Information processing and sensing with photonic crystal microcavities in SOI

Philippe M. Fauchet

Department of Electrical and Computer Engineering Computer Studies Building room 518 Hajim School of Engineering and Applied Sciences University of Rochester, Rochester NY 14627, USA Phone: +1-585-275-1487 Email: fauchet@ece.rochester.edu

1. Introduction

Photonic crystals (PhCs) result from the periodic arrangement of two different dielectrics [1]. Electromagnetic waves incident on the structure undergo multiple scattering events, which modifies the dispersion curve. For specific geometries, light propagation is prohibited in a range of wavelengths, thus producing a photonic bandgap (PBG). 2-D PBGs can be achieved in SOI by drilling a periodic array of holes in the top Si layer. Photonic crystal microcavities result from breaking the translational symmetry, which is done by changing the size of or removing one or several holes. Defect levels are thus created inside the photonic bandgap. When the incident light is resonant with the defect level frequency, transmission is allowed through the structure and the electromagnetic field is concentrated in a very small volume at or near the defect. For well-engineered, yet realistic structures, the modal volume on resonance is very small ($<<\lambda^3$) and the resonance is very sharp (Q= $\Delta\lambda/\lambda >> 1$, where $\Delta \lambda$ is the FWHM of the resonance). Under these conditions, the 2D PBG transmission peak is strongly shifted even if the refractive index change in the modal volume is very small [2]. This principle has been used to develop biosensors capable of detecting tiny amounts of biological targets [3,4] such as a single virus, and electro-optic (E-O) modulators that require only ~1 fJ of electrical energy to switch an optical bit [5,6].

2. Results and Discussion

This presentation will contain three parts. We will start by describing the design and performance of low-power, all-silicon or hybrid [7,8] E-O modulators to be used for on-chip optical interconnects. We then will describe biosensors capable of detecting well below 1 fg of biological matter, that is a single virus. Finally, we will briefly investigate the novel PBG microcavities [9,10,11] that further improve the device functionality or performance. Figures 1, 2, and 3 illustrate some of these new geometries.



Fig. 1 Microcavity coupled to a photonic crystal waveguide. Different microcavities have been coupled to the same waveguide, allowing for multiplexing or redundancy in biosensing experiments. After Ref. 10.



Fig. 2 Slotted ring waveguide photonic crystal microcavity obtained by inserting a "rod" in the center of a large defect microcavity. The very tiny modal volume of this device makes it very sensitive to a small change in refractive index due to the capture of small particles, in this case nanoshperes. After Ref. 11.



Fig. 3 Photonic crystal microring cavity coupled to a waveguide. In the slow-light regime, near the photonic bandgap edge, the free spectral range is variable and light can be coupled in both directions of a second, drop waveguide. After Ref. 12

Acknowledgments

This work was supported by the National Science Foundation, the National Institutes of Health, and the Air Force Office of Scientific Research (G. Pomrenke). Device fabrication was performed in part at the Cornell NanoScale Facility, a member of the National Nanotechnology Infrastructure Network, which is supported by the National Science Foundation. The author thanks Jonathan Lee, Sean Anderson, Dr. Mindy Lee, Dr. Elisa Guillermain, Dr. Sudeshna Pal, and Prof. Benjamin Miller for their contributions to the results presented here.

References

- J. D. Joannopoulos, R. D. Meade, and J. N. Winn, *Photonic Crystals: Molding the Flow of Light*, Princeton Press, 1995
- [2] P. M. Fauchet, B. L. Miller, L. A. DeLouise, M. R. Lee, and H. Ouyang, "Biodetection Using Silicon Photonic Crystal Microcavities," in *Biophotonics*, L. Pavesi and P. M. Fauchet editors (Springer, Berlin, 2008), pp 101-126 (2008)
- [3] M. R. Lee and P. M. Fauchet, "Nanoscale Microcavity Sensor For Single Particle Detection," Optics Lett. 32, 3284-3286 (2007)
- [4] M. Lee and P. M. Fauchet, "Two-Dimensional Silicon Photonic Crystal Based Biosensing Platform For Protein Detection," Opt. Express 15, 4530-4535 (2007)
- [5] S. P. Anderson and P. M. Fauchet, "Ultra-Low Energy Switches Based On Silicon Photonic Crystals For On-Chip Optical Interconnects," in *Silicon Photonics V*, J. A. Kubby and G. T. Reed, editors, Proc. SPIE (SPIE,

Bellingham, WA, 2010), Vol. 7606, pp. 76060R 1-8 (2010)

- [6] S. P. Anderson and P. M. Fauchet, "Ultra-Low Power Modulators Using MOS Depletion In a High-Q SiO₂-Clad Silicon 2-D Photonic Crystal Resonator," submitted to Optics Express
- [7] S. P. Anderson, M. Haurylau, J. Zhang, and P. M. Fauchet, "Hybrid Photonic Crystal Microcavity Switches On SOI," in *Silicon Photonics II*, J. A. Kubby and G. T. Reed, editors, Proc. SPIE (SPIE, Bellingham, WA, 2007), Vol. 6477, pp 647712 1-8 (2007)
- [8] S. P. Anderson, A. R. Shroff, and P. M. Fauchet, "Slow Light With Photonic Crystals For On-Chip Optical Interconnects," Adv. Opt. Technol. 2008, 293531 (2008)
- [9] E. Guillermain and P. M. Fauchet, "Multi-Channel Biodetection Via Resonant Microcavities Coupled To A Photonic Crystal Waveguide," in *Frontiers in Pathogen Detection: From Nanosensors to Systems*, P. M. Fauchet, editor, Proc. SPIE (SPIE, Bellingham, WA, 2009), Vol. 7167, pp. 71670D1-D11 (2009)
- [10] S. Pal, E. Guillermain, R. Sriram, B. Miller, and P. M. Fauchet, "Microcavities In Photonic Crystal Waveguides For Biosensor Applications," in *Frontiers in Pathogen Detection: From Nanosensors to Systems II*, P. M. Fauchet and B. L. Miller, editors, Proc. SPIE (SPIE, Bellingham, WA, 2010) Vol. 7553, pp. 755304 1-10 (2010)
- [11] J. Y. Lee, M. Lee, and P. M. Fauchet, unpublished results
- [12] J. Y. Lee and P. M. Fauchet, unpublished results