Optical coupling between whispering-gallery mode and waveguide mode in photonic crystal

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INTRODUCTION

We study optical coupling between whispering-gallery mode (WGM) and waveguide mode in photonic crystal. Figure 1 shows photonic crystal structure we studied. WGM formed in cavity as shown in Fig. 1. It shows high quality factor and is nondegenerate. By controlling radius *R* of cavity, it is possible to shift resonance frequency for wavelength division multiplexing (WDM) communications. However, difference in light extraction efficiency between different size cavities is unfavorable for practical operation. We theoretically address the issue by tuning waveguide parameter.

STRUCTURE

The cavity resonator consists of 19 missing air holes aligned hexagonally. We modified positions of the air holes on the periphery of the cavity so that these air holes align on a circle (modified H3 defect). Waveguide (line defect) is set aside the cavity. We can change waveguide modes by letting both sides of the air holes line lessen by ΔW. We evaluated coupling efficiency defined

$$\eta = \frac{[\text{Light loss from waveguide}]}{[\text{overall loss}]} \qquad (1)$$

by carrying out two-dimensional finite-difference time-domain (FDTD) calculations, so as to examine correlation between η and structural parameters such as R and ΔW.

RESULTS AND DISCUSSION

First, we investigate relation between the coupling efficiency and shrinkage width of waveguide ΔW. Fig. 2 shows the coupling efficiency plotted as a function of ΔW for the cavity R=2.85a. The coupling efficiency shows a remarkable peak at $\Delta W \simeq 0.08a$. We found that the peak appears when inclination of the waveguide mode is approximately zero at resonance frequency in photonic band diagram. This result shows that coupling strength depends on the density of state of waveguide modes.

Next, we investigate the coupling efficiency for different radius cavities. For cavity of R=2.76a, 2.80a, 2.85a, and 2.90a, we shrink waveguide width by ΔW=0.20a, 0.14a, 0.10a, and 0.05a, respectively to couple waveguide mode 11 on each WGMs strongly. In Fig.3, filled circles denote η when the WGM strongly couples to waveguide mode labelled 11, shown in the inset.

Furthermore, we investigated coupling to the mode 12 by ΔW= -0.005a, -0.035a, -0.069a, and -0.105a, for each size of cavity resonators. Open circles denote η relating to the mode 12. Fig. 3 shows that η with mode 11 is larger than that with mode 12 in all resonators. This difference between mode 11 and 12 can be explained by symmetry of waveguide mode profile. Fig. 4 shows waveguide magnetic field amplitude of mode 11 and 12. They are totally symmetric and antisymmetric with respect to the center of the WGM, respectively. WGM can more easily excite mode 11 than mode 12. From this, optical coupling to the mode 11 is stronger than that to the mode 12.

In summary, we found that strength of optical coupling between WGM and waveguide modes depends on symmetry of the modes as well as on the density of states of the waveguide mode.

The present results are useful to suppress the difference of the light extraction efficiency to realize WDM devices.

REFERENCE

[1] K.Nagahara, et al, *Optical coupling between a cavity mode and a waveguide in a two-dimensional photonic crystal,* Photon. Nanostr. Fundam. Appl. **9**, 261 (2011)

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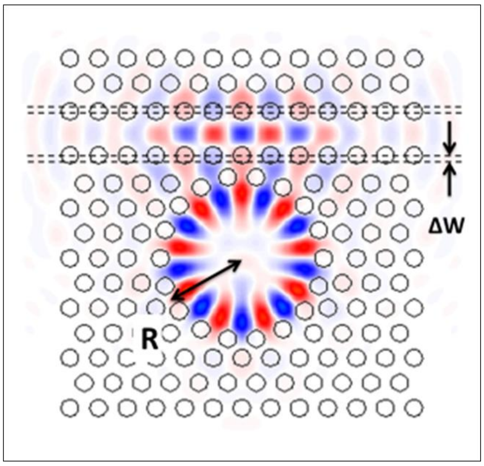

Fig. 1. Photonic crystal structure we studied. Magnetic field amplitude of the WGM and the waveguide mode are also shown.

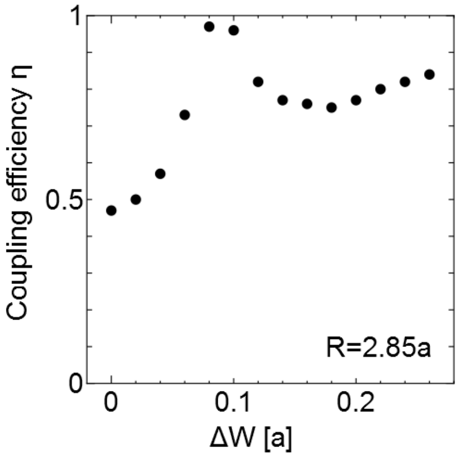

Fig. 2. Coupling efficiency between the cavity mode and the waveguide mode as a function of shrinkage width of waveguide ΔW at R=2.85a.

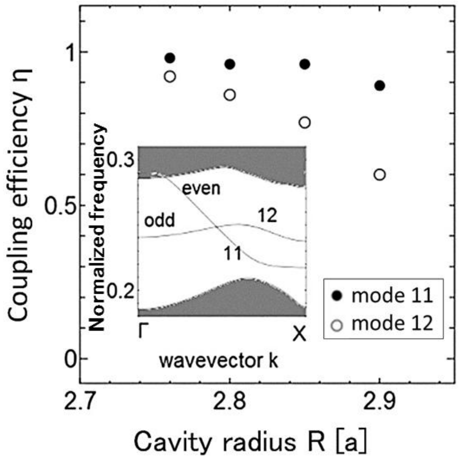

Fig. 3. Coupling efficiency of cavity radius R=2.76a, 2.80a 2.85a, and 2.90a. Filled circles and open circles denote the coupling efficiency related to the mode 11 and 12. Inset: Photonic band diagram. The curves labeled as 11 and 12 are waveguide modes.

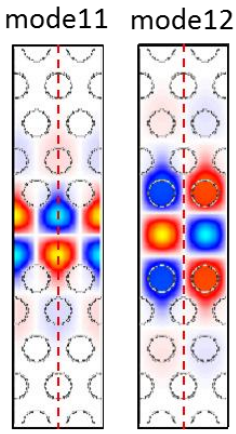

Fig. 4. Calculated magnetic field amplitude of mode 11 (left) and 12 (right) for wave vector X. Mode 11 and 12 have even and odd symmetry, respectively with respect to the center of the WGM (red dash line).