Vertical One-Dimensional Photonic Crystals for Optofluidic Applications

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In this work, design, fabrication, characterization and modeling of vertical, high-order one-dimensional photonic crystals (1D-PhCs) for optofluidic applications in the near infrared region are presented. Vertical, high aspect-ratio (up to 30) silicon/air 1D-PhCs with spatial period from 1 up to 8 µm and high-order (up to 25th) photonic bandgap at 1.55 µm were designed according to the so-called hybrid quarter-wavelength structure, and fabricated by electrochemical micromachining (ECM) of silicon. Reflectivity spectra of 1D-PhCs were measured in air as well as in the presence of liquids (ethanol, isopropanol, water), in the near infrared region between 1.0 and 1.7 µm at normal incidence with an experimental setup, which exploited single-mode optical fibers with lensed terminations. Numerical calculations were performed using the characteristic matrix method (CMM), modified to take into account non-idealities of the device under test (i.e. surface roughness) and limitation of the optical setup (i.e. limited resolution bandwidth of the optical spectrum analyzer). Finally, fabrication of closed-loop optofluidic microsystems exploiting silicon-based 1D-PhCs and integrating both optical and fluidic functionalities on the same chip are discussed.

Optofludics [1] attempts to unify optics and microfluidics, thus providing new ways for optical device integration and tuning. In optofluidic devices, part of the optical structure is in contact with a proper fluid, providing new ways for optical device integration and tuning. In optofluidic devices, part of the optical structure is in contact with a proper fluid, thus changing optical properties of the structure itself. Pho
crystal (PhC) structures obtained by air-void formation in high-refractive-index materials are, therefore, good candidates for optofluidic device fabrication, as air can be easily replaced by a suitable fluid. Moreover, thanks to the high sensitivity of the PhC optical properties to tiny changes of dielectric constant, PhCs can be efficiently used as core elements of optofluidic devices, although only a few examples of this kind of PhC-based devices have been reported so far [2].

Vertical silicon/air 1D-PhCs are periodic structures of two alternating materials (i.e. silicon and air) along one axis [3, 4]. Such structures are very appealing in optofluidics as they allow the in-plane light flow (i.e. the light traveling in the plane of the silicon substrate) to be controlled also as a function of the liquid filling the air-gap. High-order 1D-PhCs having a complex line-shape of the reflectivity spectrum are desirable for optofluidic applications in order to enhance optical changes induced by liquid insertion within the structure. Increasing the spatial period of the structure allows the fabrication of 1D-PhCs that feature better mechanical stability, especially in the presence of liquids (typical of optofluidic applications), while simultaneously exploiting high reflectivity order at the selected wavelengths.

Fig. 1 shows the SEM cross-section of a 1D-PhC with period of 8 µm, in which high horizontal (parallel to the wafer surface) and vertical (perpendicular to the wafer surface) uniformity is clearly observable. Fig. 2 shows the optical measurement setup, based on a single-mode fiber (smf-28) coupler connected to a lensed fiber for device interrogation. The reflected power spectrum of the as-fabricated microstructure (i.e. in air) was collected just before the addition of the liquid and used as a reference spectrum. Then, the power spectra in the presence of liquids as well as after evaporation, which is associated with a rapid return of the band-gap pattern to the reference situation, were recorded. A typical sequence is reported in Fig. 3 for the tested alcohols. In both cases, the power spectrum collected after evaporation is well superposed to the reference, even after a number of insertion/evaporation cycles. Such result demonstrates that vertical 1D-PhCs with period of 8 µm feature a good mechanical stability for optofluidic applications. Furthermore, a reliable red-shift is observed in the presence of water and alcohols that allows to discriminate refractive index variation with a sensitivity of 1 nm/RIU. Experimental data were found in very good agreement with numerical results, as shown in Fig. 4, once surface roughness of the silicon walls and finite resolution bandwidth (RB) of the optical spectrum analyzer were taken into account [5].


![Figure 1: SEM picture of a vertical 1D-PhC with spatial period of 8µm, depth of 100µm, aspect-ratio of 33, fabricated by silicon ECM.](image)

![Figure 2: Fiber-optic setup for reflectivity measurements (WLS: White light source; OSA: Optical spectrum analyzer).](image)

![Figure 3: Experimental reflected power spectra (RB=10nm) before and after infiltration of ethanol (top) and isopropanol (bottom) in the air gaps, and in the presence of the liquid inside the gaps.](image)

![Figure 4: Experimental (dark trace) and theoretical (light trace) reflectivity spectra (RB=10nm) before infiltration of ethanol (top) in the air gaps, and in the presence of the liquid inside the gaps (bottom).](image)