Photonic resonators with microring-like behavior based on standing wave cavity pairs with opposite-symmetry modes

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Abstract: We emulate the reflectionless response of a traveling-wave resonator using two bus-coupled photonic crystal nanobeam cavities with respective symmetric and antisymmetric modes. The scheme may enable new active device platforms beyond ring resonators.

Traveling-wave resonators, such as microring resonators, are key enablers of integrated wavelength-division multiplexed (WDM) systems due to their channel add-drop functionality [1]. However, standing wave resonators, such as photonic crystal (PhC) nanobeam cavities, provide superior spatial confinement of light allowing enhanced light-matter interaction [2] which could make them more advantageous for building active devices such as modulators and detectors. Unlike traveling-wave resonators, however, when a bus waveguide is evanescently coupled to a standing-wave resonator, light within the resonator is coupled back into the bus waveguide with a portion traveling in the forward direction, and the rest in the backward direction. The amount of reflected light depends on the coupling strength between the bus and the resonator, and can reach up to 100% in case of strong coupling, resulting in the resonator acting like a frequency-selective mirror. This reflection is highly undesirable in WDM systems and communication links. It amounts to optical loss and contributes to a power penalty for links, and/or calls for the introduction of on-chip isolators and circulators.

Over the years, several geometries were proposed to emulate a traveling-wave resonator using standing-wave resonators. In the concept presented in [3–6], two identical standing wave resonators are used. This approach suffers from two major drawbacks which complicate the design and add to the power consumption of the device: (i) practical implementation requires three phase shifters, two to tune the cavities to the same resonance wavelength and the third to tune the phase delay between the cavities; (ii) either direct coupling between the cavities or a drop-port connecting the two cavities is required to cancel the effect of indirect coupling between the cavities due to the input waveguide, which complicates the design or adds to the device footprint. An alternate approach [7], based on mode-converting Bragg mirrors placed within the cavity, sacrifices mode confinement and quality factor of the PhC nanobeam cavity. In this work, we propose a novel resonator geometry that emulates the through-port response of a traveling wave resonator using two standing wave resonators. Moreover, we experimentally demonstrate it in a new 45 nm CMOS electronics-photonics foundry platform (GlobalFoundries 45SPCLO). The proposed concept, illustrated in Fig. 1(a), uses two standing wave resonators, evanescently coupled to the bus waveguide, aligned and with opposite field symmetries. Since the two cavities are tuned to the same resonance wavelength and have the same quality factor, the

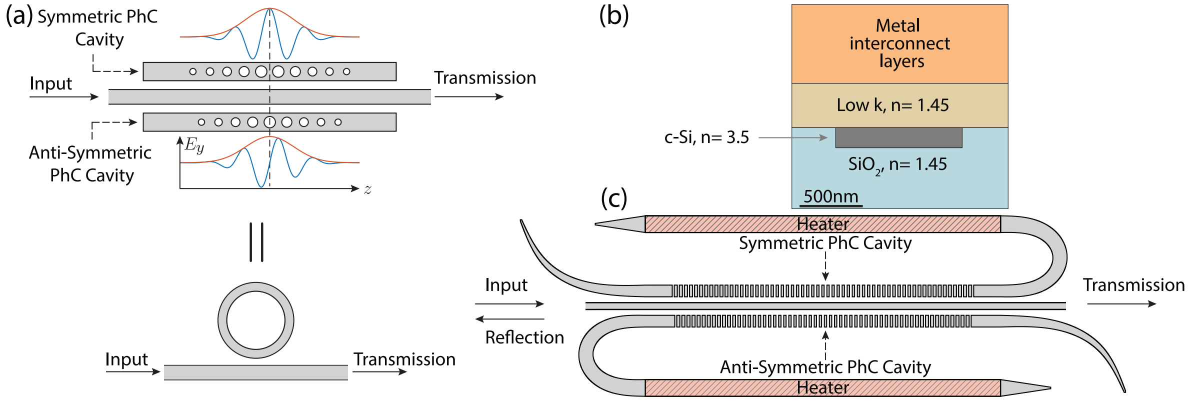

Fig. 1: (a) Proposed resonant system concept showing the symmetric and anti-symmetric fields in each cavity. (b) Cross section of the cavity; (c) device geometry as laid out on the design mask.

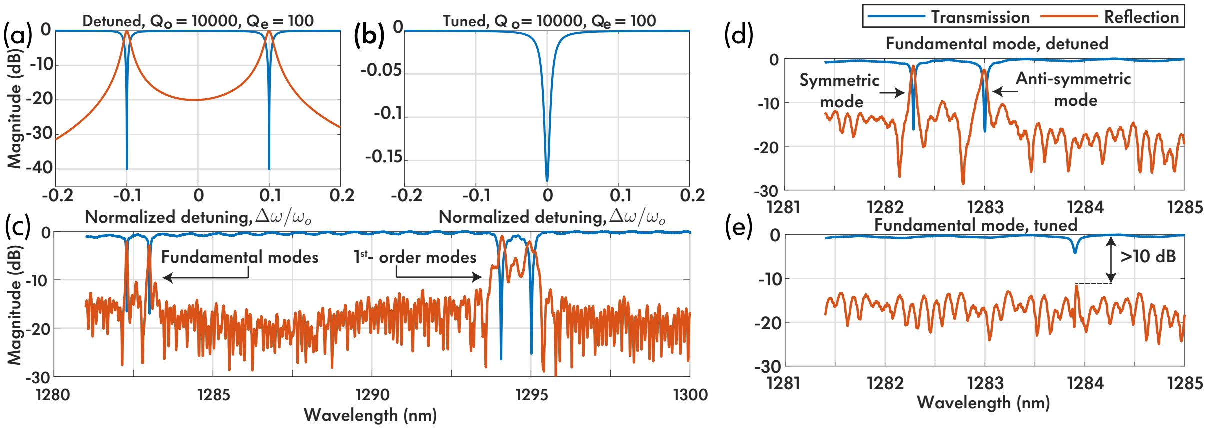

Fig. 2: (a) Response, given by CMT model, of detuned PhC nanobeam cavity strongly coupled to the input waveguide; (b) response (CMT model) after tuning the resonances; (c) experimental wide spectrum of detuned cavities showing the fundamental modes and the first-order modes; (d) spectrum around the fundamental modes before tuning, and (e) after tuning the symmetric cavity.

opposite symmetries cause light coupled in the backward direction from the respective resonators to have π-radian phase difference. Thus, reflected light destructively interferes, and no reflection results.

The device was fabricated in the GlobalFoundries 45SPCLO 45 nm node CMOS monolithic electronics-photonics process. The PhC nanobeam cavities were designed to support the dielectric resonant mode at 1300 nm using the approach outlined in [2]. The PhC nanobeam cavity waveguide width was set to 700 nm and the period to 304 nm. The mirror strength was increased linearly over 20 periods on each side of the cavity. Ten additional periods with the maximum mirror strength were added on each side of the cavity to act as a mirror, thereby increasing the intrinsic quality factor. The low-index etch holes were implemented by fully etching slots across the entire waveguide width and the mirror strength was varied by varying the duty cycle of the etch holes, as shown in Fig. 1(c). Microheaters for thermo-optic tuning, implemented using n+ doped silicon resistors, were implemented next to each resonator.

To fully demonstrate the reflection-canceling capability of the proposed device architecture, we designed PhC nanobeam cavities to be strongly coupled to the input waveguide such that reflection reaches nearly 100%. The theoretical response, given by a coupling of modes in time (CMT) model, is shown in Fig. 2(a) when the cavities are detuned from each other with the intrinsic quality factor $Q_o = 10,000$ and the external quality factor due to coupling to the input waveguide $Q_e = 100$. The case when the resonances are tuned to the same frequency is shown in Fig. 2(b). Reflection is completely eliminated and a small dip (under 0.2 dB) remains in the transmission response from residual loss, resembling a strongly coupled ring resonator. Figs. 2(c,d,e) show the measured response of the fabricated proof of concept device. A wide spectrum in Fig. 2(c) shows the fundamental and first-order modes of the cavity. The free spectral range (FSR) between the two modes is around 11.8 nm for both cavities. Fig. 2(d) shows the fundamental modes of the detuned cavities, with intrinsic quality factors Q_o measured around 200,000 for both cavities. With the symmetric cavity heater actuated (3.2 V, 21.5 mW), the cavities were aligned at the same resonance frequency as shown in Fig. 2(e). The symmetric mode was red-shifted by 1.6 nm; the antisymmetric mode was also red-shifted, by 0.9 nm, due to thermal cross-talk. After tuning, the transmission dip was reduced by 12 dB to -4 dB and the largest peak in reflection was reduced by >10 dB to below -11 dB. The result shows clear microring-like traveling-wave behavior.

This demonstration of high-Q PhC pairs that emulate microring behavior in an advanced monolithic electronic-photonic CMOS platform opens the door to novel highly efficient, small mode volume PhC active device platforms that may outperform currently favored ring resonator WDM links and other applications.

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