Proceedings of IC-NIDC2010

THE PROPERTIES AND STRUCTURE OPTIMIZATION OF SLOT PHOTONIC CRYSTAL WAVEGUIDE

Xuan Zhang, Huiping Tian, Daquan Yang, Yuefeng Ji

Key Laboratory of Information Photonic and Optical Communication(BUPT), Ministry of Education, School of Information and Telecommunication Engineering, Beijing University of Posts & Telecommunications, Beijing, China
zhangxuanbeijing08@163.com, hptian@bupt.edu.cn, yangdq5896@163.com, jyf@bupt.edu.cn

Abstract

The properties of the guide mode by adjusting the widths of the air-slot and the radii of the air-holes in the first and second rows have been studied respectively in the slot photonic crystal waveguide (PCW). It is very interesting that the guide mode's shifts to the high frequencies as increasing the width of air-slot, the radii of air holes in the first two rows adjacent to the waveguide. We set the appropriate these parameters to optimize the slot PCW obtaining single guide mode. The optimized slot PCW confines the light very well in the slot region by analyzing the filed distribution and transmission compared to the conventional slot PCW. These results provide theory basis for the further research on the slot PCW, especially the sensor and dispersion compensator.

Keywords: Slot Photonic crystal waveguide, Guide Mode, Electric Field, Transmission

1 Introduction

In the past few years the photonic crystals with its special properties that can be used to control electromagnetic wave have undergone rapid development. As internet of things and the sensor network booming developed, the micro and low power consumption sensors are great required. The PCW can be used to realize the sensor for the advantages of small-size, easy integration, working under room temperature, great potential bandwidth, and realizing slow light in arbitrary wavelength. Slow light in PCW has a variety of potential applications such as optical delay line devices, optical buffers and memories in future all optical communications and information processing systems[1-3].

However, in conventional PCW, light is usually strongly confined in the high-index guiding layer, which may counteract the interaction between light and low index materials. Recent researches indicate that the slot PCW can confine light in a narrow slot filled with low-refractive index material which is more convenient and feasible for fabrication. The light localization in the slot PCW may effectively enhance the interaction between light and low-index materials which are filled in the slot[4-7]. The slot PCW can be filled with nonlinear or electro-optical (EO) material to construct various applications, such as all-optical logical switch, modulators and EO material-based active optical devices[8-10]. Moreover, structure optimizations of PCW can further improve the performance[11-14]. So the research on the properties of slot PCW becomes very important.

In this paper we focus on the properties of the guide mode by adjusting the widths of the air-slot and the radii of the air-holes in the first and second rows by 3D plane wave expansion (PWE). We find that guide mode shifts to the high frequency as the increase of width of air-slot, radius of air holes in the first two rows adjacent to the waveguide. Secondly we set the appropriate these parameters to optimize the slot PCW with single guide mode in the photonic band gap (PBG). The optimized slot PCW confines the light very well in the slot region by analyzing the field distribution and transmission compared to the conventional slot PCW.

2 Structure model and guide mode analysis

Here we employ the 3D PWE method to analyze the dispersion behavior and localization characteristics. A narrow air-slot is cut into the centre of a line defect (W1) slab waveguide. The slot PCW slab is triangular lattice with air holes, where the radius of air hole r is 0.32a, a is the lattice constant, and w is the slot width, r_1 is the

978-1-4244-6853-9/10/$26.00 ©2010 IEEE

radius of the air-holes in the first two rows adjacent to the air-slot, r_2 is the radius of the air-holes in the second two rows as shown in Figure 1. The thickness of the Si slab is 0.5a. The refractive index of Si is 3.48, and 1 for air. The dispersion curves for TE polarized mode in slot PCW can be numerically calculated and analyzed.

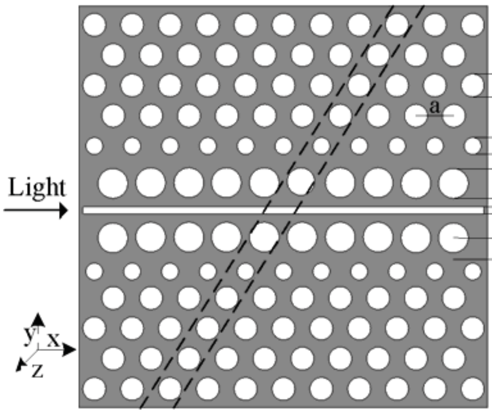

Figure 1. The model of slot photonic crystal waveguide

There are two guide modes in the PBG, one is even mode, and the other is odd mode. The even mode of the W1 waveguide is suppressed due to symmetric constraint; the odd mode is pushed towards higher frequency which leaks the energy in the slab mode. So in this paper we will mainly focus on the even mode. The slope of the dispersion curve is opposite to that of the ordinary PCW. There exists multi-mode transmission related loss which is harmful for the light propagation[5,7]. We will optimize the structure to ensure that the structure only supports single even mode in the PBG which has better performance.

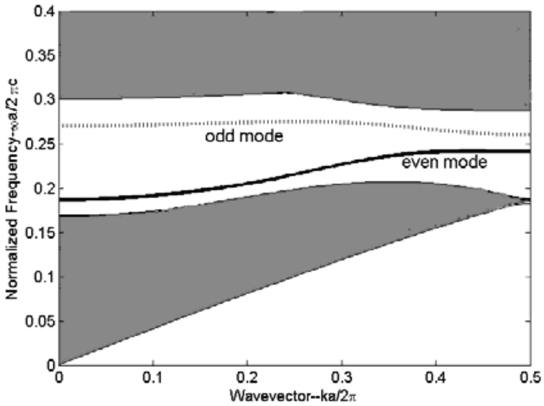

Figure 2. The band diagram of the conventional slot photonic crystal waveguide with w=0.2a

2.1 Adjusting the width of air-slot

The width of the slot provides an extra degree of freedom to tailor the propagating property of the slot PCW. Fig.3 shows the band curves for a series of slot width in PCW. For w = 0.1a—0.4a with step 0.05a and r1=r2=r=0.32a, the guide mode shifts to higher frequency as the increase of the slot width. The band curve near the right band edge changes greater than the left edge.

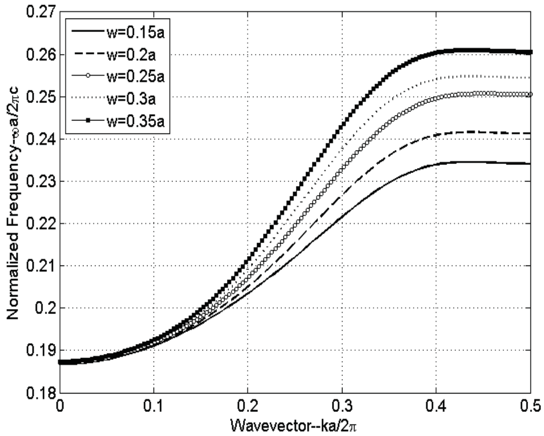

Figure 3. The even guides mode with different widths of the air-slot

2.2 Adjusting the radii of hole in the most adjacent two rows to the slot PCW

Keep the width w=0.2a, r_2=r=0.32a the same, only adjusting r_1 from 0.2a~0.4a, the result is shown in Figure 4. The increase of the r_1 also shifts the guide mode to higher frequency, the cut-off wavelength shifts correspondingly. The band curve near the right band edge changes greater than the left edge. The shape of the guide mode also changes.

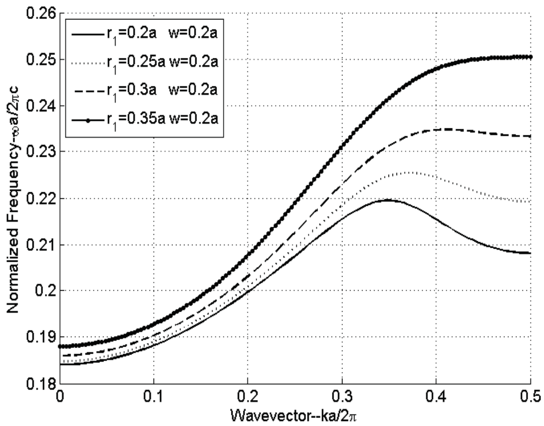

Figure 4. The even guide modes with different radii of air-holes in the first row, slot width w=0.2a

2.3 Adjusting the radii of holes in the second most adjacent two rows to the slot PCW

Keeping the width w=0.2a, r_1=r=0.32a the same, only adjusting r_2 from 0.2a~0.35a, the results are shown in Figure 5. The increase of the r_2 also shifts slightly the guide mode to higher frequency. The shape changes slightly.

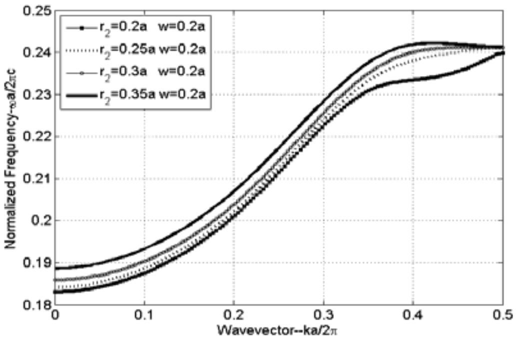

Figure 5. The even guide modes with different radii of air-holes in the second row, air-slot width w=0.2a

From analyses of the above three types of slot PCWs, we find interesting that as the increase of the width of slot, $r_1$and r_2, the guide mode frequency shifts upward in all cases. These rules perform greatly different from the conventional PCW and provide theory evidences for the structure optimization in the future applications in the all optical network, such as sensor, compensator, optical delay line devices and optical buffers.

3 The optimized slot PCW

As shown in the Figure 2, we obtain two guide modes in the photonic band gap (PBG). There exists multi-mode transmission related loss. We optimize the structure to ensure that the structure only supports single mode in the PBG. According to the forgoing studies, single even guide mode in the PBG is obtained by setting appropriate values to the parameters r1, r2, w. At r1=0.35a, r2=0.25a and w=0.2a single mode is obtained as the optimized structure, and the frequency range of single even guide mode is also wider. The band diagram is shown in Figure 6.

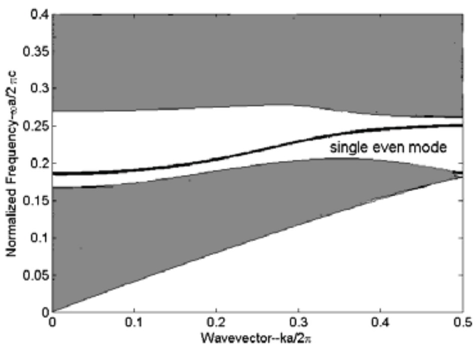

Figure 6. The band diagram of the optimized slot PCW, w=0.2a, r_1=0.35a, r_2=0.25a

We also analyze the Ey electric field distributions and the transmissions of the optimized slot PCW and the conventional slot PCW. Compared to the conventional slot PCW, the transmission of the optimized structure in the single guide mode is larger which means the light is easier to propagate through the optimized slot PCW as shown in Figure 7. The electric field mainly localized in the air-slot is shown in Figure 8. The optimized slot PCW shown in Figure 8 (a) can confine more light energy in the slot waveguide than the conventional slot PCW in Figure 8 (b) because the multi-mode having more related loss weakens the localization.

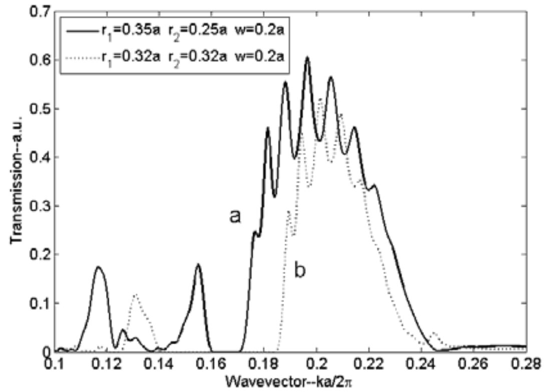

Figure 7. The transmissions of slot PCW, a is the optimized structure with r_1=0.35a, r_2=0.25a, w=0.2a, r=0.32a, b is the conventional slot PCW with r_1=r_2=r=0.32a, w=0.2a

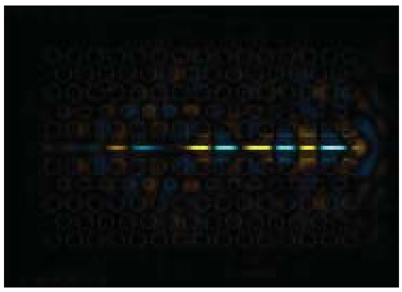

Figure 8 (a). The electric field distribution of the optimized slot PCW

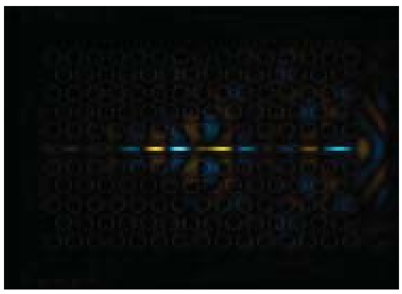

Figure 8 (b). The electric field distribution of the conventional slot PCW

4 Conclusions

The properties of the guide mode by adjusting the widths of the air-slot and the radii of the air-holes in the first and second rows have been studied respectively. It is very interesting that the guide mode shifts to the high frequencies as the increase of the width of air-slot, the radii of air holes in the first two rows adjacent to the waveguide. These rules perform greatly different from the conventional PCW and provide theoretical evidences for the structure optimization. We appropriately set these parameters to optimize the slot PCW with single guide mode. The optimized slot PCW confines the light very well in the slot region by analyzing the filed distribution and transmission compared to the conventional slot PCW. These results provide theory basis for the further research on the slot PCW, especially in the future applications in the all optical network, such as sensor, compensator, optical delay line devices and optical buffers.

Acknowledgements

This research was supported in part by National 863 Program (No. 2009AA01Z214), NSFC (No. 60707001), National 973 Program (No. 2007CB310705), NCET (07-0110), P. R. China.

References

[1] Toshihiko Baba. "slow light in photonic crystal", NATURE PHOTONICS, VOL 2 (2008)

[2] Lars H.Frandsen, Andrei V.Lavrinenko, Jacob Fage-Pedersen, and PeterI.Borel. "Photonic crytal waveguide with semi-slow light and tailored dispersion properties" OPTICS EXPRESS, VOL 14 (2006)

[3] A. Di Falco, L. O'Faolain, T.F. Krauss, "Photonic crystal slotted slab waveguides", Photonics and Nanostructures Fundamentals and Applications, VOL 6 (2008)

[4] A. Di Falco, L. O'Faolain, T. F. Krauss, "Slotted Photonic Crystal waveguides and cavities for slow light and sensing applications", Group IV Photonics, 2008 5th IEEE

[5] WU Jun PENG Chao, LI Yan-Ping, WANG Zi-Yu," Light Localization in Slot Photonic Crystal Waveguide", CHIN. PHYS. LETT. VOL 26 (2009)

[6] Biao Qi, Ping Yu, Yubo Li, Yinlei Hao, Qiang Zhou, Xiaoqing Jiang, Member, IEEE, and Jianyi Yang, Member, IEEE, "Ultracompact Electrooptic Silicon Modulator WithHorizontal Photonic Crystal Slotted Slab", IEEE PHOTONICS TECHNOLOGY LETTERS, VOL 22 (2010)

[7] WU Jun, LI YanPing, YANG ChuanChuan, PENG Chao & WANG ZiYu, "Slow light in tapered slot photonic crystal waveguide", Chinese Science Bulletin (2009)

[8] Jan Hendrik Wülbern, Alexander Petrov, and Manfred Eich," Electro-optical modulator in a polymerinfiltrated silicon slotted photonic crystal waveguide heterostructure resonator", OPTICS EXPRESS, VOL 17 (2009)

[9] Xiaonan Chen, Alan X. Wang, Swapnajit Chakravarty, and Ray T. Chen," Electrooptically-Active Slow-Light-Enhanced Silicon Slot Photonic Crystal Waveguides", IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL 15 (2009)

[10] Sergei F. Mingaleev1, Andrey E. Miroshnichenko2,and Yuri S. Kivshar2," Coupled-resonator-induced reflection in photonic-crystal waveguide structures", OPTICS EXPRESS, VOL 16 (2008)

[11] Shiyun Lin, Juejun Hu, Lionel Kimerling, and Kenneth Crozier, "Design of Nanoslotted Photonic Crystal Waveguide Cavities for Single Nanoparticle Trapping", CLEO/IQEC (2009)

[12] Zheng Zheng , Muddassir Iqbal , Jiansheng Liu, "Dispersion characteristics of SOI-based slot optical waveguides", Optics Communications VOL 281 (2008)

[13] A. Di Falco, L. O'Faolain, and T. F. Krauss," Dispersion control and slow light in slotted photonic crystal waveguides", APPLIED PHYSICS LETTERS VOL 92 (2008)

[14] M.Notomi, K.Yamada, A.Shinya, J.Takahaashi, C.Takahashi, and I.yokohama. "Extremely large group velocities dispersion of line-defect waveguides in photonic crystal slabs" Phys. Rev. Lett, VOL 87 (2001)