Photonic Crystal Cavity-Based Wavelength Routers

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***Abstract*— We have characterized the optical properties of wavelength routers in a 2D photonic crystal with a triangular lattice of air holes. The router designs are aimed for realization of monolithically integrated mechano-optical switches.**

Keywords- photonic crystal; cavity; filter; switch;router; silicon

I. INTRODUCTION

We have studied the optical properties of two different photonic crystal (PhC) cavity-based wavelength routers. The first one is based on a Y splitter with an asymmetric cavity at the junction; the second one, known as a channel drop filter, consists of two parallel waveguides, coupled through a cavity. The optical designs are aimed at monolithic integration with a nanomechanical actuator, in order to actuate the switching function. For such an integration the small size of PhC structures is beneficial due to compactness and fast actuator operation [1].

The Y splitter device is designed for operation at a specific wavelength; the input signal can be switched between two output ports by selectively filling either of two holes, thus effectively mirroring the structure, see Fig 1. The channel drop filter is designed to drop a certain wavelength band from the "bus" channel to the "drop" channel, see Fig. 3. By changing the effective index of the structure with a mechanical element, the drop wavelength can be tuned [2].

The optical structures have been fabricated by the silicon photonics platform of IMEC, Leuven [3]. In the process the devices are patterned into a 220-nm thick silicon device layer of a SOI wafer with a 2 µm buried silicon dioxide layer.

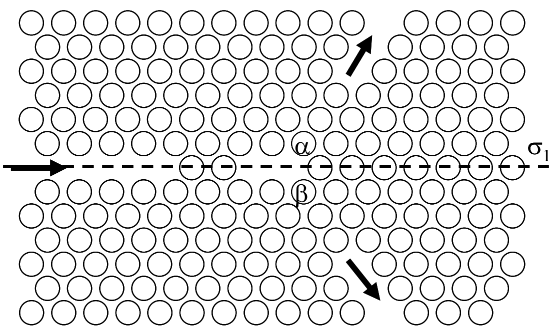

Figure 1. Principle of a PhC cavity-based Y splitter. The labels α and β indicate the positions of the switching holes. The asymmetric cavity at the junction (α or β filled) couples input light to only one of the output ports at a specific wavelength. By selectively filling either hole, the structure is effectively mirrored about the dashed line, thus interchanging the output ports.

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II. Y SPLITTER DEVICE

The functionality of the Y splitter design is based on symmetry of the cavity. By filling either hole α or β, the device symmetry is changed, and at a resonance wavelength light is coupled to either one of the output ports.

Based on our modeling results we have chosen a PhC lattice period of 420 nm and a hole diameter of 255 nm, in order to obtain an operating wavelength of 1550 nm. The actual hole diameter depends on the lithographic exposure dose. A SEM image of the fabricated device (hole β filled) is shown in Fig 2a.

Fig. 2b shows the measured transmission spectrum (hole β filled) and the result of a corresponding 2D FDTD simulation [4]. Light was coupled into the PhC device using a vertical fiber coupling method [5]. The measured transmission spectra have been normalized with respect to a straight Si photonic wire waveguide, similar to the access waveguides. For the simulation we assumed a hole diameter of 250 nm and an effective index of 2.82. The simulated curve has been fitted to the experimental data by shifting it in horizontal direction by –23 nm (accounting for inaccuracy introduced by using the effective index method in 2D calculations) and in vertical direction by -7 dB (average excess loss). The typical loss of a 25 periods long PhC W1 waveguide was measured to be 5 dB; near the mode cut-off it is 10-15 dB. The near mode cut-off loss is attributed to the slow light [6].

From Fig. 2b it can be seen that at resonance wavelength 1560 nm most of the light is coupled through the cavity to the *out1* waveguide branch, operating similar to a Fabry-Perot resonator. The on/off ratio at 1560 nm between ports *out1* and *out2* is about 12 dB.

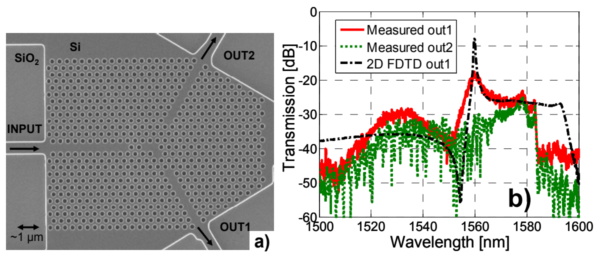

Figure 2. a) SEM image (top view) of the PhC Y splitter. b) Measured and simulated transmission spectra for the asymmetric cavity design; transmission from the *input* to the *out1* waveguide branch, using the normalization procedure mentioned in the main text.

III. CHANNEL DROP FILTER DEVICE

A SEM image of the cavity-based PhC channel drop filter is shown in Fig. 3. In the ideal case the light at a specific wavelength propagating along the bus channel is transmitted to the drop port (*out2*) while the light at the other wavelengths continues travelling through the bus channel to output port *out1*. The cavity should be designed such that the power at the drop wavelength is fully coupled to the drop port. This kind of performance requires (quasi)degenerate resonance modes with different field symmetries [7] at the operation wavelength. These resonant modes should have opposite symmetry with respect to the mirror plane centered on the cavity and perpendicular to the waveguides. The odd resonant mode excites forward and backward travelling guided modes in the PhC waveguides with π phase shift, whereas the even resonant mode excites them in phase, thus causing destructive interference for the backward travelling waves [7].

For the PhC structure we have selected a period of 440 nm and a hole diameter of 240 nm, as according to our simulations these parameters give device operation that is in the desired wavelength range of 1530-1565 nm. The PhC structure under study, shown in Fig. 3, consists of two symmetrically arranged W1-type waveguides, separated by 7 rows of holes, with a cavity in between. The diameter of the boundary holes adjacent to the W1 waveguides are made larger than the rest of the slab holes, in order to obtain single mode operation [8] and to adjust the dispersion curves for the cavity cross-section such that the desired wavelength drop performance is achieved.

Two versions of the device were fabricated; one with a boundary hole diameter (BHD) of 320 nm and the other with a BHD of 330 nm. Figs. 4a and 4b show the measured transmission spectra of the channel drop devices, normalized with respect to the transmission of a straight W1 waveguide of equal dimensions. Due to measurement noise, the transmission seems to be slightly above 0 dB in some regions.

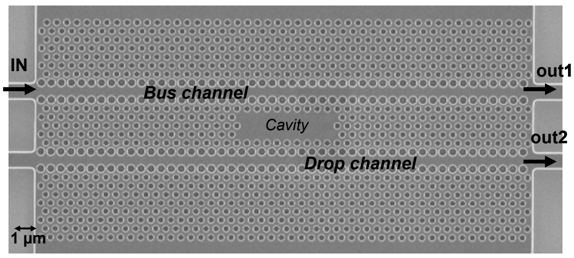

Figure 3. SEM image (top view) of a PhC channel drop filter. Ideally the cavity drops one wavelength from the bus to the drop channel, while other wavelengths continue in the bus channel.

As seen from the measured transmission spectra, both channel drop filters have a drop wavelength of 1561 nm. For a design with BHD of 330 nm the on/off ratio between ports *out1* and *out2* is higher; 16 dB compared to 10 dB. The full width at half maximum of the drop band is approximately 2.5 nm for both designs. Fig. 4a also shows the transmission spectrum of a reference device without a cavity but otherwise similar. From this reference curve (OUT2 Ref.), it can be seen that the device suffers from considerable cross talk at wavelengths longer than 1570 nm. Therefore the device should not be operated at wavelengths larger than the drop wavelength. The device with 320 nm BHD appears to have less crosstalk outside the drop band.

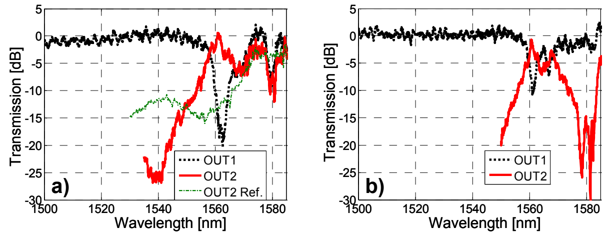

Figure 4. Measured transmission spectra of channel drop filters from the *in* to the *out1* and *out2* ports. a) device with 330 nm boundary hole diameter (BHD). Also shown a reference curve (see text). b) device with 320 nm BHD.

IV. CONCLUSIONS

Photonic crystal cavity-based devices for integrated mechano-optically actuated wavelength router devices have been designed and fabricated. The optical properties of the devices were characterized. For the Y splitter device a 12 dB on/off ratio between the output ports at the operation wavelength was measured. For the two slightly different channel drop filter devices cross talk values of 16 dB and 10 dB respectively have been measured at the drop wavelength. The optical loss of the deep UV fabricated PhC waveguides (25 periods long) are from 5 dB to 15 dB, depending on the wavelength.

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