Printed Active Photonic Crystals in High Refractive Index Functional Materials for Visible Light Applications

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The development of advanced photonic circuits working in the visible light promises a revolution in a broad range of areas from bio-chemical sensing to quantum computing. Over the last years, novel nanophotonic devices were demonstrated but are mainly still limited to research laboratories due to their complex fabrication and challenging scalability for large areas.

Here we present a novel approach to drastically simplify the fabrication process via nanoimprint lithography (NIL) and demonstrate the first printed active photonic crystals with embedded quantum dots (QDs), fabricated by a powerful route involving the combination of top-down and bottom-up approaches [1-3]. One- and two-dimensional photonic crystal slabs were patterned by direct printing of functional TiO_2 based high refractive index materials. Thermally stable CdSe/CdS core/shell quantum dot nanocrystals (active medium) were synthesized and uniformly incorporated to form an active hybrid organic-inorganic matrix with high refractive index (n=2.1). The active hybrid material was successfully patterned by direct nanoimprint techniques on hard and flexible substrates with high resolution and fidelity. The printed devices exhibited excellent optical properties (Figure 1).

Fluorescence intensities of QDs were compared between the regions with and without printed photonic crystals and a fluorescence enhancement factor of ~ 10 was measured from the patterned regions. Furthermore, we show that the degree of photoluminescence enhancement is highly frequency dependent. The largest fluorescence enhancements comes from photonic crystals with the guided mode resonance frequency that spectrally overlaps with the excitation and emission frequency of the QDs used for this study. In contrast, when there is no spectral overlap, we do not observe any fluorescence enhancement (Figure 1). Arrays of photonic crystal nanocavities were imprinted in a single step with quality factors (Q) of 1000 (Figure 2). Advanced applications are under current development including optically pumped nanolasers and high efficiency light emitting diodes. This work represents a powerful and cost-effective route for the development of numerous nanophotonic structures and devices that will lead to the emergence of new applications.

References:

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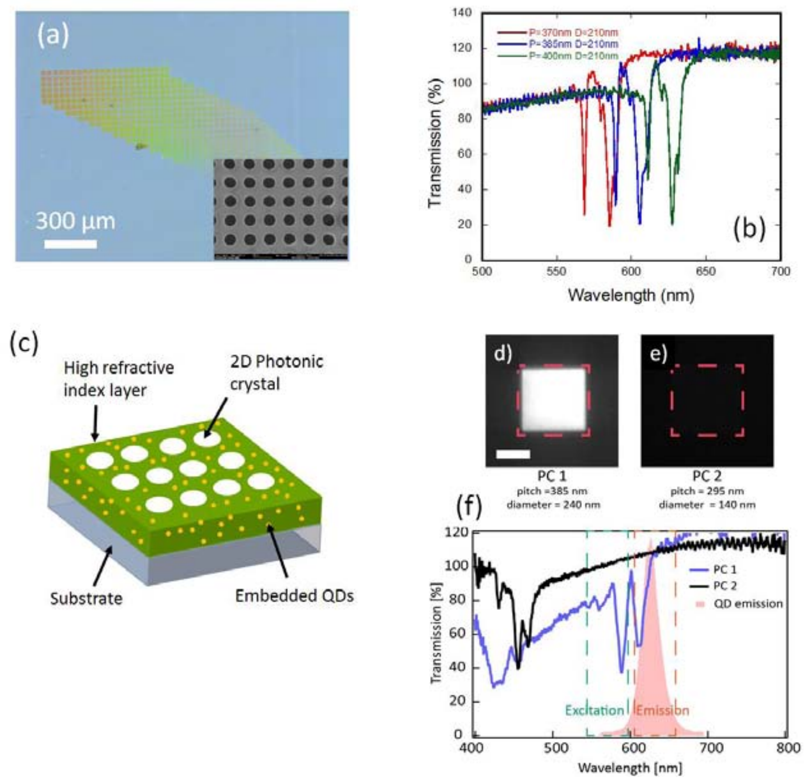

Figure 1: a) Optical picture of a printed photonic crystal in a high refractive index material (n=2.1) for visible light, inset: SEM cross section of the photonic crystal pattern; b) optical measurements of guided mode resonance in the printed photonic crystal at variable pitch. c) A scheme of a printed photonic device with embedded CdSe/CdS QDs. Fluorescence micrographs taken from different printed photonic crystals with QDs: d) PC 1 (pitch = 385 nm, diameter = 240 nm) and e) PC2 (pitch = 295 nm, diameter 140 nm). Red dashed lines highlight the location of the printed photonic crystals. f) Transmission spectra of PC1 and PC2. Green and Red dashed lines indicate the wavelengths used to excitation (green) and collection (red) of QD photoluminescence. Red shaded spectrum is the photoluminescence of the QDs used in this study. (Scale bar = 50 µm)

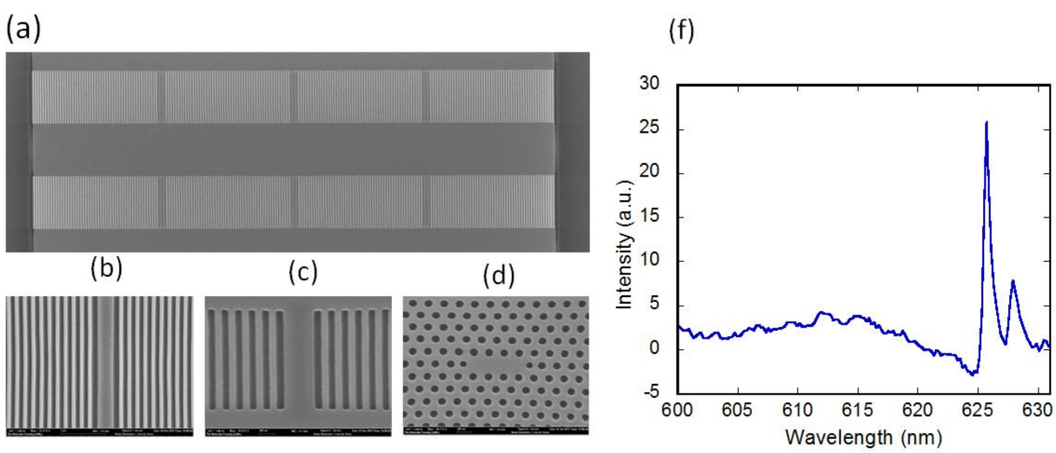

Figure 2: a) low magnification SEM image of a 1D nanocavity array printed in a high refractive index material; b,c) high magnification SEM image a 1D nanocavity; d) 2D photonic crystal. f) Resonance peak measurement in cross polarization of a 1D cavity with a quality factor of 1000.