Engineering Defect Modes in Symmetry Reduced 1D Photonic Crystal Nanobeam Waveguide

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***Abstract*— In this paper, nanobeam cavity studies were performed on low-symmetric 1D photonic crystals. An eligible comparison between low-symmetric structure and a regular cavity is held. Due to nature of the resonance, reduced symmetry is expected to decrease confined resonance field; however, authors focused on the tuning of the extra parameters arisen from degenerated symmetry and promising results are obtained. Quality factor enhancement with respect to varying structural parameters is observed. To the best of authors' knowledge, this is the first time that the cavity is enhanced with controlled low symmetric structures. Also, mode profile variation and spectral response shift due to structural parameters are analyzed. Results hold potential for further integrated photonic device research such as filtering, optical memory units, quantum cryptology.**

1. INTRODUCTION

It is known that in the photonic crystal (PC) structures emission of light can be partially suppressed by the photonic bandgap effect. Additionally, if an irregularity occurs in the periodic refractive index modulation of the PC lattices, photonic nanocavity is produced. In last decade for many type of researches, defect mode modifications are performed as the cavity region tailoring which is created in a Bloch structure [1]. Conventionally, mirror segments of the structure create photonic bandgap and modification of the cavity region reduces loss due to high reflection [1-2]. In recent years, low symmetric 2D photonic devices have become a necessity because of their different electrical and optical properties in different propagation directions of the structure [3]. At the same time, studies on the materials used in the design of low symmetric photonic devices are continuing [4-6]. In this manuscript a brand new approach is proposed to manipulate optical modes trapped in the defect. A classic silicon-on-insulator (SOI) 1D PC cavity structure is regenerated with the same waveguide, lattice constant and filling ratio. Differently, new design deploys low-symmetric elements inside the unit cells. It is clear to see that the recombination of the resonant mode reflections would reduce due to decreased symmetry, however; additional structural parameters add at least one more degree of freedom to modify the cavity structure. Conventional nanobeam cavity structure and generated low symmetric cavity structure is seen in Fig. 1. In the figure the parameter "θ" shows elevation angle of the air hole with smaller radius with respect to the bigger one. "r_1" is the radius of regular unit cell air hole and "r_2" and "r_3" are radii of the bigger and smaller air holes in low symmetric design, respectively. To make an accurate comparison and well define the figure of merit of the work, the structure with same filling ratio with the conventional design is analyzed to have similar low and high refractive index transition. Thus, stimulating the same spectrum with the conventional design is aimed. Numerical analyses are performed using the finite-difference-time-domain method (FDTD) [7].

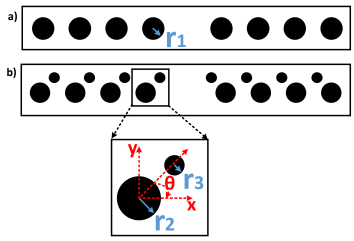

Fig. 1 a) conventional cavity design and b) proposed low-symmetric cavity design

$$r_1^2 = r_2^2 + r_3^2 \qquad (1)$$

When the Eq. 1 is assured, the effective indices and so dispersion responses of the regular and low symmetric structures would be similar. This phenomenon is observed and shared in the Fig. 2.

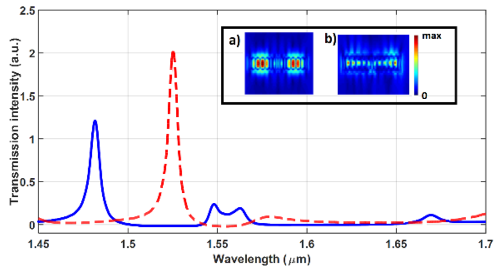

Fig. 2 Transmission graphics of conventional cavity (solid line) versus low-symmetric cavity (dashed line) when θ =0

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Also, in the figure, mode profiles of the conventional cavity and low-symmetric structures (θ=0°) are shared as inset *a* and *b*, respectively. It is seen from the inset that coupled modes are similar when the elevation angle θ=0° for the low-symmetric structure.

As expected, when the symmetry is reduced with the increasing angle the quality factor reduces dramatically, however, if the elevation angle of the smaller air hole continues to increase; unexpectedly, the quality factor starts to increase. Moreover, as it is seen in Fig. 3, the quality factor of the low symmetric structure becomes even two times higher than the regular cavity, depending on the θ variation. In the figure shaded region shows quality factor increment. Here one should note that a simple optimization is held before the simulations for the conventional cavity.

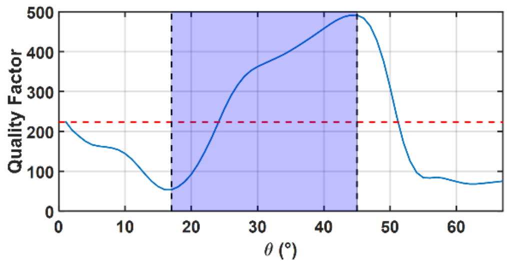

Fig. 3 The Quality factor of the low-symmetric cavity with respect to θ parameter (solid line) and quality factor of the regular cavity (dashed line).

The results are highly interesting because increment of the overlapped fields is related to the spatial symmetry of the medium. Therefore, cavity enhancement is always assured with fully symmetric, refractive index transition engineering for 1D cavity structures. To the best of authors' knowledge, this is the first time that the cavity is enhanced with controlled low symmetric structures. Another elucidative result is that, as mentioned above, the spectral response of the cavity changes with parameter θ variation. In Fig. 4, it is clearly seen that

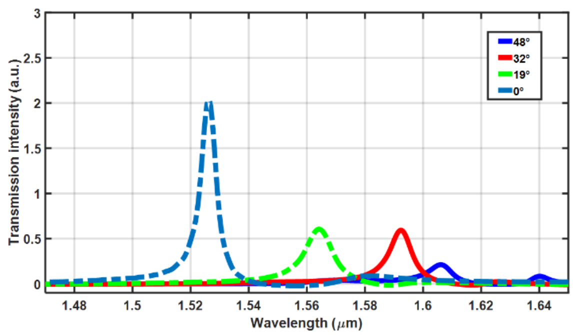

Fig. 4 Spectral shift of the cavity for θ=0°, θ=19°, θ=32°, θ=48° from left to right, correspondingly.

cavity frequency is increasing proportionally to θ value. Because the cavity tuning is not limited to within the defect, the penetration or reflection mechanisms of the emissions in the cavity are very different between regular and low-symmetric designs. Mode profiles of reduced symmetries are shared in the Fig. 5. It is seen in the figure that confined modes of the low-symmetric structures with high θ values drastically differ than regular cavity mode which shared in Fig. 2. With decreasing symmetry the confined mode profile obviously alters.

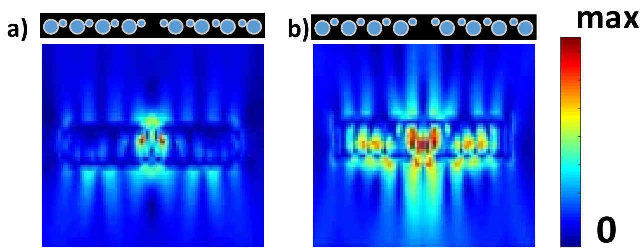

Fig. 5 a) Low-symmetric (θ =22°) with Q=350 b) Low-symmetric (θ =38°) with Q=500

In conclusion, in the present research low-symmetry effect on 1D cavity is investigated. On the contrary to former cavity studies which provide trapping with emissive region tailoring, quality factor enhancement is obtained with reduced symmetry for the first time. Investigations show varying structural parameters would cause spectral shift and manipulate the mode profile of the cavity. Results are promising for further studies targeting designs of filtering, mode conversion, and optical memory units.

2. ACKNOWLEDGEMENT

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