High Q, Compact Photonic Crystal Nanobeam Cavity for an Active Device Platform in a CMOS Silicon Photonics Process

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***Abstract*—We demonstrate a high Q, compact photonic crystal nanobeam cavity in the new 45 nm GlobalFoundries 45CLO monolithic electronics-photonics platform optimized for silicon photonics – with an intrinsic Q of 134,000, FSR of 24.17 nm, and a theoretical Q/V of 2.2$\times 10^5(\lambda/n)^{-3}$.**

I. Introduction

The major advancement of integrated optical links culminated in the recent demonstration of a bandwidth density > 1 Tbps/mm^2 with an energy-per-bit of 0.83 pJ/bit [1]. This was made possible by two synergistic factors. The first was replacing Mach-Zehnder modulators with much smaller and more energy efficient microring modulators, resulting in increasing the number of realizable wavelength-division multiplexing (WDM) channels, for a given chip area. The second was due to the monolithic integration of electronics and photonics in an advanced 45 nm SOI CMOS platform which allowed for large number of photonic devices and dense electronics to be realized on the same chip.

Photonic crystal (PhC) nanobeam cavities are well poised to provide the next leap in integrated optical links performance, beyond microring resonator based links, due to their small footprint and superior ability to confine light both temporally and spatially as measured by the metric Q/V.

In this paper we report a high quality factor and compact PhC nanobeam cavity realized in the GlobalFoundries 45CLO platform [2]. The 45CLO process is a new 45 nm-node monolithic electronic-photonic SOI CMOS process which has been optimized for silicon photonics. A novel architecture allowing for seamless integration of PhC nanobeam cavities in on-chip WDM links [3] and the first PhC nanobeam modulator in CMOS [4] were both recently demonstrated in the 45CLO platform, paving the way for ultra-low energy and compact WDM optical links based on PhC nanobeam cavities.

Compared to the previous demonstration of PhC nanobeam cavities in a monolithic CMOS platform [6], the device presented here is more compact, has higher quality factor, and is designed to operate in the O-band which is of interest for short-reach optical links [1].

II. Design and Simulation

The PhC nanobeam cavity was designed to support a dielectric resonant mode in the O-band around 1300 nm. The design procedure presented in [5] was used to synthesize the cavity. Fig. 1(a) illustrates the proposed device while Fig. 1(b) shows an optical micrograph of the PhC nanobeam cavity indicating the device and the different I/O ports. The PhC nanobeam cavity was implemented in a crystalline silicon waveguide with a width of 700 nm. Low-index etch holes with a constant period of 304 nm were realized by etching away the complete width of the waveguide. The mirror strength of the holes was increased linearly along the device length by varying the duty cycle of the etch holes. The parameter N_{cavity} shown in Fig. 1(a) controls the optical size of the cavity and hence the mode volume and free-spectral range (FSR). That is, a smaller N_{cavity} results in a smaller mode volume and a larger FSR and vice versa. Moreover, the parameter N_{mirror} indicates the number of mirror holes with the maximum mirror strength added to each side of the cavity in order to minimize leakage of light into the waveguide from both ends of the cavity. In the current

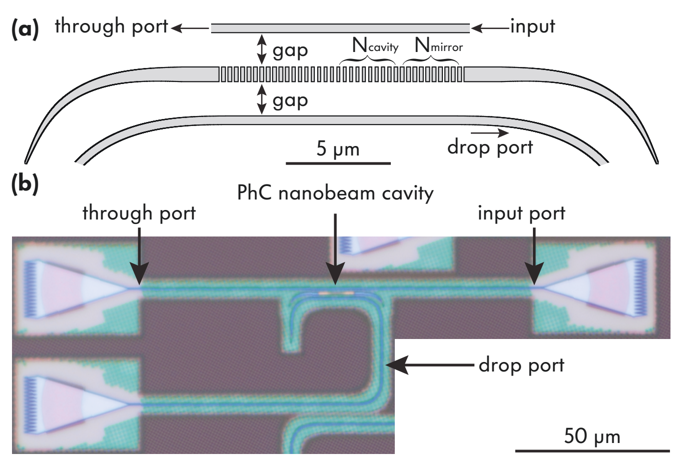

Fig. 1. (a) Geometry of the PhC nanobeam cavity as laid out on the design mask. (b) Optical micrograph of the device.

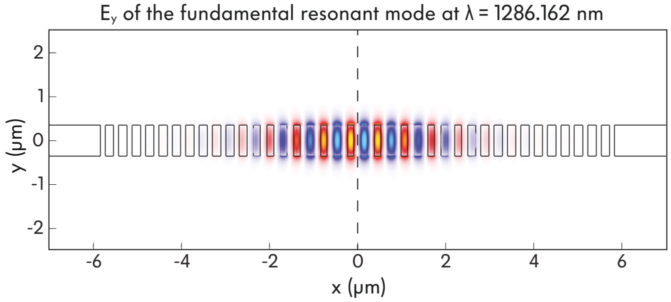

Fig. 2. E_y field component of the fundamental resonant mode

implementation, the cavity has a total of $2(\mathrm{N_{cavity}}+\mathrm{N_{mirror}})-1$ holes, where both $\mathrm{N_{cavity}}$ and $\mathrm{N_{mirror}}$ are set to 10. The footprint of the device is 139.2 μm^2 which is comparable to a microdisk resonator with an outer radius of 6.6 μm.

The device was simulated using 3D FDTD simulations and three resonant modes were observed at the following resonance wavelengths: 1286.162 nm, 1310.33 nm, and 1333.978 nm, resulting in a theoretical FSR of about 24 nm. The intrinsic quality factors Q_o of the modes are as following: 290233, 32046, and 2726, respectively. The E_y field component of the fundamental resonant mode is depicted in Fig. 1 exhibiting an odd symmetry about the center of the cavity. The field of the fundamental mode is almost completely confined longitudinally within 6 μmeters, making the cavity an excellent candidate for low-energy active device such as modulators or detectors. The mod volume of the fundamental mode was calculated to be 0.071 μm^3 or $1.33(\lambda/n_{\mathrm{si}})$ where $\lambda = 1286.162$ nm and $n_{\mathrm{si}} = 3.416$ resulting in a Q/V of $2.2{\times}10^5(\lambda/n_{\mathrm{si}})^{-3}$.

III. Experimental Characterization

In order to accurately characterize the intrinsic quality factor of the cavity, we employ edge-coupling where light is evanescently coupled in (out) the cavity via a bus (drop) waveguide. As the gap between the device and the surrounding bus (drop) waveguide increases, the linewidth of the resonance approaches the intrinsic linewidth [6]. The device with a gap of 400 nm from the input bus(drop) waveguide was characterized using a tunable laser source (Santec TLS-510) operating in the O-band. The through port and drop port spectra are shown in Fig. 3(a) with two resonances at 1279.499 nm and 1303.672 nm, resulting in an FSR of 24.17 nm. Figure 3(b) shows the fundamental mode resonance fitted with a temporal coupled mode theory model [6] from which an intrinsic quality factor of around 134,000 was extracted. Even though the quality factor is lower than the record 750,000 reported in [7]. The obtained quality factor is suitable for active devices such as modulators [4] or detectors and we expect it to increase as the process is improved by reducing propagation loss. Moreover, the presented device has the advantage of being realized in an advanced CMOS platform suitable for realizing large number of photonic devices [1] unlike the device in [7] which was realized using electron-beam (e-beam) lithography.

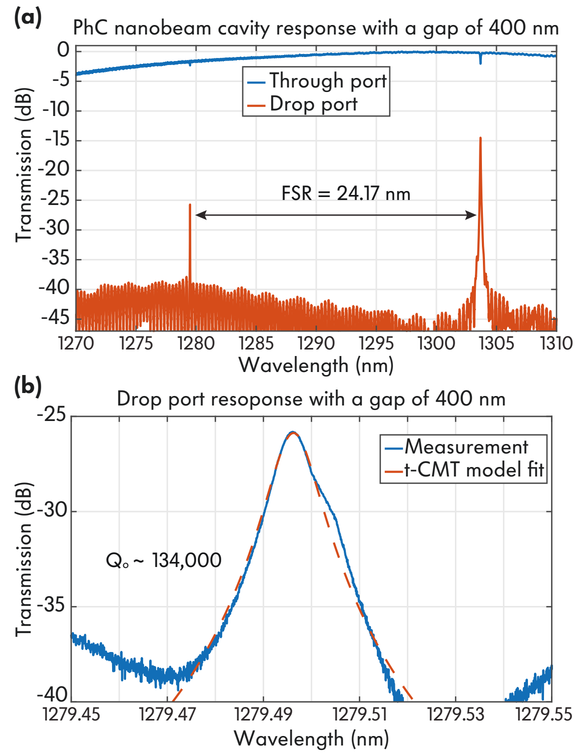

Fig. 3. (a) Experimental wide spectrum of a device with a 400 nm gap showing the fundamental mode and the first-order mode; (b) Drop port spectrum around the fundamental mode fitted with a t-CMT model.

IV. Conclusion

We have demonstrated a compact PhC nanobeam cavity with a measured Q_o of 134,000 and an FSR of 24.17 nm. The device is realized in a new 45 nm SOI CMOS platform optimized for silicon photonics and could be used in the next generation of integrated optical links beyond the current microring resonator based links.

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References

[1] Wade, M., *et al.*, “A bandwidth-dense, low power electronic-photonic platform and architecture for multi-Tbps optical I/O.” ECOC. IEEE, 2018.
[2] Rakowski, M., *et al.*, “45nm CMOS-silicon photonics monolithic technology (45CLO) for next-generation ...” OFC. OSA, paper T3H.3 2020.
[3] Al Qubaisi, K., *et al.*, “Reflectionless dual standing-wave microcavity resonator ...” Opt. Express 28.24 (2020): 35986-35996.
[4] Al Qubaisi, K., *et al.*, “Photonic crystal ...” 2021 OFC. IEEE, 2021.
[5] Quan, Q., *et al.*, “Deterministic design of wavelength scale, ultra-high Q photonic crystal ...” Opt. Express 19.19 (2011): 18529-18542.
[6] Poulton, C. V., *et al.*, “Photonic crystal microcavities ...” IEEE Photon. Technol. Lett. 27.6 (2015): 665-668.
[7] Deotare, P. B., *et al.*, “High quality factor photonic crystal nanobeam cavities.” APL 94.12 (2009): 121106.