission efficiency of thin films of polymer (mr-NIL 6000) doped with rhodamine 6G.

First, a photonic crystal (PhC) is made in the active polymer film by nanoimprint lithography (NIL). Fig. 1 shows an example of a stamp structure and the corresponding PhC imprinted on a glass substrate. PL spectra of an unpatterned sample (reference) and of three different honeycomb lattice PhCs are shown in Fig. 2a. The PL intensity for the 700 nm lattice constant PhC is increased by 2.8 compared to the reference. As shown in the 2D band diagram calculated using a plane wave algorithm (Fig. 2b), the rhodamine emission linewidth falls above the light cone in a high density of state area. This results in very low group velocity photons and an enhanced coupling to the radiative modes out of plane.

Secondly we matched metal surface plasmon (SP) energies to the emitted light energy. A comparison is made between unpatterned dye-doped thin polymer films deposited on glass substrate and on 50 nm thick Al-, Au-, and Ag-coated substrates. Emission spectra are presented in Fig. 3a. We observe a 9.3 fold enhancement in the PL intensity for emitters made using Ag-coated substrates compared to the reference. This can be attributed to the interaction between the excited dye molecules and SPs. The out-coupling of the SP modes may be achieved by the roughness and the imperfections of the metallic layer[1] (Fig. 3b).

Finally, the two effects have been combined: a 700 nm honeycomb lattice PhC has been imprinted in the active polymer and on an Ag-coated substrate. A 27-fold enhancement of the PL intensity is measured compared to an unpatterned sample on a glass substrate (Fig. 3c). This enhancement is attributed to light coupling to the leaky modes of the PhC slab and to the coupling between the emitted photons and surface plasmons.

In conclusion, our results indicate that nanoimprint lithography is well suited to fabricate these challenging photonic structures and that the combination of surface plasmons and nanoimprinted photonic structures in an active layer may lead to a new class of cost effective and high efficient OLEDs.

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[1] K. Okamoto et al., *Nature Materials*, **3,** 601–605 (2004)

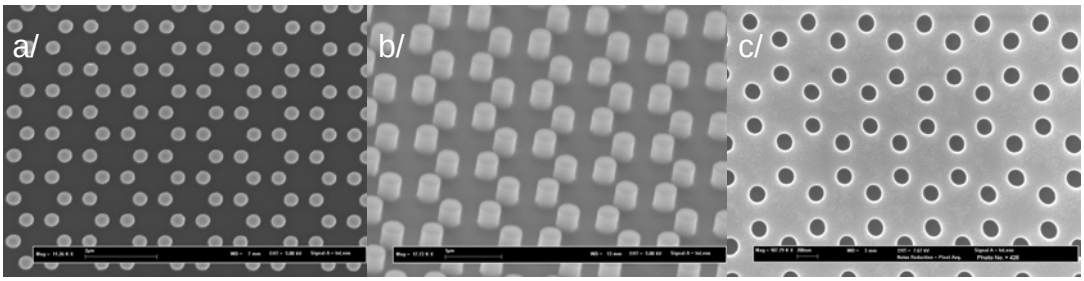

Figure 1: a/ SEM micrographs of a silicon stamp containing a 700 nm lattice constant two-dimensional array of pillars, b/ the associated tilted view (etch depth 350 nm), and c/ SEM micrographs of an imprint in an 400 nm polymer film.

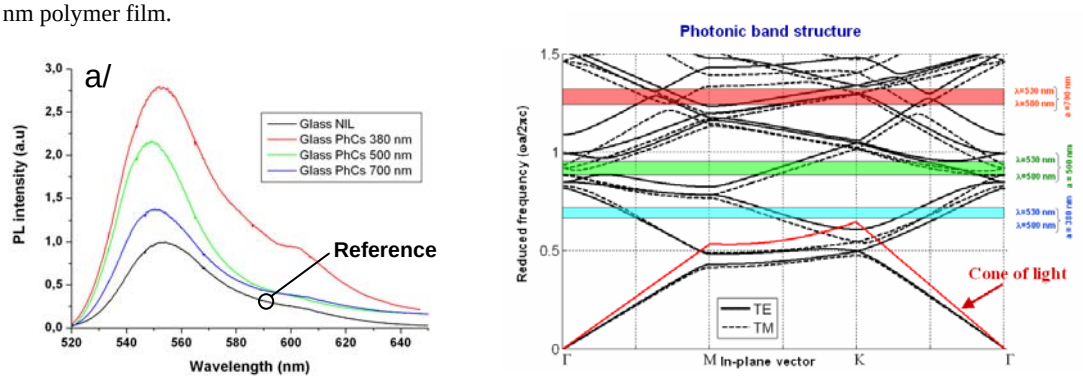

Figure 2: a/ PL spectra of a flat surface imprinted on a quartz substrate (dark blue line), PL spectra of a 2D photonic crystal with a 380 nm lattice constant (light blue line), with a 500 nm lattice (green line) and with a 700 nm lattice (red line), b/ Photonic band structure of a honeycomb lattice of air hole PhCs calculated with a plane-wave-basis frequency-domain method ''*a*'' is the lattice constant and ''λ'' is the wavelength. The red, blue and green bands correspond to the emission bandwidth of rhodamine for a PhCs lattice constant *a*=380 nm, *a*=500 nm and *a*=700 nm, respectively.

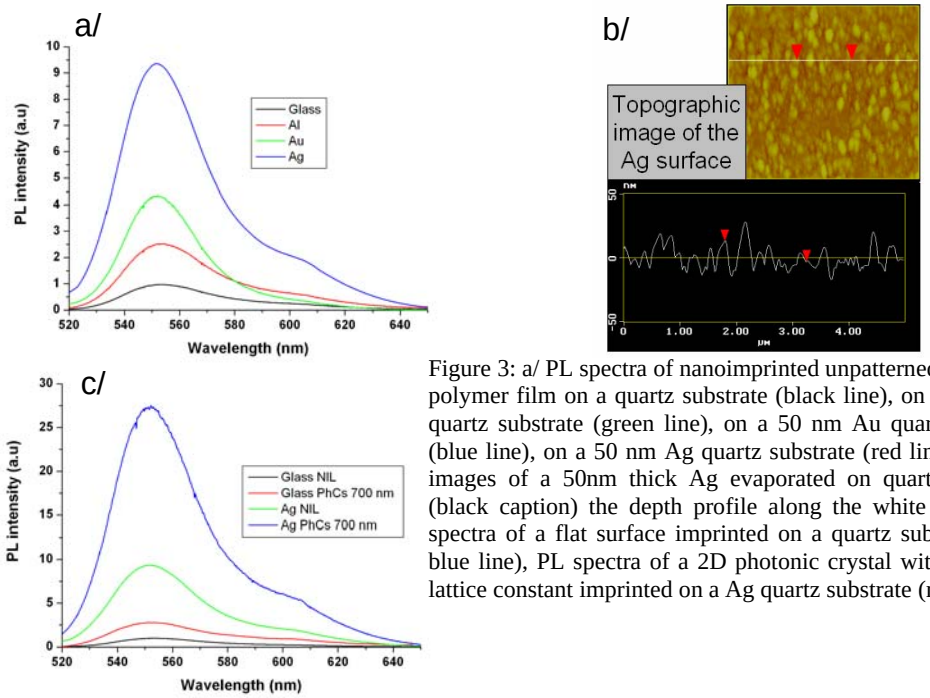

Figure 3: a/ PL spectra of nanoimprinted unpatterned dye-doped polymer film on a quartz substrate (black line), on a 50 nm Al quartz substrate (green line), on a 50 nm Au quartz substrate (blue line), on a 50 nm Ag quartz substrate (red line), b/ AFM images of a 50nm thick Ag evaporated on quartz substrate, (black caption) the depth profile along the white line, c/ PL spectra of a flat surface imprinted on a quartz substrate (dark blue line), PL spectra of a 2D photonic crystal with a 700 nm lattice constant imprinted on a Ag quartz substrate (red line).

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