Optimized Design of an Optomechanical Resonator as Wavelength Filter

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Abstract

Electro- magnetic manipulated mechanical actuation of Photonic crystal cavity for wavelength selection is presented. Two high Q, 1-D photonic crystal cavities coupled by the optical forces is presented. The beam widths are optimized through simulation, to produce symmetric and anti symmetric cavity modes, with spacing between the beams being the controlling parameter for wavelength selection. Through simulation, optimization of process step for release of the beam pair, for micro fabrication on silicon wafer is presented.

Keywords: Optical force, Micro-fabrication, Cavity modes, Photonic crystal, Resonator

I. Introduction:

Nano-photonic devices find wide application in energy efficient demands of today's technology. Nano-opto-mechanics have gained significance as it facilitates electromagnetic manipulation of silicon based nano-devices such as disc resonators [1], zipper cavity resonators [2] etc. High Q, low mass and compact size adds to utility of 1-D photonic crystals (PhC) for opto-mechanical applications. The work presents simulation of, cavity modes and micro-fabrication process steps of two high Q, 1-D photonic crystal cavities coupled by the optical forces. The symmetric and anti-symmetric cavity modes, that results respectively in attraction and repulsion of the nano-photonic beams is made use of in wavelength filtering and optical trapping of biomolecules, to name a few. Mechanical actuation of photonic crystal cavity for wavelength selection by electromagnetic manipulation is presented. Time duration of wavelength selection also when controlled, this can be used for simultaneous wavelength selection and time chipping.
Section-2 presents theory of operation of the resonator pair that result in even and odd cavity modes. Section- 3 presents design and dimensions of the resonator pair. Section-4 gives details of micro-fabrication process steps and optimization of the release step of the resonator pair.

II. Theory of operation:

The optical forces developed and the resulting displacement of the nano-beams based on equation (1) [3] is utilized in the FEM simulation of the zipper cavity resonator.

$$F_{optical} = \frac{\frac{d\omega}{dx} U}{\omega} \qquad (1)$$

Where, g_{om} = (dω/dx) is the opto-mechanical coupling coefficient and U is cavity energy. ω is the Eigen frequency of the waveguide system and x the distance of separation between the beams.

According to [3-4], two identical waveguides when brought together result in coupling of Eigen modes and formation of anti symmetric and symmetric modes. The corresponding Eigen frequencies being $\omega_{-} = \omega_0 + \Delta\omega_{-}(x)$ or $\omega_{+} = \omega_0 + \Delta\omega_{+}(x)$ respectively.

III. Design of Opto-mechanical Resonator:

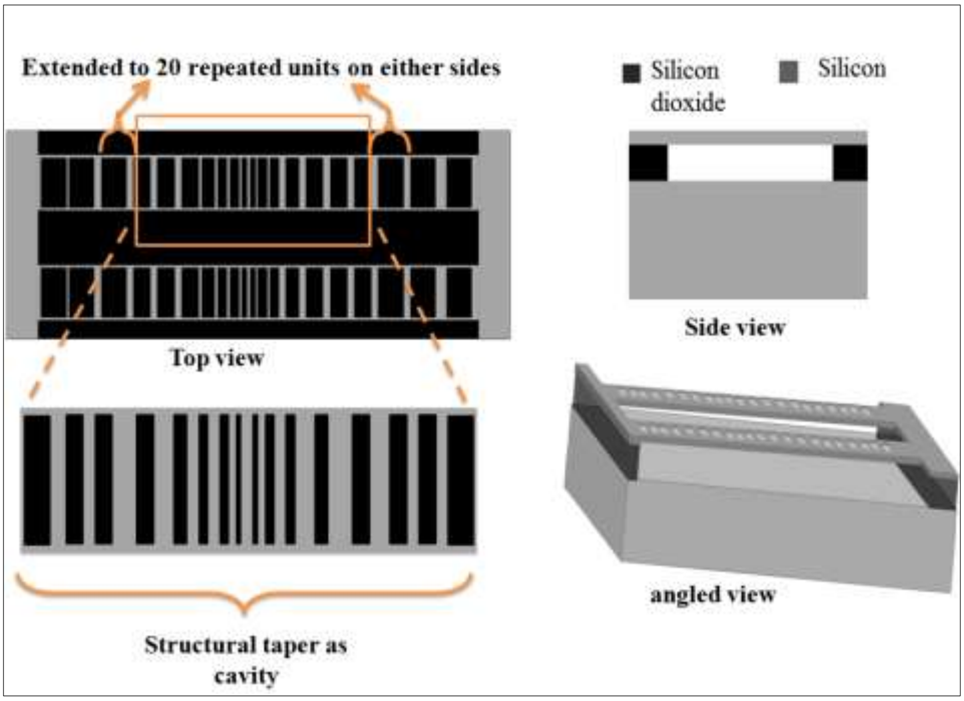

Fig.1 Schematic of the design dimensions

The resonator pair has two parallel beams, each beam being 24 micrometers long with 20 periods of rectangular holes on either sides of a cavity consisting of seven rectangular holes tapering in terms of length and spacing. One set of beams are 450nm wide and have a hole width of 400nm. On the other hand, the next beam pair is 550nm wide with 400nm hole width. Fig.1 shows schematic of the resonator pair design.

IV. Patterning of SOI wafer:

RCA cleaned SOI wafer is oxidized up to 500nm thickness. Pattern is transferred to Sio_2 hard mask using e-beam lithography and reactive ion etching (RIE). The 260nm device silicon layer of the SOI wafer undergoes etching using RIE. This is followed removal of by wet etching of the BOX layer to the release the beams. The process flow is illustrated in Fig.2.

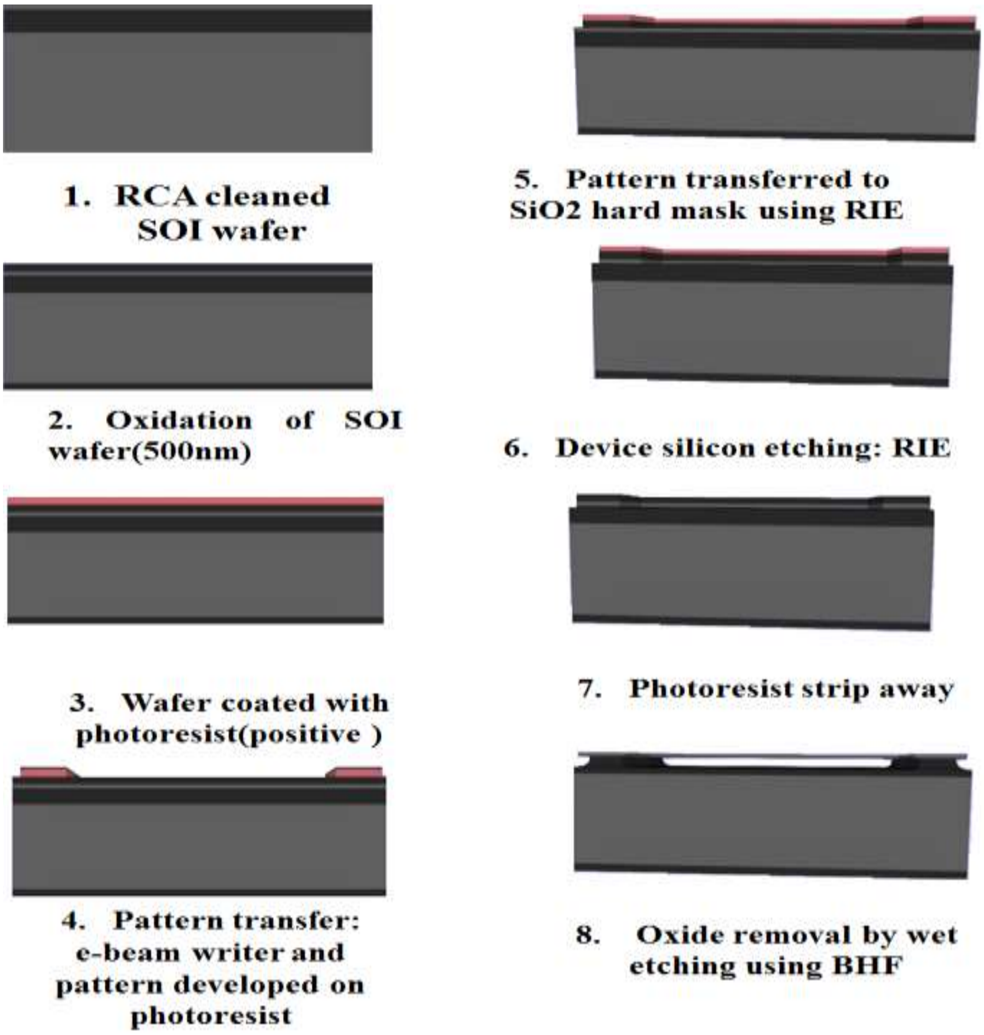

Fig.2 Fabrication process steps of the resonator pair

IV (A) Details of the release step

As Buffered Hydrogen Fluoride (BHF) etching does not affect Si device layer, the dimensions of the device are not likely to vary. Time of etch is optimized based on the device length and such that it should just etch away the SiO_2 underneath and release the device (resonator pair), still leaving behind enough SiO_2 providing the required anchor on either sides. Etch rate of SiO_2 in BHF is 80 nm/min [5].The parameters used for virtual prototype of the release step are as follows. Type of etching is Isotropic etching (selective etching of SiO_2). Maximum depth of SiO_2 to be etched is 500 nm each. Virtual prototyping of device was done using Intellifab. The optimized release step of the resonator pair without collapse of design is given in Fig.3.

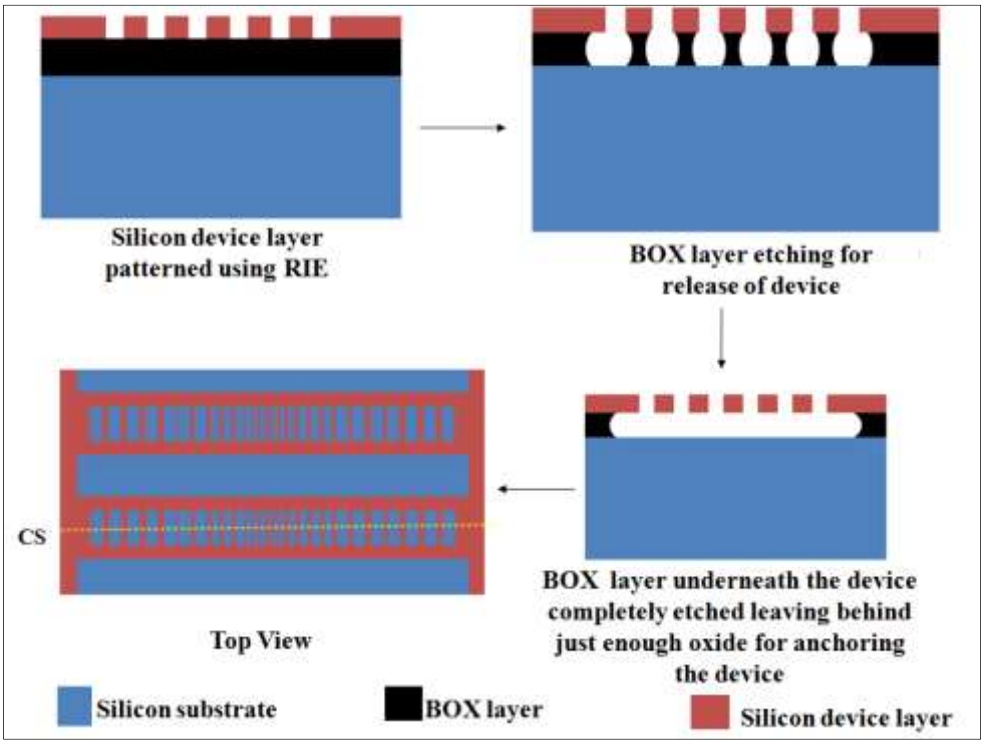

Fig.3 Fabrication process steps of the resonator pair

V. Results and Discussions:

As per intellisuite, structure after wet etching of 500nm SiO_2 hard mask using BHF is given below in figure 4. This shows release of the device with enough (3µm deep) buried oxide (BOX) layer left providing the required anchorage to the device. During the optimized release step, the concentration of HF used is 13.34% at a temperature of 21^0C. Time required to etch away SiO_2 is found to be 6.25 minutes.

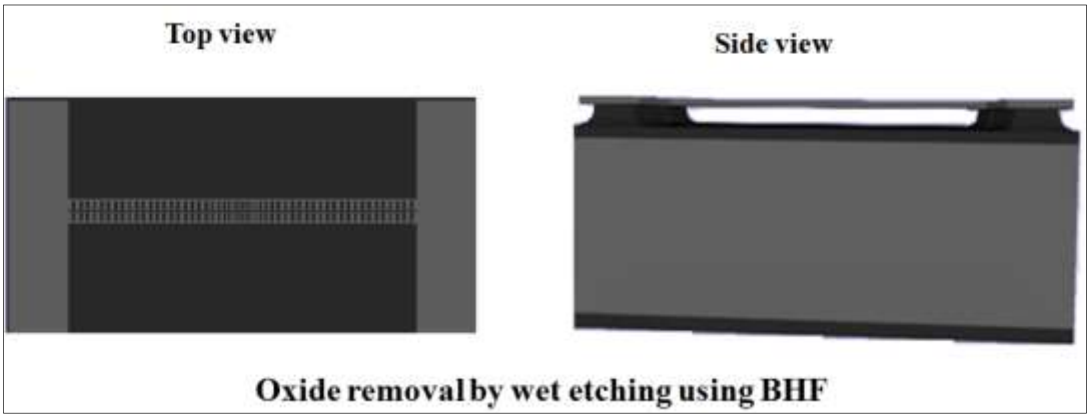

Fig.4: Top view and side view of the final device after release step

The mode profiles of even and odd mode at resonance are as in Fig. 5(a) & (b). Comsol MultiPhysics software is used to perform the 2-D simulation. Beams that are 450nm wide with hole width of 400nm, gives even modes at resonance. On the other hand, the beam pair 550nm wide with 400nm hole width, gives odd modes at resonance.

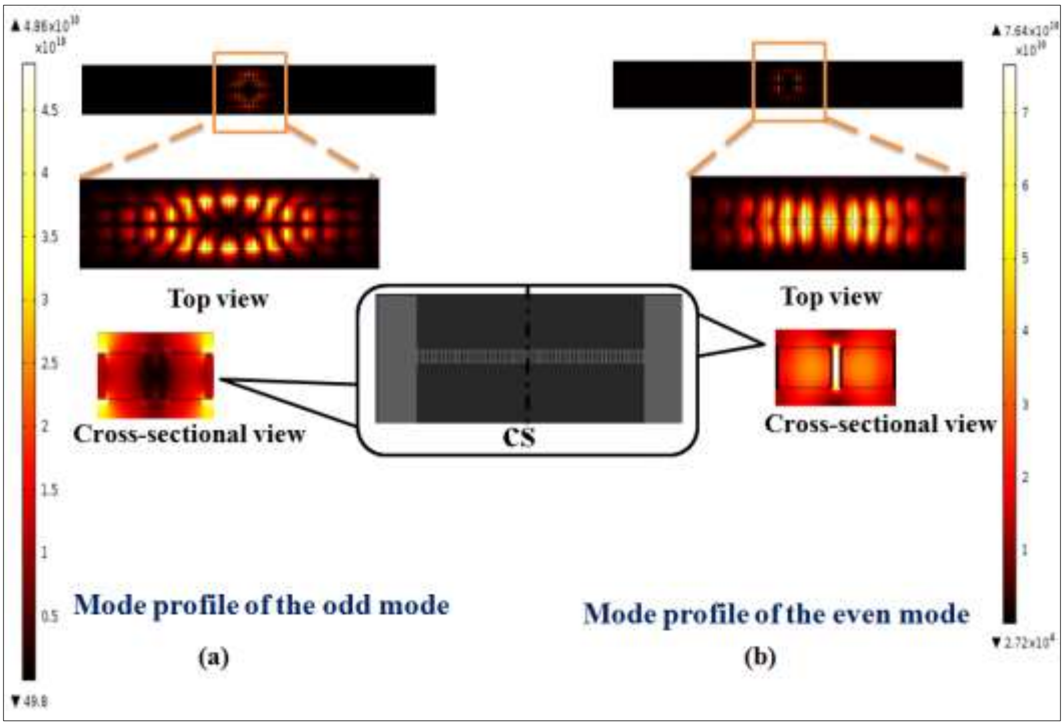

Fig.5 Mode profile of (a) odd mode and (b) even mode

Wavelength tuning curves are shown in Fig. 6(a) & (b). Anti symmetric mode shows wavelength selection from 1550nm to 1660nm for a spacing of 20 to 80 nm respectively between the resonator pair. Symmetric mode shows wavelength selection between 1520nm and 1570nm(C-band), for a spacing of 20 to 80 nm respectively between the resonator pair and is hence can be used for wavelength filter applications.

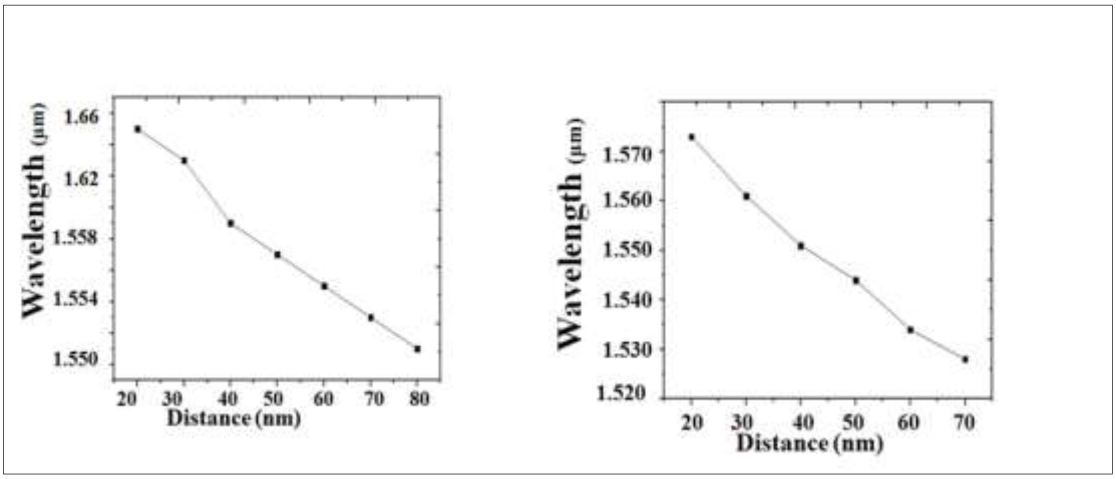

Fig.6 wavelength tuning with displacement (a) Anti symmetric & (b) symmetric modes of the resonator pair

VI. Conclusion

Mechanical actuation of Photonic crystal cavity using optical forces for wavelength selection is presented. Beam pair 450nm wide with hole width of 400nm and those 550nm wide with 400nm hole width gives even modes and odd modes at resonance, respectively. The optimized beam widths that produce symmetric and antisymmetric cavity modes, results in attraction and repulsion of the beam pair respectively, where the former resulted in wavelength selection in the intended C-band. Process step for release of the beam pair is optimized as 6.25 minutes of BHF etch of the BOX layer.

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