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Dynamic Wavelength Conversion in Photonic crystal slab Waveguide

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Abstract: Photonic crystals (PhC) are one of the excellent elements in modern optics for guiding and confining light on the order of the optical wavelength due to its periodic structure. In this paper, we report the dynamic wavelength shift of 5.32 nm corresponding to the blue shift. This is observed due to the slow light effect in the considered Si photonic crystal waveguide.The wavelength of light is shifted when the index of the medium through which it propagates changes instantaneously called as dynamic wavelength conversion (DWC)

OCIS codes: (130.5296)Photonic crystal waveguides; (230.7400) waveguides; (260.2030) Dispersion;

1. Introduction

The interest in manipulating the speed of propagating light has increased dramatically in recent years for applications such as optical delay lines, optical buffers, and all-optical switches. Slow light produces strong light-matter interaction due to the small group velocity which enhances absorption, non-linearity and gain per unit length that benefits numerous optical devices such as detectors, amplifiers and lasers. In recent years, the engineered slow light photonic crystals (PhC) have drawn a great deal of attention by researchers due to the flexibility in design and compatibility for on chip applications. An important application of slow light is wavelength conversion which can be achieved by parametric four wave mixing and Kerr based cross phase modulation in fibers [1] and can be induced optically, electrically and mechanically in microdevices. The wavelength of light is shifted when the index of the medium through which it propagates changes instantaneously called as dynamic wavelength conversion (DWC) and was first discussed by Yanik and others [2,3].DWC has a drawback of small wavelength shift which strongly depends on the change in index. To overcome this problem trajectory dependent DWC in photonic crystal waveguide (PhCW) was introduced [3] but have a low value of wavelength shift. In this paper, lattice shifted PhCW has been used to generate a propagating refractive index due to the plasma dispersion of free carriers induced by two photon absorption (TPA) leading to the dynamic wavelength conversion.

2. Structure Design

In this paper,we consider aphotonic crystal structure composedof triangular lattice arrangement of air holes in silicon slab of thickness 210 nm. The radius of air holes has been taken as 120 nm with a lattice constant of 420 nm. Initially, a W1 waveguide has been created. Then the first row of air holes has been displaced along the positive x axis by Δx in order to obtain a slow light structure as shown in figure 1.

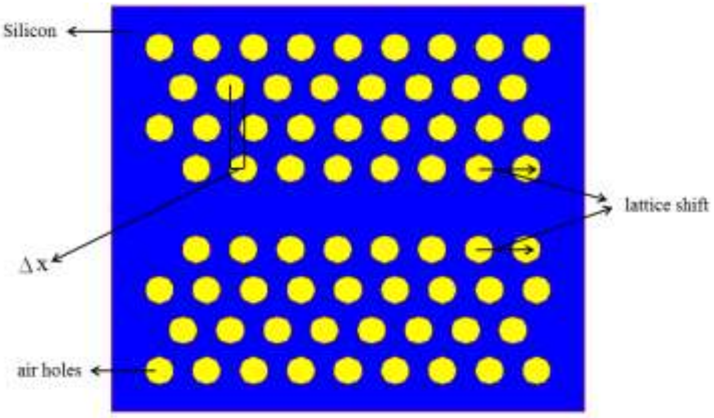

Fig.1 Schematic representation of slow light structure showing dynamic wavelength shift

Figure 2(a) shows the dispersion relation with the displacement of the first row of air holes for various values of normalized displacement Δx/a. Figure 2(a) showsthat with the change in the displacement of first row of air holes the propagating mode shifts towards the higher frequency. Figure 2(b) shows the variation of the group index with normalized frequency for various values of Δx/a. It indicates that with the displacement of first row of air holes the group index decreases. To obtain the optimized value of Δx/a, the group velocity dispersion (GVD) has been calculated. From the analysis of GVD and group index, the optimized value of Δx/a = 0.285has been obtained, that corresponds to the high value of group index and low value of GVD, which are the basic requirements for the slow light structure.

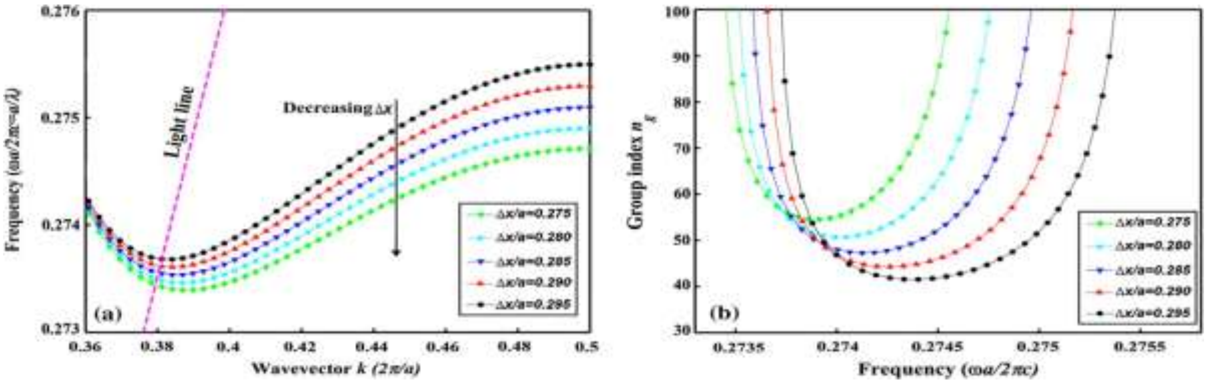

Fig.2 (a) Dispersion relationshowing the variation of the propagating modewith frequency for various values of Δx/a

Fig.2 (b)variation of group index(n_g) with frequency for various values of Δx/a

After the optimization of the PhC structure thetwo co-propagating pulses of slightly different wavelengths have been launched in the PhCW. Out of the two pulses, one is the controlpulse having high power and other isthe signal pulse with low power. When control pulse propagates through slow light structure it gets spatially compressed and its peak intensity enhances which causeslarge TPA, generation of free carriers and reduction of the refractive index. If the signal pulse overlaps with the control pulse, its wavelength shifts.

The corresponding wavelength shift is given by

$$\Delta\lambda = \frac{\lambda\xi}{n}\int_0^T \frac{\partial}{\partial t}\Delta n(z,t)dt \qquad (1)$$

where, λ is the wavelength, T is interaction time of two pulses andξ is the dependence of normalized band frequency on normalized change in refractive index, defined as

$$\xi = \frac{n}{\omega}\left(\frac{\partial\omega}{\partial n}\right) \qquad (2)$$

where *n* is the refractive index of the medium and ω is the frequency with in the band gap range [3-5].The refractive index of Si changes with carrier density as

$\Delta n = KcNc\ (t)$ (3)

where, $Kc=1.35x10^{-27}m^3$is free carrier dispersion coefficient andNc (t) is given by

$$N_c(t) = \frac{\beta_{TPA}P_{in}^2T_0}{2h\nu_0A_{eff}^2}\sqrt{\frac{\pi}{8}}(1+erf(\frac{\sqrt{2}}{T_0}t)) \qquad (4)$$

For Si,$\beta_{TPA} = 5x10^{-12}$m/w, P_{in} = 22 watt, T_0=5.6 ps, Aeff = 0.14μm^2. in a slow light structure β_{TPA} and K_c are replaced by $\beta_{TPA}S^2$ and K_cS respectively, where S is the slow down factor equal to the ratio of the group index n_g over the silicon refractive index. On solving equation (4) the carrier density is obtained as $N_c=7.07x10^{24}$ for t=30ps. The maximum change in refractive index for the optimized PhC structure has been obtained as Δn=0.0096.By using equations (2), (3), and (4) in equation (1) the wavelength shift Δλ has been calculated to be 5.32nm which is more than that as reported earlier [3]. This very large value of wavelength shift towards the blue region, which can prove advantageous in demultiplexing and wavelength conversion. Hence it has been concluded that proposed structure can be used for DWC and temporal changes in index of the medium.

3.Conclusion

In this paper we have proposed a design for dynamic wavelength conversion in photonic crystal waveguide. The structure composed of triangular lattice arrangement of air holes in Si slab has been considered. The dynamic wavelength conversion due to the slow light effect in the optimized structure leads to blue shift in the wavelength. Hence the proposed structure makes a promising platform for its practical applications in wavelength conversion.

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