Photonic Crystal Ring Resonator: A Promising Device for a Multitude Applications

Yadunath T.R*[a,c], Resmi R Kumar[a], Sreenivasulu T.[a], Anusree Kandoth[a], Kamal John[a], Rohit K Ramakrishnan[a], Partha P Das[c], Badrinarayana T[a], Mohan S.[b], Gopalkrishna Hegde[b], T Srinivas[a]
[a]Applied Photonics Lab, ECE Department, Indian Institute of Science, Bengaluru, India - 560 012
[b]Centre for Nano Science and Engineering, Indian Institute of Science, Bengaluru, India-560012
[c]Department of Physics, National Institute of Technology Karnataka, Surathkal, India - 575 025

ABSTRACT

In this paper a 2D Photonic Crystal array in SOI platform having hexagonal periodicity with a ring defect incorporated along with two bus waveguides is conceptualized and realized for various applications of optical communication, sensing etc. The ring structure filters out a resonant wavelength from the spectrum carried to it through the line defect where the resonated peak is determined by the effective ring radius. The hexagonal architecture enables more coupling length than an ideal ring structure which helps in better intensity accumulation. The resonant peak exhibited at 1554nm in simulation, which is observed in the optical characterization at 1543nm. This is attributed to the fabrication tolerance.

Keywords: Photonic Crystal, Ring Resonator, Integrated Optics

1. INTRODUCTION

The area of integrated optics is getting matured by the advent of high resolution fabrication technologies in research and the well-established routes of submicron electronics foundry. Among them, Photonic Crystals are one promising area where, scope of fundamental studies such as the light matter interaction[1,2,3,4], few photon studies[5,6,7] etc and application diversity covering sensors[8,9,10], filters[11], sources[12], optical buffers[13], switches[14], are being addressed. Future systems are expected to replace many electronic techniques due to the inherent bandwidth, high sensitivity, immunity towards electromagnetic interference etc of integrated optical devices. Functionality and compactness are the key features of photonic crystal based photonic integrated circuits. Ring resonators are frequency dependent and frequency sensitive devices providing functionality independent of power levels involved, and expected to be more sensitive, efficient and compact[10,15].

In this work we are demonstrating a basic design of Photonic crystal hexagonal ring resonator coupled with two bus waveguides. The device is intended to work in the communication band of optical spectra with center wavelength at 1550nm. Grating couplers with periodicity of 630nm and etch depth of 70nm is embedded on the same device layer along with tapered strip waveguides and 90^0 bends to facilitate i/p and o/p coupling of the PCRR device. The device is also demonstrated by adding free standing micro cantilever structure by etching underneath BOX layer for deflection sensing or tuning applications.

2. DESIGN AND SIMULATION

The Photonic Crystal device is designed using the commercial packages such as RSOFT-Fullwave and Lumerical FDTD. We chose to work at 1550nm wavelength as center frequency due to the intended applications of filtering, WDM and DWDM in optical communication field and the easy availability of sources for optical characterization. With a line defect, by removing the holes along a line completely, the structure supported two guided modes to pass through as in Fig 1 and the spectrum allowed through is shown in Fig 2. In the design of ring resonator, a hexagonal ring with the two edges facing two bus waveguides is incorporated with a spacing of two consecutive lines of holes giving a separation of 1065nm between the ring defect and line defects. This design is similar to that shown by Lee et.al[16]. The device is optimized with a lattice constant 'a' 410nm, hole radius 'r' 120nm, thickness of Silicon slab 't' 220nm to have band gap at 1240nm-1600nm. The design of the ring resonator is given in Fig 3. In simulations we noticed that the ring is resonating at a frequency ~1554nm as shown in Fig 4. This can be considered as the condition of zero applied force[16], when this PCRR is considered at the base of the cantilever. In simulations, this ring is having a Quality Factor (Q) of 856.

*yadunath.tr@gmail.com;phone:+91-9535773188;

Silicon Photonics XII, edited by Graham T. Reed, Andrew P. Knights, Proc. of SPIE Vol. 10108, 101081J
 · doi: 10.1117/12.2252702

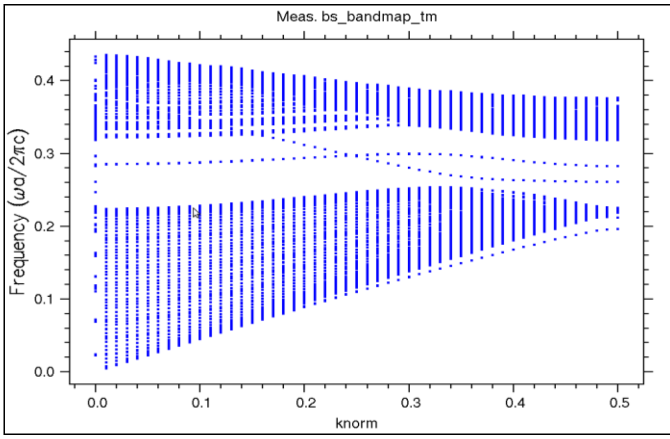


Figure 1. Guided modes in a line defect

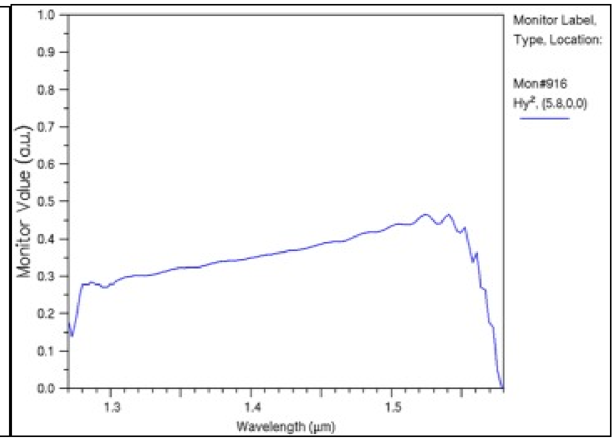


Figure 2. Spectrum transmitted through line defect

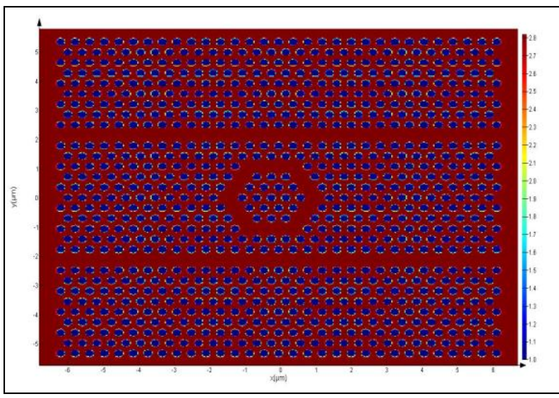


Fig 3. Photonic crystal ring design

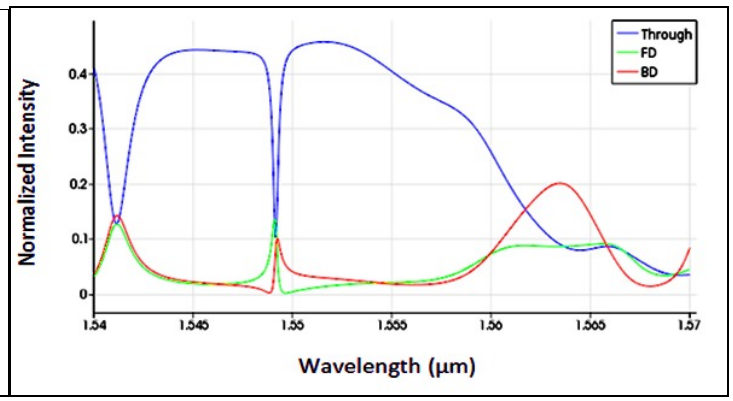


Fig 4. Ring Resonator Resonating at ~1554nm

3. FABRICATION

Fabrication of the device was carried using the Nano fabrication facilities available in National Nano Fabrication Centre (Centre for Nano Science and Engineering, Indian Institute of Science, Bangalore). The fabrication process was initially optimized by fabricating the individual components separately. The optimized process flow is given in Fig 5. Fabrication is carried out using Raith E-line Electron beam lithography facility. The device platform is Silicon-On-Insulator (SOI) with device layer thickness of 220nm. PMMA A4-950 spin coated at 6000rpm is used as photoresist. Combination of dil.MIBK and IPA in the ratio 3:1 is the developer used. The developing time is 35sec.

Lithography followed by reactive ion etching (RIE) and wet etching are the processes employed in the fabrication. RIE is performed using Oxford Instruments Plasma Technology: ICP-RIE (Fluorine).The gases used for RIE process are SF_6, C_4F_8 and ChF3. Besides, isotropic etching of underneath SiO_2 is carried out using dil. HF, followed by critical point drying (CPD) to release the complete device. The SEM image of grating coupler is shown in the Fig 6. Grating couplers with periodicity of 630 nm and etch depth of 70nm is fabricated on the same device layer along with tapered strip waveguides of width 500nm and depth 220 nm. The waveguides are bend in 90^0 in order to facilitate input and output coupling of the device from fibers at opposite sides. Fig.7 shows PCRR with hole diameter 253nm and depth 220nm. For the fabrication we considered the photonic crystal device over a silicon cantilever. This is to check the feasibility of such a configuration as shown in Fig.8 presented in literatures[10, 16]. Cantilevers are fabricated by etching underneath BOX layer of 2µm thickness. Cantilever with width 15µm, length 50µm and thickness 220nm is fabricated. The SEM images of the fabricated complete device and the hanging cantilever with photonic crystal ring resonators are show in Fig 9 (a) and (b) respectively.

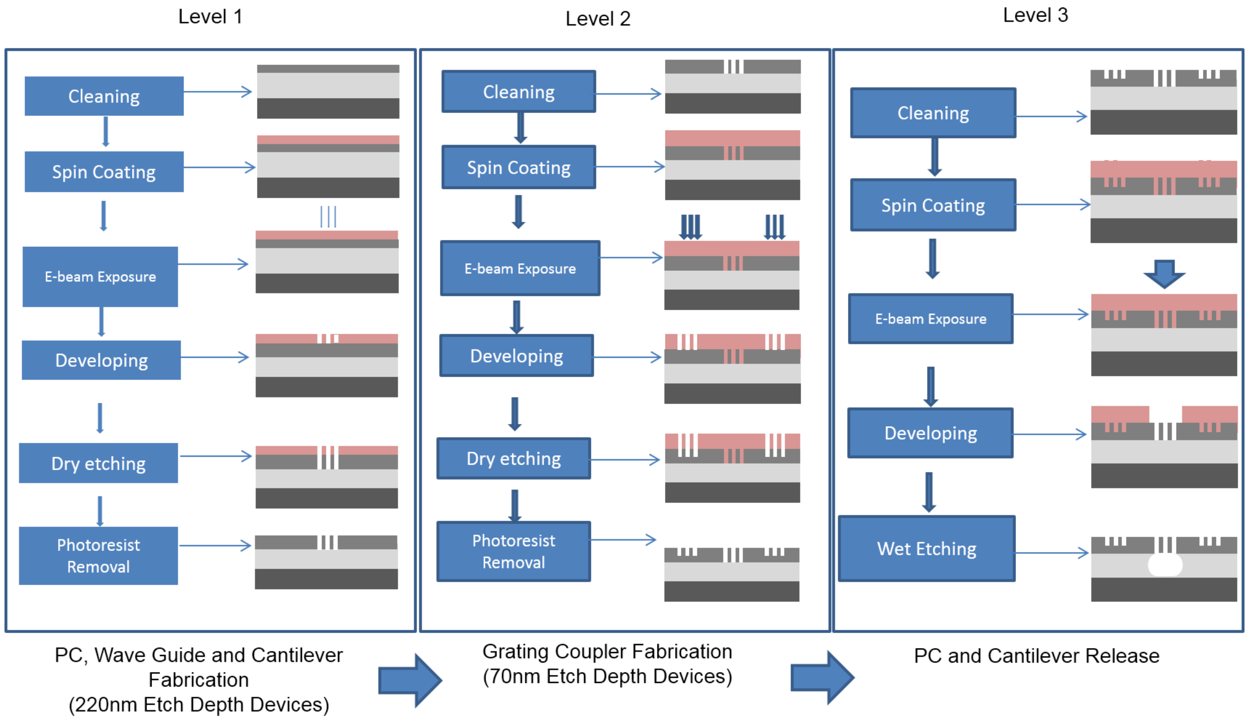
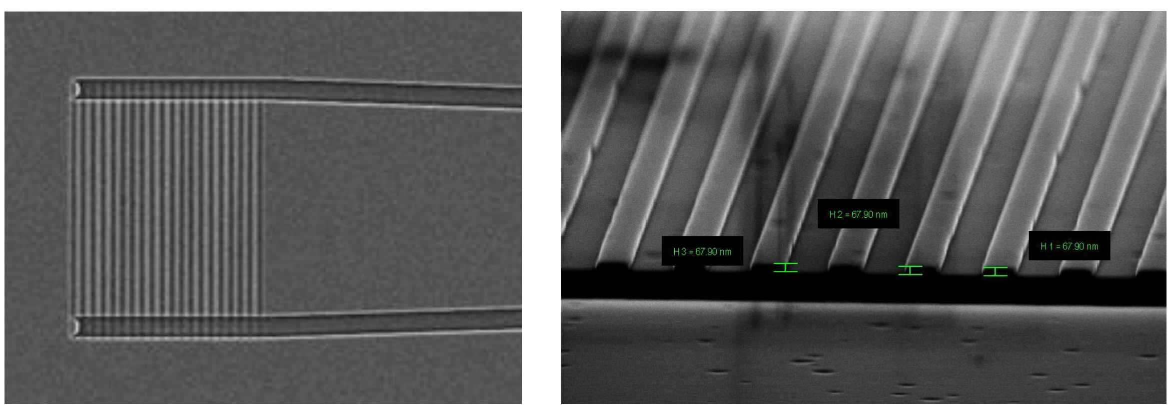


Fig 5. Fabrication process flow



(a) (b)

Fig.6 Grating coupler, (a) Top view, (b) Cross sectional view

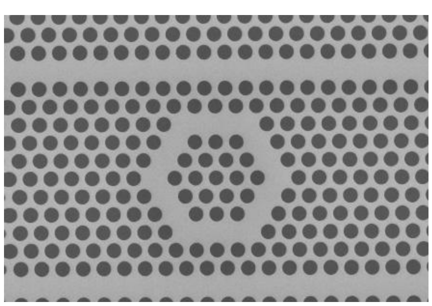


Fig 7. Photonic Crystal Ring Resonator (PCRR)

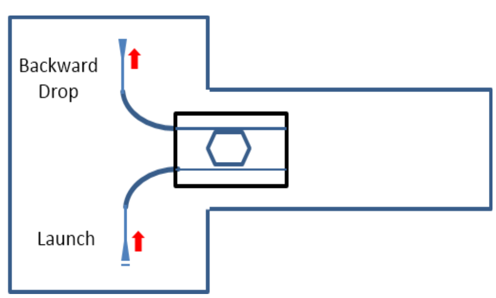
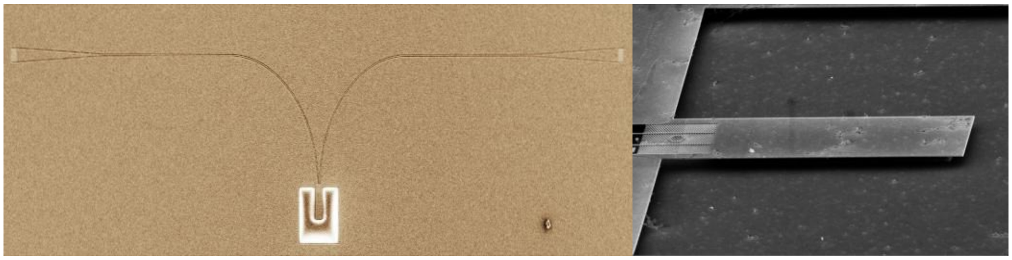


Fig 8. Schematic of Photonic Crystal Ring Resonator on cantilever



(a) (b)

Fig.9: (a) False colored SEM image of completed fabricated device. (b) Released cantilever structure with photonic crystal

4. CHARACTERIZATION

The schematic of characterization setup is shown in Fig 10.The broadband ASE source operating in C and L band (OZ Optics limited) having high frequency spectral stability ensures better measurement and sensing. Optical spectrum analyzer (Yokogawa AQ6370) with high wavelength resolution of 0.02nm enables fast measurement. Light from broadband source is launched into the device using launching fiber and fabricated input grating coupler. The PCRR resonates at a particular wavelength that is measured using optical spectrum analyzer (OSA) with the help of fabricated output grating coupler and collecting fiber. Both fibers are single mode polarization maintaining optical fiber which are inclined at 10^0 into the grating in order to provide efficient coupling. The resonant peak exhibited at ~1554nm in simulation is observed at 1543nm in optical characterization as shown in the Fig 11. The variation is owing to the cumulative effect of various fabrication tolerance.

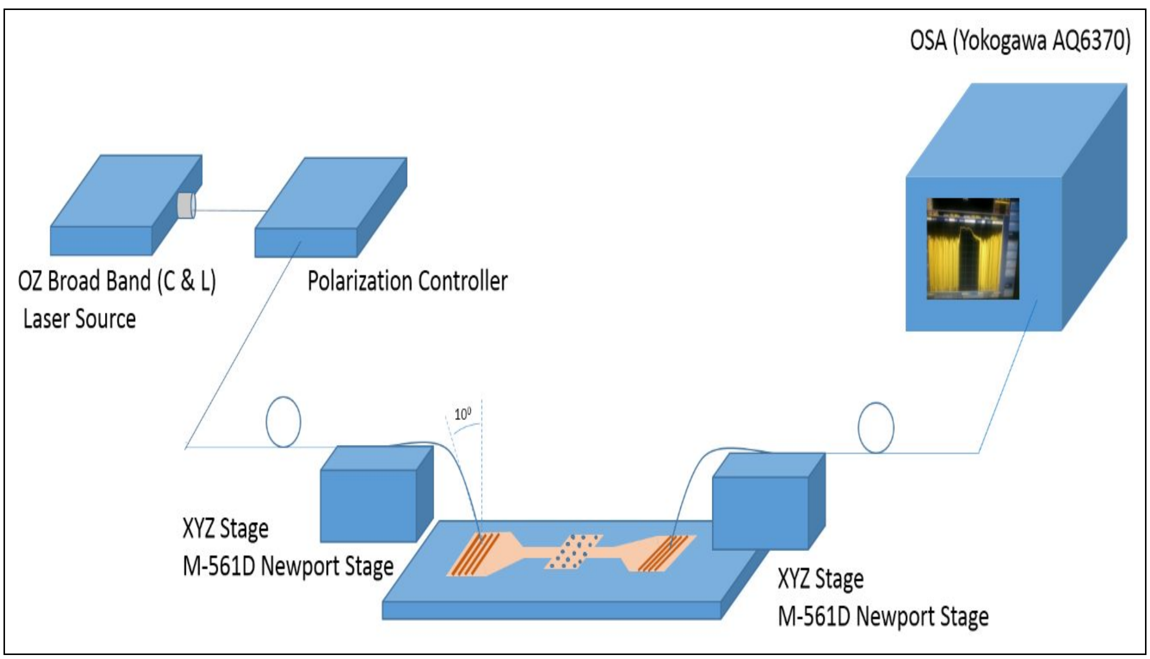


Fig.10 Schematic of optical characterization setup

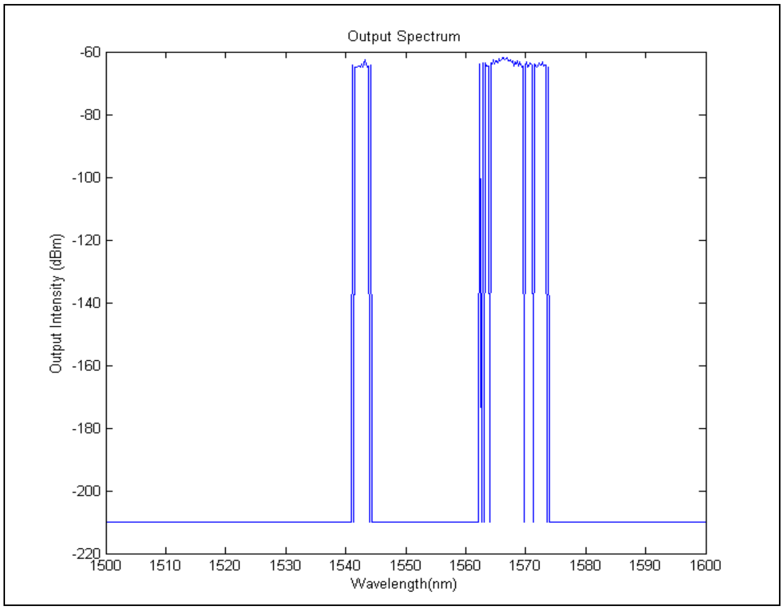


Fig 11. PCRR Resonating at 1543nm at no force condition

CONCLUSION

We have successfully fabricated and demonstrated a PCRR structure on a 220nm thin Si cantilever which can be used for various sensing applications. This PCRR device is designed for optical communication wavelength, hence can be extended to use as opto-mechanical switches or for filtering applications in various communication systems when suitable actuating schemes are followed. Optical characterization of the fabricated device yielded good agreement with the simulation results within the fabrication tolerance

ACKNOWLEDGEMENT

We would like to thankfully acknowledge the funding agency IRDE, Dehradun and CeNSE, IISc for providing the fabrication facilities.

REFERENCES

[1] Burresi, M., Kampfrath, T., van Oosten, D., Prangsma, J. C., Song, B. S., Noda, S., & Kuipers, L. "Magnetic light-matter interactions in a photonic crystal nanocavity," Physical review letters, 105(12), 123901, (2010).
[2] Mahmoodian, S., Prindal-Nielsen, K., Söllner, I., Stobbe, S., & Lodahl, P., "Engineering chiral light–matter interaction in photonic crystal waveguides with slow light," Optical Materials Express, 7(1), 43-51 (2017).
[3] van Oosten, D., Burresi, M., Kampfrath, T., Prangsma, J. C., Song, B. S., Noda, S., & Kuipers, L., "Light-matter interaction in photonic crystal nanocavities," In Transparent Optical Networks (ICTON), 2011 13th International Conference on (pp. 1-1). IEEE, (June 2011).
[4] Andreani, L. C., & Gerace, D., "Light–matter interaction in photonic crystal slabs," Physica status solidi (b), 244(10), 3528-3539, (2007).
[5] Loo, V., Arnold, C., Gazzano, O., Lemaitre, A., Sagnes, I., Krebs, O., & Lanco, L., "Optical nonlinearity with few-photon pulses using a quantum dot-pillar cavity device," In Lasers and Electro-Optics Europe (CLEO EUROPE/IQEC), Conference on and International Quantum Electronics Conference (pp. 1-1). IEEE, (May 2013)

[6] Majumdar, A., Rundquist, A., Buckley, S., Kim, J., Wu, S., Bajcsy, M.,& Vuckovic, J., "Towards few-photon optoelectronics with photonic crystal devices," In Laser Science, Optical Society of America, (pp. LTu4H-3). (October 2014).

[7] Bose, R., Sridharan, D., Kim, H., Solomon, G. S., & Waks, E., "Low-photon-number optical switching with a single quantum dot coupled to a photonic crystal cavity," Physical review letters, 108(22), 227402. (2012).

[8] Krause, A. G., Winger, M., Blasius, T. D., Lin, Q, & Painter, O., "A high-resolution microchip optomechanical accelerometer," Nature Photonics, 6(11), 768-772, (2012).

[9] Lambrecht, A., Hartwig, S., Schweizer, S. L., & Wehrspohn, R. B., "Miniature infrared gas sensors using photonic crystals," In Integrated Optoelectronic Devices 2007 (pp. 64800D-64800D). International Society for Optics and Photonics. (February, 2007).

[10] T. Srinivasulu et.al, "Photonic crystal based force sensor on silicon microcantilever," IEEE Sensors 2015 –14 th IEEE international conference on Sensors, Busan, S. Korea, (1-4 Nov 2015)

[11] Qiang, Z., Zhou, W., & Soref, R. A., "Optical add-drop filters based on photonic crystal ring resonators. Optics express," 15(4), 1823-1831, (2007).

[12] Park, H. G., Kim, S. H., Kwon, S. H., Ju, Y. G., Yang, J. K., Baek, J. H, & Lee, Y. H, "Electrically driven single-cell photonic crystal laser. Science," 305(5689), 1444-1447, (2004).

[13] Zhai, Y., Tian, H., & Ji, Y., "Slow light property improvement and optical buffer capability in ring-shape-hole photonic crystal waveguide," Journal of Lightwave Technology, 29(20), 3083-3090. (2011).

[14] Yu, Y., Xue, W., Hu, H., Oxenløwe, L. K., Yvind, K., & Mork, J., "All-Optical Switching Improvement Using Photonic-Crystal Fano Structures," IEEE Photonics Journal, 8(2), 1-8, (2016).

[15] D W Prather et al, "Photonic Crystal Structures and Applications: Perspective, Overview, and Development," (invited paper), IEEE Journal of special topics in quantum electronics, Dec 2006

[16] Mai, T. T., Hsiao, F. L., Lee, C., Xiang, W., Chen, C. C., & Choi, W. K., "Optimization and comparison of photonic crystal resonators for silicon microcantilever sensors," Sensors and Actuators A: Physical, 165(1), 16-25, (2011).