Study of Photonic Crystal Waveguide in Microwave Regime Using 3D FDTD Simulation

3차원 FDTD모사를 이용한 마이크로웨이브 영역에서의 광결정 도파로에 관한 연구

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Unlike the conventional waveguide such as optical fiber using total internal reflection, photonic crystal waveguide(PCW), a waveguide made of a line defect in a photonic crystal(PC) structure, does not admit an analytic approach due to its complexity but requires a direct numerical approach.

Here, we present numerical results of computer simulation for PCW by using the three-dimensional(3D) Finite-Difference Time-Domain(FDTD) algorithm. Most numerical works in PCW have been performed through the use of the two-dimensional(2D) FDTD method(1) or plane wave expansion(PWE) method(2) since 2D FDTD simulation is easier and requires less computing power. Though suitable for the band calculation, PWE does not show time dynamics. The 2D FDTD method also provides only the qualitative picture different from real systems, since the TE and TM modes are treated as independent, decoupled modes in the 2D FDTD algorithm. In real systems, the TE and TM modes are coupled to each other due to the loss mechanism and through the intrinsically 3D nature of PC geometry. Furthermore, the 2D FDTD algorithm fails to give us correct properties of PCW such as energy loss. Thus, in order to compare with real experiments, we need the 3D FDTD algorithm, in which the TE and TM modes are coupled to each other.

3D FDTD simulation in PCW was performed by the Caltech group(3), who simulated slab triangular waveguide with the source of 1550nm light. Their structure was a hole-type PCW, which consists of slab dielectric material with periodic holes without any confinement in the vertical direction. Recently, we proposed a rod-type PCW, which consists of periodic rods covered with aluminum plate in vertical direction in order to minimize the loss arising from the leakage into the vertical direction as well as the bending of PCW,(4) and demonstrated numerically very small bending losses in this design. This agreed well with experimental results.

In this talk we present detailed numerical studies on PCW. We studied numerically the physical properties of PCW by changing its configuration: lattice geometry(square lattice and triangular lattice), the height and the radius of rods, and with and without the covering aluminum plate. Each configuration is simulated for the straight waveguide and bended waveguide.

The following figures show typical results of 3D FDTD simulation in our structure, where the distance between rods is 9mm, and the radius of the rod is 1mm, and the height 16mm.

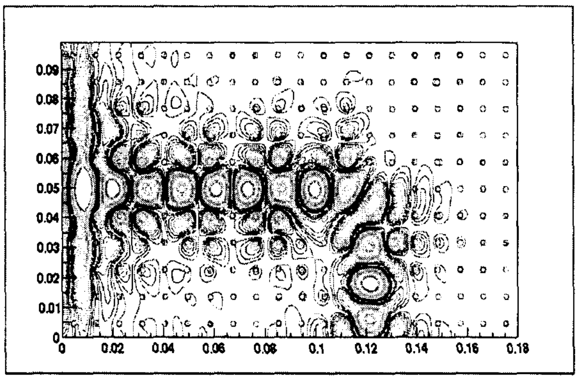

Fig. 1 bended light at r=1mm

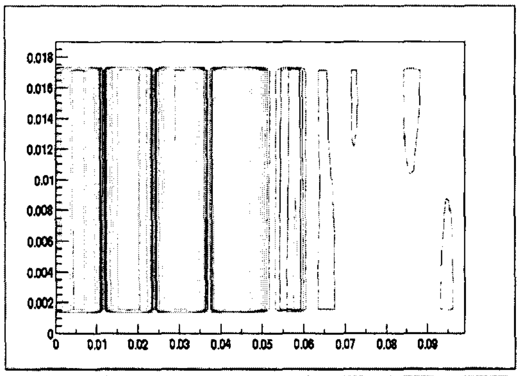

Fig. 2 bended light at r=1mm in bended position, viewed in the vertical cross section

We also address the issue of rod-size versus the internal modes inside the rod. As the radius of rod becomes thicker, we found that whispering gallery mode appears inside a rod, as shown in Fig. 3(the radius of rod in the figure below is 3mm). This also shows a buildup of photonic bandgap in a dynamical way.

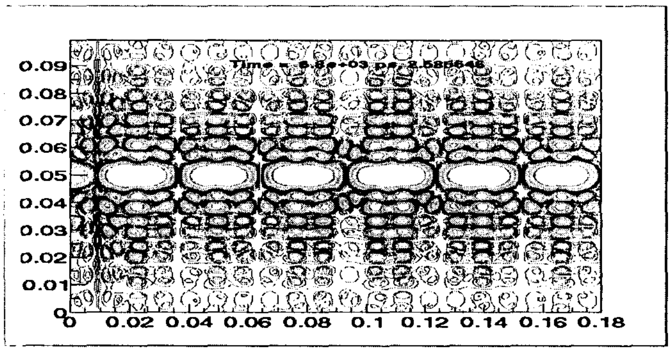

Fig. 3 Straightly propagating light at r=3mm

We also point out that the change of 90° bending geometry as given in Ref. [2] by moving one of the rod position, in fact, does not make any significant difference in bending losses.

References

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