Exploring the possibilities of fabrication of photonic crystals on inorganic materials with non-linear optical and laser properties

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Photonic crystals (PCs) are a class of dielectric or semiconductor materials with artificially fabricated periodicity of the refractive indexes. Such class of materials has been subject of considerable research interest for more than a decade, since, with a proper design, they exhibit prohibited spectral bands for concrete wavelengths (photonic band gaps) and they can serve as instruments to manipulate light generation and light flow [1]. These photonic crystals exists in one dimension (1D), two dimension (2D), and three dimension (3D) forms, and can be easily produced in polymers [2]. However, to produce such 1D, 2D and 3D PCs on inorganic materials with optical properties is a more challenging objective, and several techniques have been tested for their fabrication [3]. In fact, one of the main challenges for the production of photonic structures with higher dimensionality is the fabrication of these structures with sufficient precision to prevent scattering losses blurring the crystal properties. For this reason, the fabrication techniques for such structures have to be analyzed carefully.

In this paper we analyze the results obtained using four different techniques of fabrication of such 1D, 2D and 3D PCs on crystals with non-linear optical properties belonging to the $KTiOPO_4$ (KTP) family, such as the same KTP and $RbTiOPO_4$ (RTP), and also on $LiNbO_3$. Photonic crystals fabricated in nonlinear optical materials, or non-linear photonic crystals (NPC) have been an attractive topic for their modulation of the non-linear coefficient $\chi^{(2)}$ together with a periodic modulation of the linear susceptibility $\chi^{(1)}$. Such structures can be generated by fabricating a surface relief structure on the surface of a non-linear optical material. In this way the refractive index and the $\chi^{(2)}$ susceptibility are modulated periodically between the values of the nonlinear optical material and those of the surrounding medium. Such structures can enhance, phase match or even hold a non-vanishing second-order interaction even if the material is centrosymmetric. Also, this kind of structures may allow to demonstrate backward parametric oscillation, a non-linear effect predicted many years ago but that has not been demonstrated experimentally. Furthermore, new non-linear optical effect have also been expected to occur, such as the generation of asymmetric diffraction patterns of the second-harmonic generated light that we reported very recently.

We also explored the possibilities of fabricating those PCs in thin epitaxial layers of materials with laser applications as they are the monoclinic potassium double tungstates, $KRE(WO_4)_2$, grown on substrates of the same family. Those materials are well known for the large absorption and emission cross sections that active lanthanide ions exhibited when they are hosted in this family of materials, and also because concentration quenching effects for emissions of lanthanide ions in these crystals are low due to the large distance among lanthanide ions in these structures. In these crystals we are especially interested in analysing generation and propagation of light through PC structures.

The techniques used to fabricate such PCs include laser ablation, selective wet-chemical etching in periodically poled non-linear optical crystals, focused ions beam (FIB) and an alternative approach to fabricate PCs by combining two well known techniques: the fabrication of porous silicon membranes and the epitaxial growth of the materials of interest by liquid phase epitaxy (LPE) techniques [4].

Ultrafast laser ablation constitute a unique tool for micro-machining a diverse range of materials. This technique uses very short and intense laser pulses to remove thin layers from the surface of a bulk target by means of a physical mechanism different from those taking place in conventional laser ablation. The collateral thermal and mechanical effects around the ablated area are diminished to such an extent that precision and quality of the microstructures higher than those obtained with other techniques can be achieved. By using this technique we prepared 1D and 2D PCs on the surface of KTP and RTP crystals.

Ferroelectric domains of opposite spontaneous polarization present different etching speeds when dipped in some acid mixtures. This property has been used to reveal the domain pattern at the surface of periodically poled crystals. However, the selective etching process provides further capabilities for versatile surface engineering of domain-engineered crystals, allowing the production of deep, high aspect ratio structures, with side-walls that can be extremely smooth. This allowed us to generated 1D PCs on $LiNbO_3$ periodically poled crystals.

FIB is a suitable micro-machining tool to modify or machine materials at the micro- and nanoscale, and 2D PC structures can be fabricated by drilling a periodic pattern of holes with the appropriate diamers and separated by the adequate distances. Using this technique we fabricated 2D PCs on thin layers of $KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$ grown on $KY(WO_4)_2$ substrates that contained straight and bending defects that allowed the propagation of light through straight and bending waveguides.

Finally, we developed a procedure for fabricating 2D and 3D photonic crystals in four steps: (i) preparation of high-quality ordered macro-porous silicon templates, (ii) growth of thin layers of the desired materials within the pores of the silicon templates, (iii) polishing of the top or bottom surface of the epitaxial layers, and (iv) selective etching of the silicon matrix. In this way we prepared 2D and 3D PCs of KTP and $KYb(WO_4)_2$.

All these structures have been characterized morphologically and optically. Some details of the micro- and nanostructured PCs fabricated on these materials can be seen in Figure 1.

References

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Figures

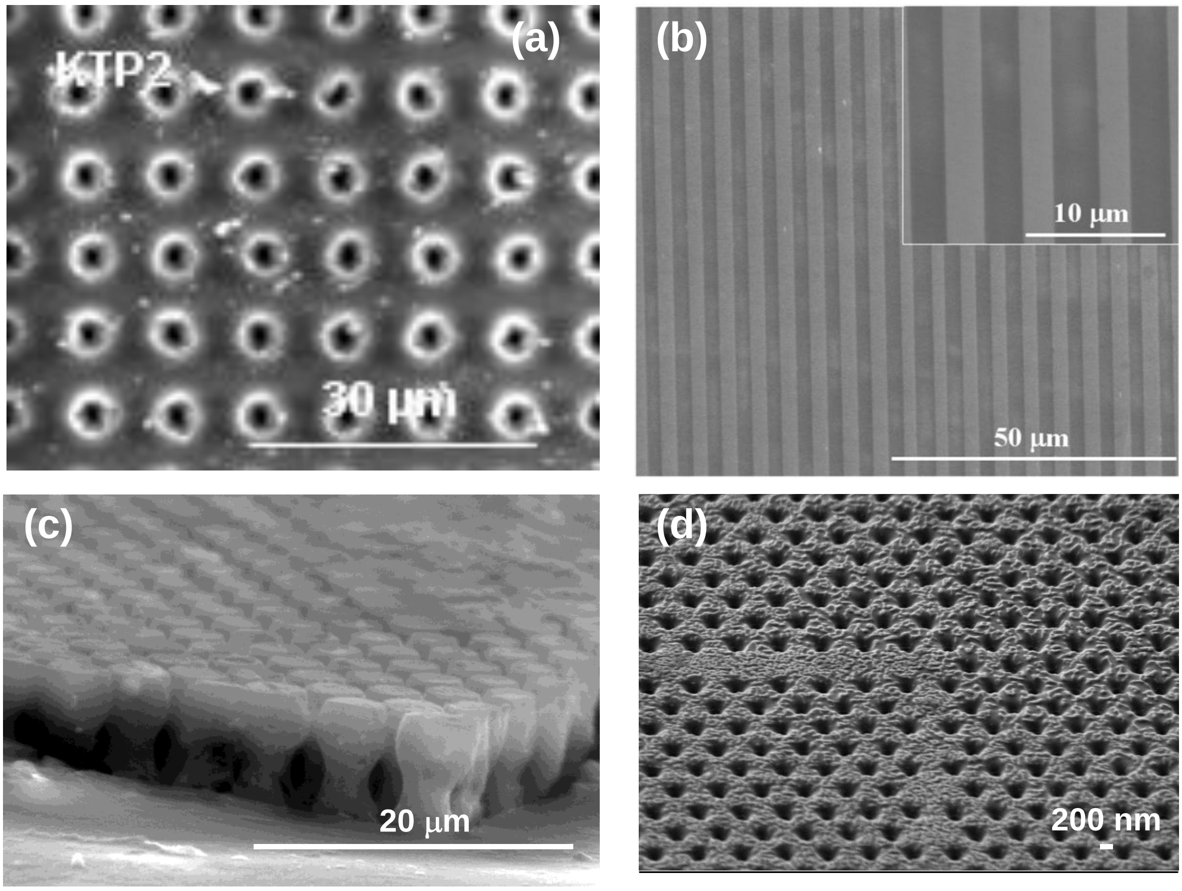

Figure 1. (a) 2D PC fabricated by ultrafast laser ablation on the surface of a KTP crystal. (b) 1D PC fabricated by selective wet-chemical etching on a periodically poled $LiNbO_3$ crystal. (c) 3D KTP PC fabricated by epitaxial growth within the pores of a silicon membrane. (d) 2D PC with a 90º bending waveguide fabricated by FIB on a $KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$ / $KY(WO_4)_2$ epitaxy.