Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 558-559

P7-2

Theoretical study on the photonic crystal slabs with hexagonal optical atoms

Lin Yang, Junichi Motohisa and Takashi Fukui
Research Center for Integrated Quantum Electronics (RCIQE),
Hokkaido University, North 13 West 8, Sapporo 060-8628, Japan
E-mail: lyang@rciqe.hokudai.ac.jp; Fax: +81-11-716-6004

1. Introduction

Although great improvements have been achieved since the first suggestion of the concept of photonic crystals (PCs), there is still a long road to their actual application. For example, the reported lowest propagation loss for GaAs PC waveguide is about 0.76 dB/mm [1], which is still one magnitude larger than that of the conventional GaAs waveguide [2]. The propagation loss is mainly determined by the non-uniformities and roughnesses of air-dielectric interfaces. In addition, most PCs are fabricated by dry etching. So the process-induced damages are inevitable, which greatly increase the threshold current of laser diodes. One way to overcome this drawback is to further optimize the dry etching process. The other way is to try other fabrication methods such as wet etching and/or selective area metal-organic vapor-phase epitaxy (SA-MOVPE). The shapes of the fabricated holes or pillars by these two methods depend not only on the formed pattern on the material surface but also on the orientation of crystal plane. Most semiconductor materials have diamond or zinc blende crystal structures. If (111) plane is used as the substrate and $\{1\bar{1}0\}$ planes are used as the sidewalls, hole- and pillar-type PCSs with hexagonal optical atoms can be fabricated by using wet etching or SA-MOVPE. Actually, uniform pillar- and hole-type PCSs have been fabricated by using SA-MOVPE [3, 4]. In this paper, we will mainly discuss the photonic band structures of photonic crystal slabs (PCSs) with hexagonal optical atoms.

2. Results and Discussion

Triangular lattice is selected as the studied object. The refractive index of the studied material is 3.374 (n_{GaAs}=3.374 at 1.55 μm). Both the up- and bottom-cladding materials are air (n_{air}=1), which corresponds to air-bridge PCS. The slab thickness is selected to be 0.6a for hole-type PCS and 2.4a for pillar-type PCS so that they have maximum band gaps. Standard plane wave expansion method together with super cell method is used to calculate the gap map of PCS with hexagonal optical atoms.

Generally, there are two standard arranges for hexagonal optical atoms with respect to the triangular lattice. If one side of hexagon is parallel to the Γ-K direction, this structure is named normal hexagonal optical atom. If one side of hexagon is perpendicular to the Γ-K direction, this structure is named orthogonal hexagonal optical atom. Shown in figures 1 (a) and (b) are the gap maps for hole-type PCS with normal hexagonal optical atoms and its 2D counterpart. For hole-type PCS, there are four band gaps in the normalized frequency range from 0.1 to 0.6, two of which are for TE-like modes and the other two are for TM-like modes. The first band gap for TE-like modes of PCS is similar to that of its 2D counterpart. The first band gap for TE-like modes of hole-type PCS shifts to the higher frequency compared with that of its 2D counterpart, which is due to the confinement to the optical field by the index difference in the z direction. There is an absolute band gap for hole-type PCS in the hole size

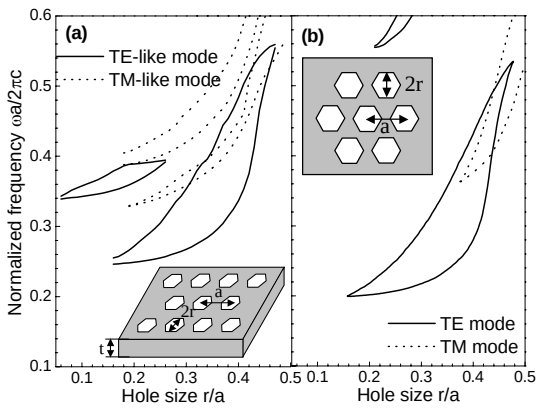

Figure 1. (a) Gap map of hole-type PCS with normal hexagonal optical atoms. (b) gap map of hole-type 2D PC with normal hexagonal optical atoms.

range from 0.306 to 0.461.

Figures 2 (a) and (b) show the gap maps for pillar-type PCS with normal hexagonal optical atoms and its 2D counterpart. For pillar-type PCS, there is only one band gap for TM-like modes in the normalized frequency range from 0.1 to 0.6. The first band gap for TM-like modes of pillar-type PCS almost locates at the same position as that of its 2D

counterpart, which indicates that the confinement to the optical field by the index difference in the z direction is very weak. The first band gap for TM-like modes of pillar-type PCS shrinks seriously compared with that of its 2D counterpart. There is no absolute band gap in the showed frequency range for pillar-type PCS, which is similar to the case for its 2D counterpart.

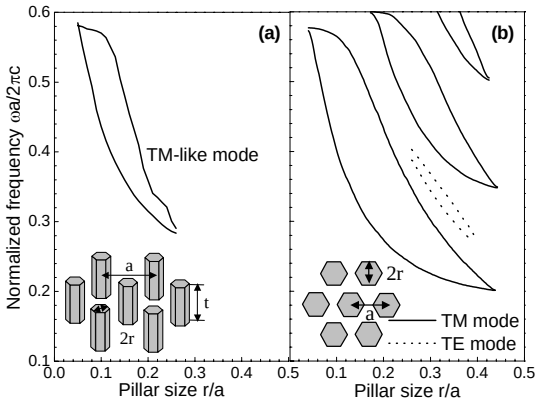

Figure 2. (a) Gap map of pillar-type PCS with normal hexagonal optical atoms. (b) gap map of pillar-type 2D PC with normal hexagonal optical atoms.

Figures 3 (a) and (b) show the gap maps for hole-type PCS with orthogonal hexagonal optical atoms and its 2D counterpart. For hole-type PCS, there are five band gaps in the normalized frequency range from 0.1 to 0.6, three of which are for TE-like modes and the other two are for TM-like modes. The first band gap of PCS is similar to that of its 2D counterpart except that it shifts to the higher frequency compared with that of its 2D counterpart. There is also an absolute band gap in the hole size range from 0.291 to 0.463.

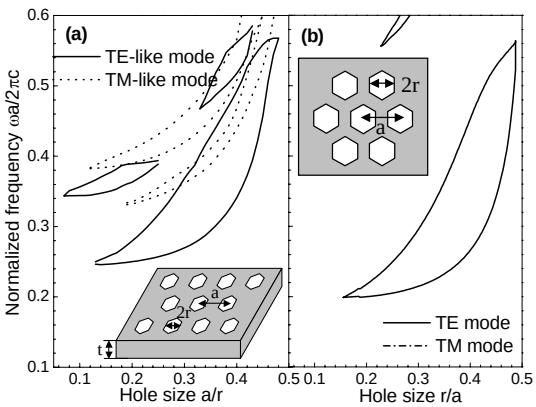

Figure 3. (a) Gap map of hole-type PCS with orthogonal hexagonal optical atoms. (b) gap map of hole-type 2D PC with orthogonal hexagonal optical atoms.

Figures 4 (a) and (b) show the gap maps for pillar-type PCS with orthogonal hexagonal optical atoms and its 2D counterpart. For pillar-type PCS, only one band gap for TM-like modes exists in the showed frequency range. The first band gap of pillar-type PCS almost locates at the same position as that of its 2D counterpart. It also shrinks seriously compared with that of its 2D counterpart.

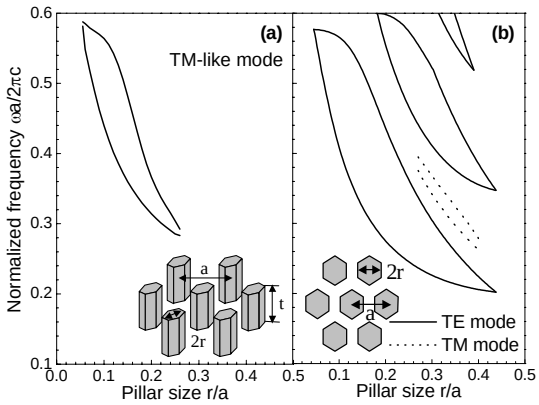

Figure 4. (a) Gap map of pillar-type PCS with orthogonal hexagonal optical atoms. (b) gap map of pillar-type 2D PC with orthogonal hexagonal optical atoms.

3. Conclusions

Hole-type PCS with hexagonal optical atoms has almost the same wide first band gap as its 2D counterpart. However, the first band gap of pillar-type PCS with hexagonal optical atoms shrinks seriously compared with that of its 2D counterpart. Hole-type PCS with orthogonal hexagonal optical atoms has a wider band gap for TE-like modes than that with normal hexagonal optical atoms. PCS with hexagonal optical atoms has band gaps that can be compared with those of PCS with circle optical atoms. So it is also a good choice for fabricating PC devices.

4. References

1. Y. Sugimoto, et al., Optical Express **12,** 1090-1096 (2004).
2. R. M. Jenkins, et al., Appl. Phys. Lett. **64**, 684-686 (1994).
3. M. Akabori, et al., Physica **E**. 1**3,** 77-81 (2002).
4. J. Takeda, et al., Appl. Surf. Sci. **190,** 236-241 (2002).