Two-dimensional nanoimprinted photonic crystals for laser applications

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Polymer photonic devices generate a great interest to serve as new platforms for planar photonic integrated circuits (PICs). However the fabrication of PhCs often requires elaborate and expensive techniques, such as electron-beam lithography and reactive ion etching. For the last ten years, nanoimprint lithography (NIL) has become an alternative cost-efficient technology to replicate features with a sub-10 nm resolution. We show here the fabrication and optical characterization of polymer PhC band edge lasers and polymer PhC with photonic band gaps fabricated by NIL in a polymer layer doped with rhodamine 6G on glass substrates.

Silicon PhCs stamps with different lattice constants were fabricated and successfully imprinted by standard NIL process. Figure 1 shows a scanning electron microscope (SEM) image of a stamp structure and the corresponding two-dimensional PhC imprinted in the active polymer. The pattern is well reproduced, with a surface roughness comparable to the one on the stamp. These polymer lasers were pumped optically using a frequency-doubled Q-switched Nd:YAG laser (532 nm, 0.7 ns, 10Hz). The beam was focused to a ~20 µm radius spot. The emission from the PhCs was analyzed with a CCD spectrometer.

Figure 2a shows the measured spectra of 460 nm lattice constant honeycomb PhCs made in polymer, excited above the lasing threshold. By scaling the lattice constant of the PhC, the emission wavelength can be tuned. Insets in Figure 2a shows the light input-output relation of these lasers, exhibiting a sharp turn-on at the laser threshold. At much higher excitation levels, multimode laser oscillations were observed. The lasing mode has been matched with a very good agreement to the expected band edge lasing modes calculated with a plane-wave-basis frequency-domain method. Furthermore, microcavities have the potential to exhibit an ideal cavity for the control of the spontaneous emission. A simulated example by 2D FDTD of the transmission of a plane wave along the ΓM direction of the microcavity is presented Figure 2b. It shows a sharp resonance inside the bandgap. The light is expected to be strongly localized in the defect induced by the PhCs exhibiting a photonic band gap (inset). Experimental validation is under progress.

In conclusion, we fabricated polymer photonic crystal band-edge lasers using nanoimprint lithography. The laser emission wavelength can be tuned by controlling the lattice constant of the PhCs, covering a wavelength range of 30 nm around 550 nm. Nanoimprinted microcavities with two-dimensionnal photonic crystals have been successfully fabricated opening the way on the realization of ultrasmall laser cavity. Unlike the electron-beam lithography commonly used for patterning nanophotonic structures, NIL offers a cost-efficient, rapid and large area processing capability. The direct transfer of the PhC pattern in an active layer reduces the number of process steps for the fabrication of this type of lasers.

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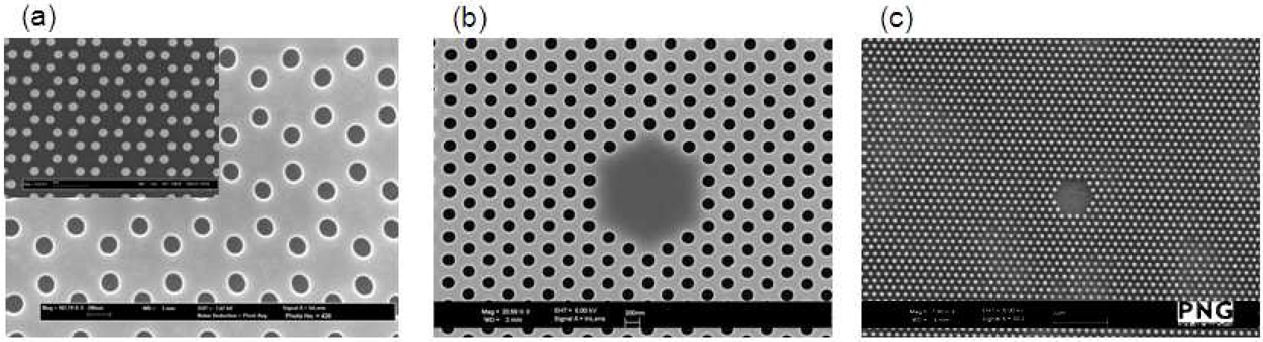

Fig. 1: a/ SEM micrographs of nanoimprinted photonic crystals in mr-NIL 6000, in which rhodamine 6G have been incorporated (concentration: 5.10^{-3} $mol.L^{-1}$), Inset: SEM micrographs of a silicon stamp containing two-dimensional honeycomb array of pillars, b/ SEM micrographs of a silicon microlaser stamp containing two-dimensional triangular array of pillars, c/ SEM micrographs of nanoimprinted photonic crystals in the dye doped polymer.

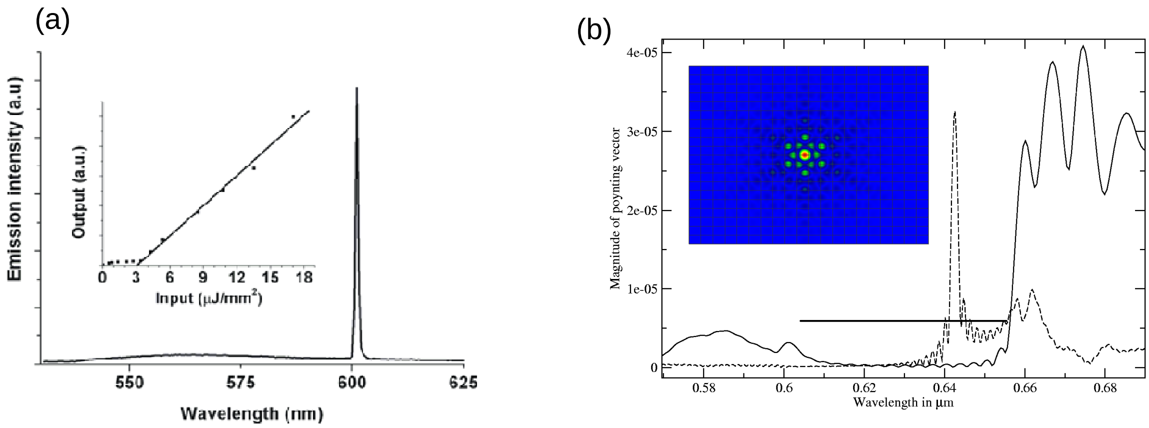

Figure 2: a/ Emission spectra of a band edge laser (lattice constant: 460 nm). Inset: Radiated power as a function of the excitation energy, b/ Results of the FDTD simulation of transmission of a plane wave through a PhC with a defect (in dotted lines) and without defect (solid line). The bandgap wavelength range is marked with a horizontal bold line. Inset: Electric field in the out-of-plane direction for the PhC at the resonant wavelength of the microcavity.