2×3 Photonic Crystal Series-Parallel Integrated Sensor Arrays Based on Monolithic Substrates Using Side-Coupled Resonator Arrays

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Abstract: We propose an alternative method to build nanoscale point and sensor-array performing highly-parallel and multiplexing capability on monolithic photonic-crystal-slab, which is the 2×3 photonic-crystal series-parallel integrated sensor-array based on integration of optimized-beam-splitter and side-coupled resonator-arrays.

OCIS codes: (130.3120) Integrated optics devices; (280.4788) Optical sensing and sensors; (160.5298) Photonic crystals; (230.1360) Beam splitters (230.5750) Resonators; (060.4230) Multiplexing.

Optofluidics opens a new research field in photonics by combining optics and microfluidics. Here, light is used for controlling and efficiently analyzing fluids, colloidal solutions, solids in a fluid, *etc*, in micro-scale devices such as labs-on-chip [1, 2]. Sensors are among the fundamental elements of optofluidics. They are required to be compact, cheap, disposable, highly sensitive, and even multiplexing sensing. New possibilities for the development of optical sensors have been opened up with the advent of photonic crystals (PhCs). The ultra-compact and multiplexing capabilities of PhCs optical sensors are their main advantages since it allows the possibility of forming highly parallel, label-free and ultra-dense sensor arrays or networks. However, most of the PhCs sensors devised until now typically operate as point sensors and the number of targets which can be screened for at one time is relatively small, see for example [3, 4].

Recently, in order to overcome this drawback and realize multiplexing sensing sites, a few attempts of multiplexing PhCs sensors have been reported in the literature, although the proposed techniques allow the multiplexing of a very limited number of sensors or make it necessary complex demodulation schemes. Examples of such systems include that of S. Mandal *et al.* [5] who demonstrated a nanoscale opto-fluidic sensor arrays based on a silicon (Si) waveguide with a 1D (one-dimensional) photonic crystal micro-cavity (side resonator) that lies adjacent to the silicon waveguide, D. Yang *et al.* [6] who demonstrated a nanoscale photonic crystal sensor arrays on monolithic substrates using side-coupled resonant cavity arrays, and Sevilla *et al.* [7] who demonstrated a photonic crystal fiber (PCF) sensor array based on modes overlapping. However, in the Ref. [5], sensor arrays consist of a silicon waveguide with a 1D photonic crystal micro-cavity, which is realized on many separate silicon strips, rather than a monolithic silicon slab. In addition, the extinction ratio of single dip of 1D photonic crystal micro-cavity in the Ref. [5] is only 4~10 dB. In the Ref. [6], although the extinction ratio of single drop of the PhC side-coupled cavity is enhanced to 20 dB, there is only one series connected sensor array on monolithic substrates, limiting the further enhancement of integration density of the photonic integrated circuits (PICs).

Here, we demonstrate a novel paradigm for highly parallel and ultra-compact multiplexing sensing that makes it possible to overcome the above limitations, which we refer to as a 2×3 monolithic photonic crystal series-parallel integrated sensor arrays (PhC-SPISAs). The architecture, which can be used as an opto-fluidic architecture for performing highly parallel, label-free, and multiplexing sensing detection system, is based on the integration between an optimized 1×2 beam-splitter and side-coupled resonator arrays. The optimized beam-splitter with parallel output ports consists of a Y-junction and two 60° waveguide bends, as shown in Fig. 1. The high transmission bandwidth of the beam-splitter ranges from1507.5nm to 1670.0nm, and covers the entire C and L-band of optical communication. The PhCs microcavities resonator arrays are side-coupled to the output waveguide of the beam splitter. Each PhCs resonator has slightly different cavity spacing and is shown to independently shift its resonant peak (a single and narrow dip) in response to the changes in refractive index (RI) in the region surrounding its cavity. The extensive simulation results demonstrate that the resonant wavelength of the mode localized in the microcavity shifts its spectral dip position following a linear behavior when the RI in the region surrounding its cavity changes, and the extinction ratio of well-defined single dip exceeds 30 dB. Here, in each PhC resonator array branch, there are three series-connected PhC resonators, which side-coupled to the output waveguides of PhC beam splitter with a triangular lattice of air holes realized on silicon slab waveguide. When n sensors are set in cascade, the transmission of the series exhibits n dips. The dips are independent of each other, thus a shift in one of them does not perturb the others, as shown in Fig. 2. This allows the implementation of simple but functional PhC-based integrated sensor arrays, and eventually of more ultra-compact PhCs-based integrated optical devices and photonic integrated circuits (PICs). Fig.2(c) shows the composed transmission spectra of the up-branch in monolithic PhC-SPISAs when one sensor (***e.g.*** PhC-S2) is under the changes in refractive index (RI) and other sensors are not. It can be seen that the position of the dip of the sensor device under RI variations changes evidently, but that of the others do not and remain completely unchanged. It also reveals that the spectral position of the resonating dip detected at the output of the PhC waveguide shifts towards longer wavelengths (red-shift) as the refractive index value is increased (the insert plot).

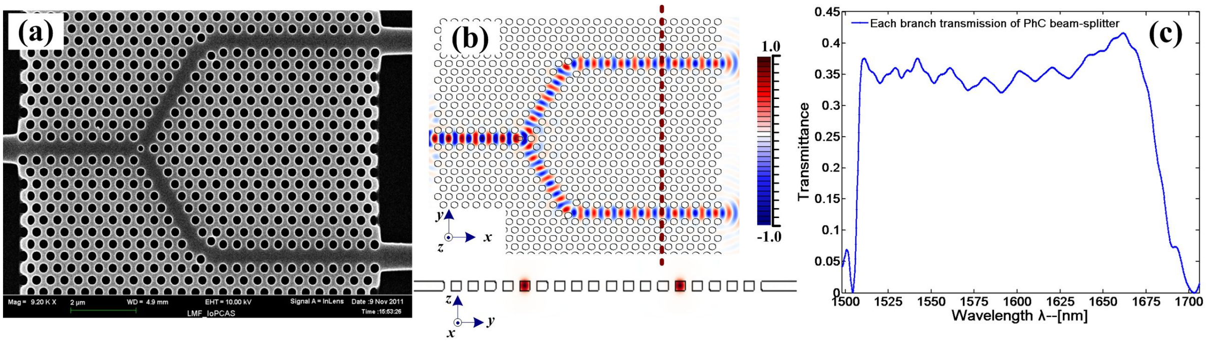
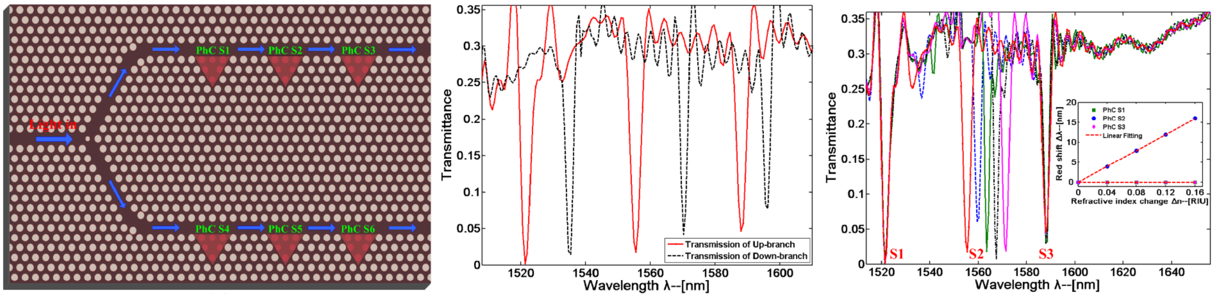


Fig. 1 (a) SEM image of triangular lattice optimized beam-splitter, completely fabricated by EBL; (b) Light propagating through beam-splitter in the *x*-*y* and *y*-*z* plane; (c) Transmission spectrum of the optimized beam-splitter.



(a) (b) (c)

Fig. 2 (a) 3D illustration structure of the 2×3 monolithic PhC series-parallel integrated sensor arrays; (b) Transmission spectra of two parallel up and down-branch observed when six sensors devices are set in series-parallel connections; (c) Composed transmission spectra of the up-branch in monolithic PhC-SPISAs when only one sensor device is under the changes in refractive index (RI) and others are not; The inset plot shows red shift in the resonant wavelength as a function of RI changes in the region surrounding its resonant cavity sensor.

It is important to point out that the demodulation of the parallel series of sensors is straightforward. Thus, we believe that the results presented here may widen the highly-parallel performance and multiplexing capability of PhCs sensors array. The technique presented here may also allow the implementation of simple but functional arrays or networks of PhCs optical sensors. Here, this research was supported in part by National 973 Program (No. 2012CB315705), National 863 Program (No.2011AA010306), and NSFC (No.61171103), P. R. China. Thanks for the great help.

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