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Optically Tuning of Defect-Induced Pass-Band in Photonic Crystal Waveguide

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1. Introduction

Recently, transmission characteristics of a photonic crystal waveguide with periodical air cavities and a finite defect length is reported [1], and a thermally tunable optical waveguide filter has also been reported [2]. However, little has been reported on the optical tuning mechanism of the defect-induced transmission frequency (DITF) and optically tunable filters. Tunable waveguide filters with a narrow bandwidth and a wide tuning range are useful devices for a WDM (wavelength-division-multiplexing) optical communication system.

We now report the simulation results of optical tuning characteristics of defect-induced pass-band in the photonic crystal waveguide including the free-carrier effect by illumination of short wavelength light.

2. Simulation model and tuning mechanism

We consider a photonic crystal waveguide shown in Fig. 1. The waveguide has a 1 μm-wide and 1 μm-thick silicon core with periodic air cavities and a 0.5 μm-thick SiO_2 cladding. A break in the periodicity of the air cavities introduces a defect into the photonic band gap (PBG). The transmission coefficient is simulated by the finite-difference time-domain (FDTD) method [3]. The cell size for computations is Δx= 50 nm and Δy=Δz= 10 nm, and used cell number is $70 \times 400 \times 1000$. The typical design parameters are as follows: air cavity width (W_{air}) is 200 nm, lattice constant (a) is 350 nm, air cavity length (d_{air}) is 200 nm, and defect length (d_{def}) is 250 nm.

When the defect region of the silicon waveguide is illuminated with a control light having a value of hυ larger than the band gap energy of silicon, electron-hole pairs are generated. Since the refractive index decreases by the free-carrier effects [4,5], the effective defect length decrease and DITF increases. To realize the proposed device, the control light of λ=0.85 μm is illuminated from the waveguide's sidewall through the attached SiO_2 waveguide [6]. This is the tuning mechanism of the proposed optically tunable filter.

3. Simulation results and discussion

Simulated transmission coefficient versus frequency is plotted in Fig. 2, in which it is assumed d_{def}=250 nm. As the power of control light increases, DITF increases and a 3-μW increment of control power results in 4.5-THz change of DITF. However, when the control light power is ranging from 2 to 3 μW, peak value of transmission coefficient (PVTC) at DITF decreases. For d_{def}=350 nm, transmission coefficient is shown in Fig. 3 and defect length dependencies of DITF and PVTC at DITF are shown in Fig. 4. 9-THz variation in DITF is obtained for a 5-μW increment of control light power. When the control light power is ranging from 0 to 3 μW, PVTC at DITF changes slightly and 6.5-THz variation in DITF is obtained; this corresponds to 4.2% change in signal frequency.

Figure 5 shows variations in DITF and PVTC at DITF as a function of defect length without illumination of control light. As the defect length increases, DITF decreases monotonously, while PVTC at DITF changes periodically. We can observe that a wide tuning range is obtained at d_{def}=350nm, in which the value of d_{def} results in the maximum PVTC.

4. Summary

An optically tuning filter is proposed and studied by using the electromagnetic field simulation. It is shown that a 3-μW power change of control light results in 6.5-THz change in defect-induced pass-band in the photonic crystal waveguide, and this corresponds to 4.2% change in signal frequency. It has been shown that the proposed optically tuning filter is useful for WDM optical communication system.

Acknowledgment

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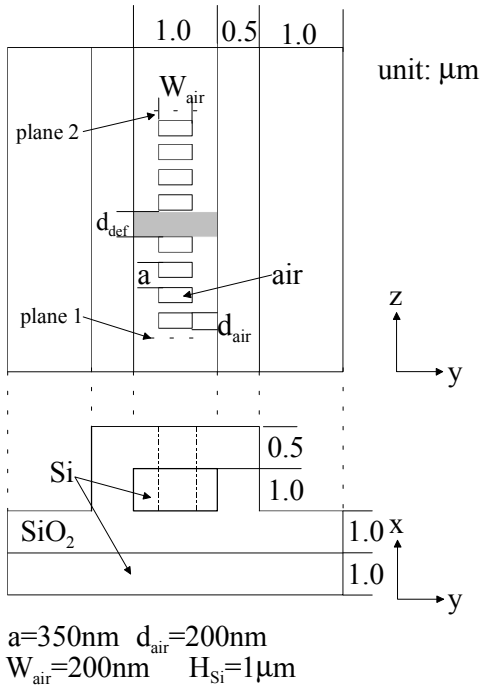

Fig. 1 Structure of a proposed optically tunable filter. Carefully defect-induced in periodically air cavities as 1st photonic crystal.

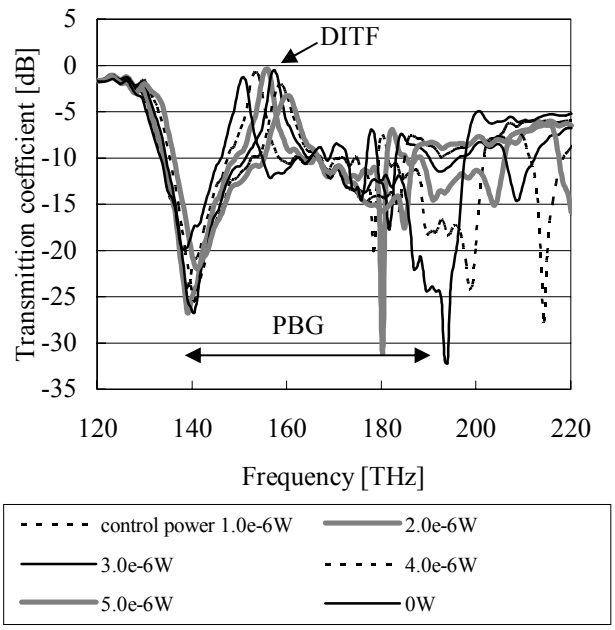

Fig. 3 Simulated transmission coefficient versus frequency for control light power ranging from 0 to 5 μW when d_{def} is 350nm.

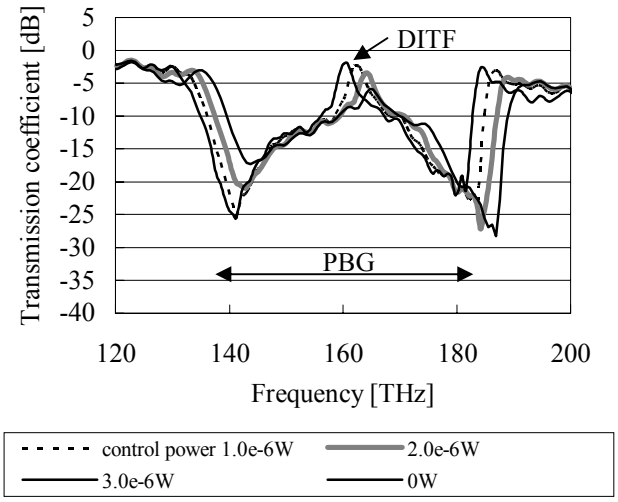

Fig. 2 Simulated transmission coefficient versus frequency for control light power ranging from 0 to 3 μW when d_{def} is 250nm.

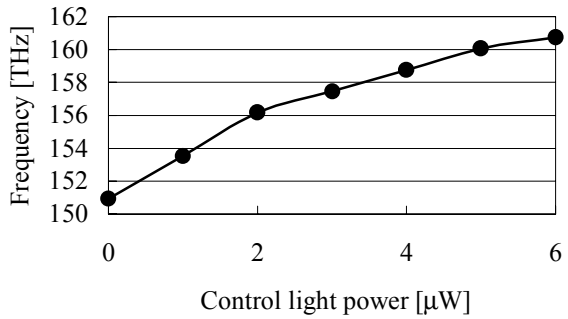

Fig.4. A variation in DITF with control light power when d_{def} is 350nm.

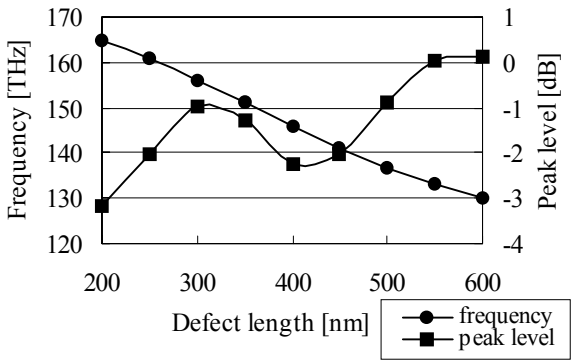

Fig.5 Variations in DITF and peak value of transmission coefficient as a function of defect length without control light.