Slab modes in photonic crystal optical waveguides

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Photonic crystals [1,2] with line defects can be used for guiding light. In all the proposals and demonstrations of photonic bandgap (PBG) waveguides, the guiding modes were restricted to the photonic bandgap. We show that there exist some guiding modes outside the photonic bandgap. We also show that by using these modes, which we refer to as the slab modes [3], efficient power transfer from a dielectric slab waveguide to a PBG waveguide over a range of frequency wider than the photonic bandgap (PBG) can be obtained. Different properties of the slab modes of a PBG waveguide is also discussed.

The main structure we used in the analysis of this paper is the connection of a dielectric slab waveguide to a PBG waveguide as shown in Figure 1. By choosing the thickness of the middle slabs of both waveguide (*d*), we can obtain single—mode propagation in both waveguides. To analyze the guiding structures, we used a computer code based on the two—dimensional finite difference time domain (2D--FDTD) method.

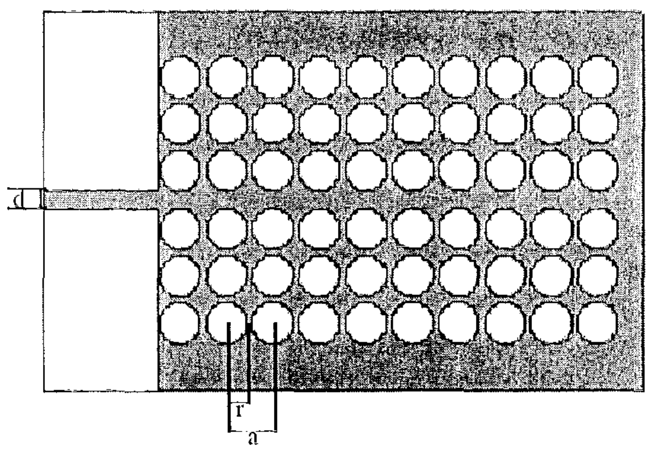

Figure 1: Connection of a dielectric slab waveguide to a PBG waveguide. The PBG waveguide is made by putting a dielectric slab of thickness *d* between two PBG mirrors. The period of the photonic crystal and the radius of the air columns are equal to a and r=0.45 a, respectively. There is a thin layer of either dielectric or air between the PBG and PML on top and bottom of the structure. The dielectric used in this paper is GaAs (ϵ=12.96).

Figure 2 shows the dispersion diagram for the TE mode (electric field normal to the computation plane) of the PBG waveguide shown in Figure 1. Calculation of the electric field pattern of the mode shown in Fig. 2 shows that the slab mode of a PBG waveguide is a confined mode with its energy concentrated mainly in the middle slab region at the frequencies in the middle of the dispersion band ($0.204< \omega a/(2\pi c) <0.267$). The mode is lossy at both edges of the dispersion band ($\omega a/(2\pi c) < 0.204$ and $\omega a/(2\pi c) > 0.267$). We have also shown the dispersion curves of the fundamental TE mode of a conventional dielectric slab waveguides with the same slab thickness and permitivity as the middle slab of the PBG waveguide. As Fig. 2 shows, the PBG waveguide mode has a similar dispersion diagram to the slab waveguide mode. The field patterns of these modes are also similar. Therefore, we expect very good coupling between the two waveguides over a relatively wide frequency range. This frequency range is limited by the loss of the PBG and also by the distributed Bragg reflection (DBR) from the periodic structure in the propagation direction.

Figure 3 shows the power transmission coefficient (from the slab waveguide to the PBG waveguide) versus frequency for the waveguide connection shown in Figure 1. As Fig. 3 shows, it is possible to have a high transmission coefficient between a slab waveguide and a PBG waveguide over a relatively wide range of frequencies (larger than the photonic bandgap) corresponding to the range of frequencies over which the PBG waveguide mode has very low loss. The smaller transmission coefficient at the higher frequencies ($\omega a/(2\pi c) > 0.28$) is due to the excitation of other modes of the PBG structure that are lossy. These modes attenuate as they propagate along the PBG waveguide. As Fig. 3 shows, putting air instead of GaAs on top and bottom of the entire PBG waveguide will affect the smaller peak (at $\omega a/(2\pi c) = 0.295$) in the transmission coefficient. However, the high transmission behavior at middle frequencies is not affected considerably by the material at the top and bottom of the structure. This is due to the fact that for these frequencies, the mode is well confined and is not influenced by the structure far from the slab region.

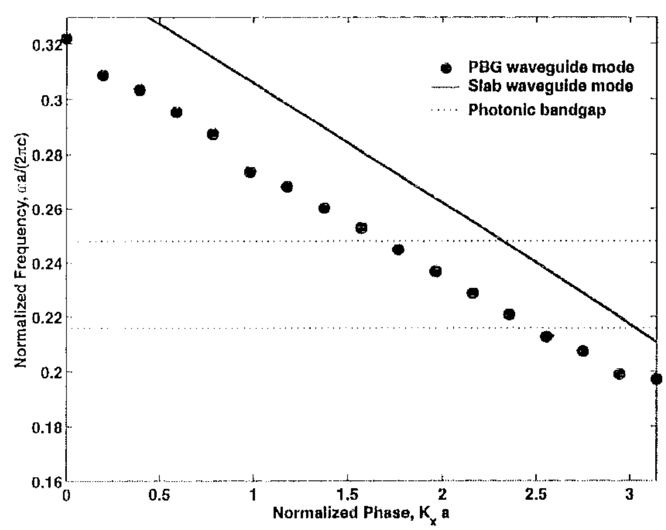

Figure 2: Dispersion curves for the fundamental modes of a PBG waveguide and a slab waveguide.

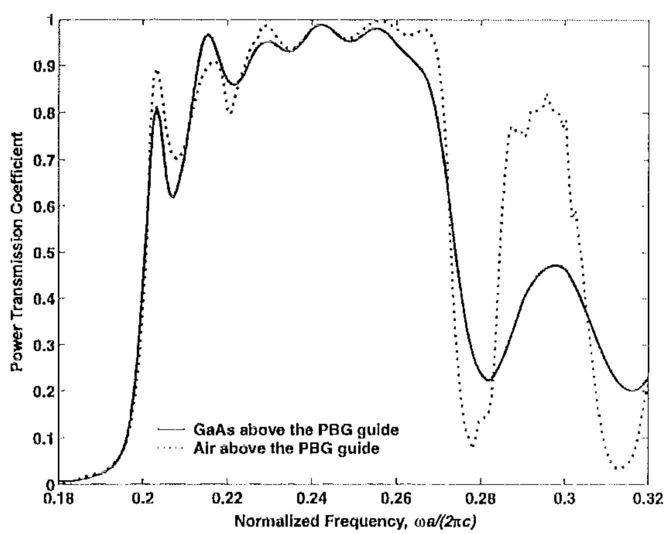

Figure 3: Spectrum of power transmission from a slab waveguide to a PBG waveguide.

References:

1. E. Yablanovtich, *Phys. Rev. Lett.* **58**, 2059-2062 (1987).
2. S. John, *Phys. Rev. Lett.* **58**, 2486-2489 (1987).
3. A. Adibi, Y. Xu, R. Lee, A. Yariv, and A. Scherer, "A new type of guiding mode in photonic crystal optical waveguides", *submitted to Phys. Rev. Lett.*