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Proposal of a novel ring waveguide device of 2D photonic crystal slab - The transmittance simulated by FDTD analysis -

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1. Introduction

In this report, we proposed a new ring waveguide device of 2D Photonic Crystal (PhC), and studied the properties by numerical analysis. The ring device is constructed by defects waveguide of circle as main part and others. For the numerical analysis to design, two dimensional finite-difference time-domain (FDTD) method is used. To account for the vertical confinement, the effective refractive index is introduced. This method has been proved good agreement between the measured and the simulated spectra[1]. We adopted the following 2D PhC slab, whose characteristics such as PBG, modes of guided waves in the line defects waveguide and so on has been studied well[2]. In the Si slab, air rods formed triangular lattice. The radius of rod is 0.29a, where a is the lattice constant. The effective refractive index is 2.76 corresponded to the refractive index 3.4 of Si at 1.55 μ m.

2. Multi-step-like defects waveguide

The sharp bend of defects waveguide is an important on 2D PhC. The transmit spectra of a bend decides utilizable frequency band of whole devices on the PhC. It is preferable that the spectrum is broad. The transmit spectra of cascaded two bends, however, changes with depending on distance between the two bends (Fig. 1). That is caused by the effect of the Fabry-Pérot resonator, and makes a design of the devices hard.

We proposed multi-step-like waveguide for bend of PhC waveguide. The transmit spectra is shown by Fig. 2. The frequency region of good transmittance is independent of the multi-step-like waveguide length, and covered about from 0.267 to 0.277 of normalized frequency (N.F.), where N.F. is lattice constant divided by wavelength in vacuum. This region agrees almost with the frequency band in that practical modes of guided waves exist[3].

3. Directional coupler

For the coupling between the ring waveguide and input/output waveguides, we adopted the directional coupler (D.C.) in this time. D.C. is one of the most basic and versatile passive devices on photonic circuits. Realization of D.C. on PhC is very important subject. The most of conventional studies about D.C. on PhC are about theoretical studies based on distributed coupling transmission line for square lattice[4] or a few experimental results of 3-port D.C. as not coupling but branching circuit[4]. Especially, 4-port D.C. on 2D PhC slab with triangle lattice is rare, as long as the authors have known.

Fig. 3 show the transmit spectra of one of 4-port D.C. whose defects pattern closes only the parts of waveguide contributing the coupling and keeps the other parts away. This pattern is very popular as an arrangement of waveguide for D.C. The coupling length is 64a. According to our preliminary calculations, this length should generate perfect coupling at 0.274 of N.F. However, the simulation results do not exhibit perfect coupling.

Fig. 4 shows the spectra of another 4-port D.C. The defects pattern is proposed by us in this time and consists of one straight waveguide and another bend waveguide. It is confirmed that the perfect coupling is realized at 0.274 of N.F in both the D.C. in Fig. 4. When multi-step-like waveguide is used, the directivity was improved. The multi-step bends also enables the frequency band expansion. This structure is promising for applications as multiplexer and de-multiplexer using about 0.271 and 0.274 of N.F.

4. Ring Device

The ring device in this report consists of ring waveguide and the D.C. 1ps optical pulse for excitation is launched at input waveguide. The pulse propagates into the ring via D.C. After the propagation of a round, the light pulse goes to output waveguide through D.C. Fig. 5 shows the ring device and its transmit spectra. Full circle length of the ring is 1232a. The propagation loss of the transition at D.C. portion and propagation along the ring waveguide are about -0.34dB and -0.12dB respectively. The relatively large loss at D.C. will be improved by optimization of the D.C. design.

5. Conclusions

The new ring waveguide device of 2D proposed and studied in 2D triangle lattice PhC slab. As components of the ring device, multi-step-like defects waveguide and Directional Coupler are proposed and analyzed. The transmit spectra of multi-step-like defects pattern is independent of the waveguide length and covered the most of frequency band in that practicable guided-wave modes propagate. The directional couplers designed in this time

realize the coupling length according to the distributed coupling theory.

The low loss transmittance of the ring device, which consists of above mentioned devices, is confirmed and this will be sufficient for applications such as delay line and so on.

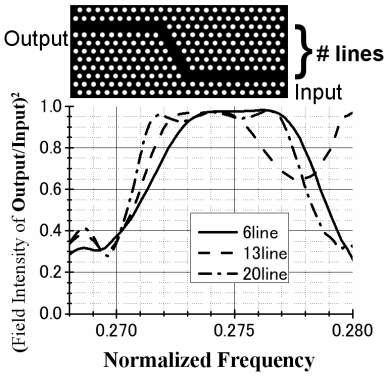

Fig. 1 Transmittance of cascaded two bends.
Single bend also has the best transmittance at 0.274.

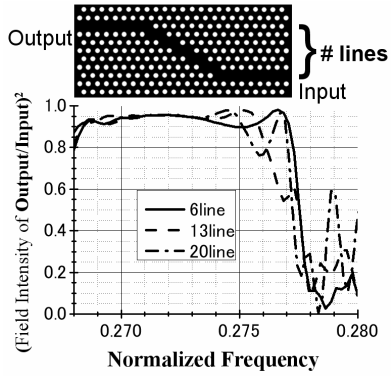

Fig. 2 Transmittance of multi-step-like waveguide.

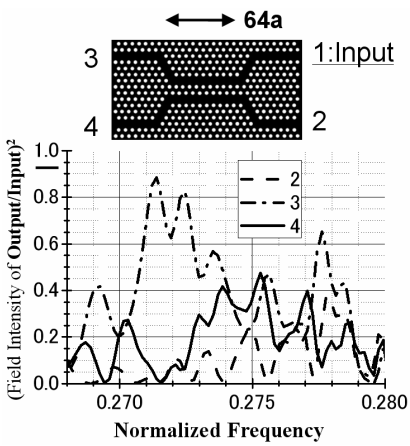

Fig. 3 Coupling coefficient and Directivity of 4-ports Directional Coupler with conventional defects pattern.

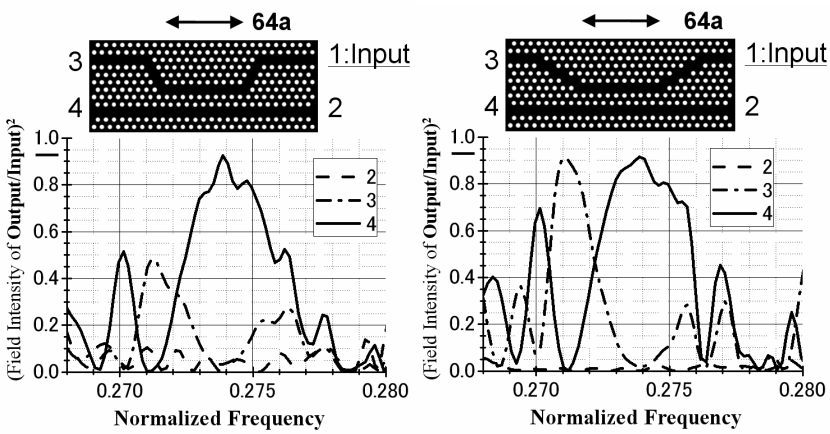

Fig. 4 Improvement of property of 4-ports Directional Coupler.
Two rows of Air rods lines up between both waveguides closing each other.

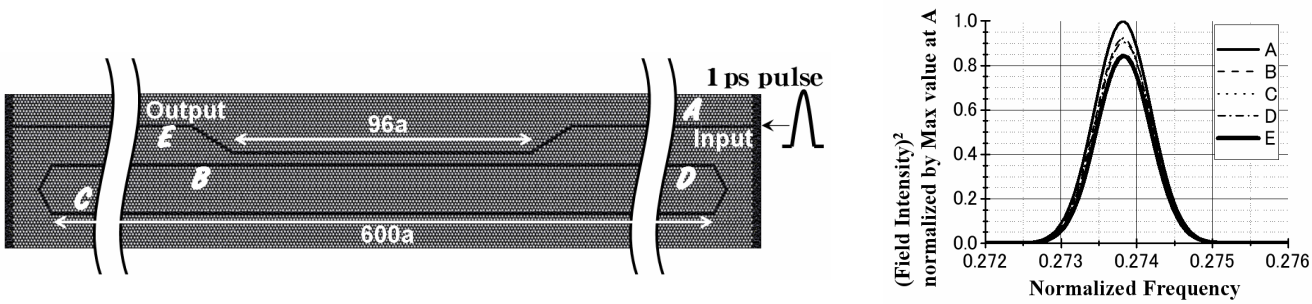

Fig. 5 Transmitance of the Ring Device.
When wave length in a vacuum is 1.55 μ m at 0.274 of N.F., time for propagation around the ring takes about 8.0ps.
Three rows of Air rods lines up between both waveguides closing each other. So coupling length is different from one in Fig.4.

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