OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 4, No. 10, October 2010, p. 1453 - 1456

Highly efficient spatial beam splitter based on coupled cavity waveguide and surface taper modification

QUAN XU*, KANG XIE, YIYING WANG[a], JUN TANG[a]
College of Optoelectronic Information, University of Electronic Science and Technology of China, Sichuan Province 610054, China
[a]*College of Physical Electronics, University of Electronic Science and Technology of China, Sichuan Province 610054, China*

We propose a highly efficient spatial beam splitter based on coupled cavity waveguide and surface taper modification structure. We analyze, by the finite time domain numerical methods. Furthermore, by modifying the number of the coupled multi-channel taper waveguide with (the number of cylinders along x) and L_y (the number of waveguides along y), the spatial electric filed and the poynting vector prosperities are analyzed.

(Received April 14, 2010; accepted October 14, 2010)

Keywords: Photonic crystal, Couple cavities waveguide, Beam splitter

1. Introduction

The diffraction limit is perhaps the most elusive principle in optics. So that light exiting from a region much smaller than half wavelength bear a strong angular spread and fill out the whole solid angle [1]. Under the condition of this, the highly directional emission has attracted attention in modern optical field in recent years. There may be summarized into two ways: one of which use the surface waves by surface corrugations at the photonic crystals [2,3] (PC) termination[4], another one is used the multiples sources results optical field distribution at the waveguide exit port [5].

Recently, a novel photonic crystals waveguide has been reported that is commonly referred to as a coupled cavity waveguide (CCW) [6-8] consisting of a chain of high Q optical cavities embedded in a PC [9].

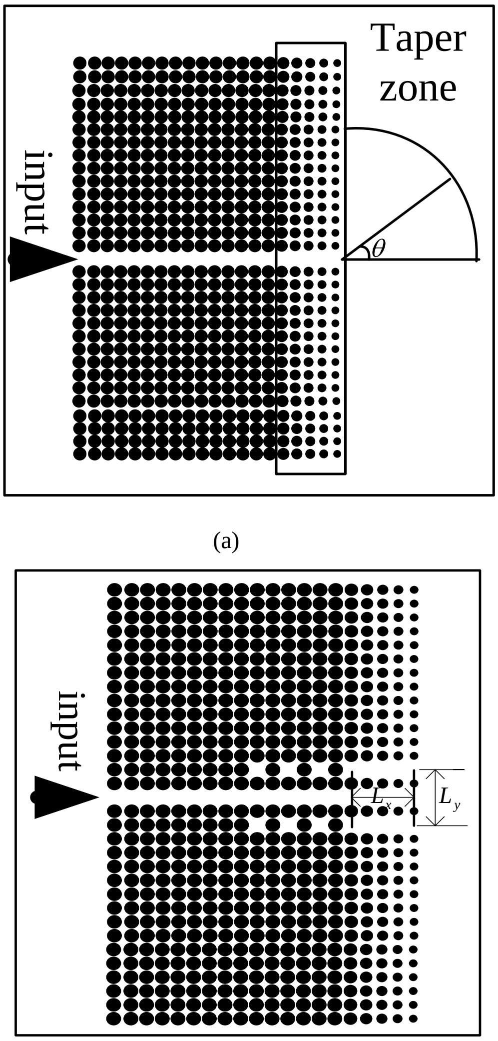
Light propagation in CCWs can be explained as photo hopping between nearby cavities as a result of overlapping of the tightly confined modes. The most prominent features of CCWs are the feasibility of tuning the frequency of the CCWs guiding modes by changing the cavities and the high ration transmission of light through sharp bends [10] can be achieved. So coupled cavities waveguides are a special optical component for integrated photonic circuits. These two methods indicate that PC plays an important role in overcoming the diffraction limit.

In this paper, we propose another system to realize highly efficient spatial beam splitter via CCW and surface taper multi-channel structure. We demonstrate that the number of sources and surface taper waveguide effect on the transmission and emission angular. Additionally, the optimum structure was shown with special wavelength for optical communication.

2. Description of the design system and principle of operation

A two dimensional PC composed of a square lattice of cylinders with refractive index of $n = 3.4$ (corresponding to the relative dielectric constant of InGaAsP-InP semi-conductor material system at a $1.55\mu m$ wavelength) in vacuum is considered. The radius of cylinders is $r = 0.2a$, where a is the lattice constant of the PC. For TM polarization (electric field parallel of the cylinders), which has widen band-gap in the normalized frequency rang from $a/\lambda = 0.29$ to $a/\lambda = 0.422$ (λ is the wavelength in free space), the plane wave expansion method is used to calculated the band-gap.

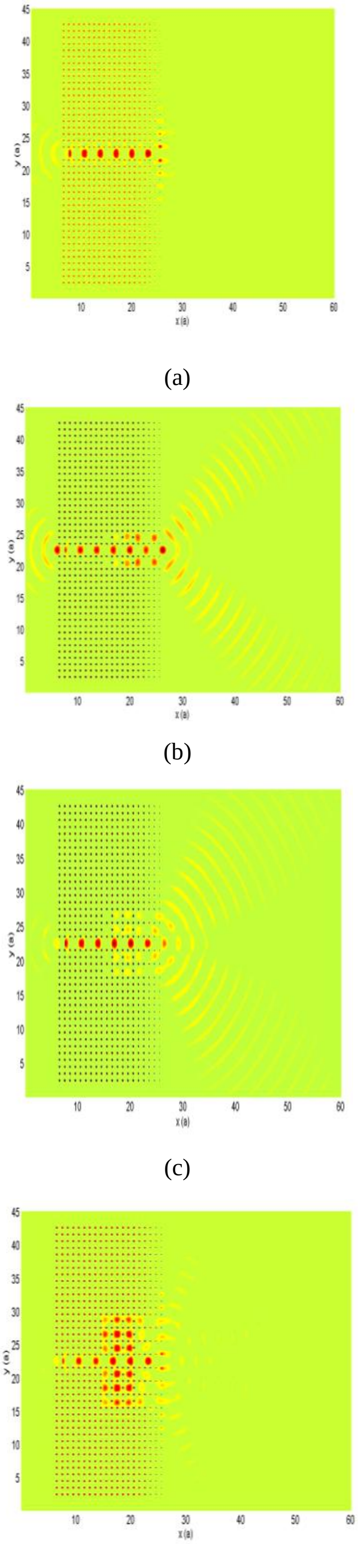
A waveguide (W1) is constructed by removing one raw of the rods along x , as shown in Fig. 1(a) and (b) CCWs are created by removing some cylinders at regular interval of $2a$ parallel to the W1, and a coupled multi-channel taper waveguide with L_x (the number of cylinders along x) and L_y (the number of waveguides along y) is added to the right side of the main structure. From the left side to the right side of the taper zone, the radius of the cylinder decrease with $0.02a$ from $0.18a$. We launched continues wave signal with a normalized frequency of 0.408 into the PC waveguide. To characterize the filed of the output port, we laid ten power detectors along the arc shown in Fig. 1 (a) with an interval of 10^0, the distance between the output port and the detectors is $10a$. All results presented are for TM polarization and have been obtained with the 2D FDTD with perfectly matched layer boundary conditions. The simulations use 20×20 grids in per unit cell.



(a)

(b)

Fig. 1. The structure and parameter introduction of which are considered below. (a) Without CCWs, (b) with CCWs and $L_y = 3$.



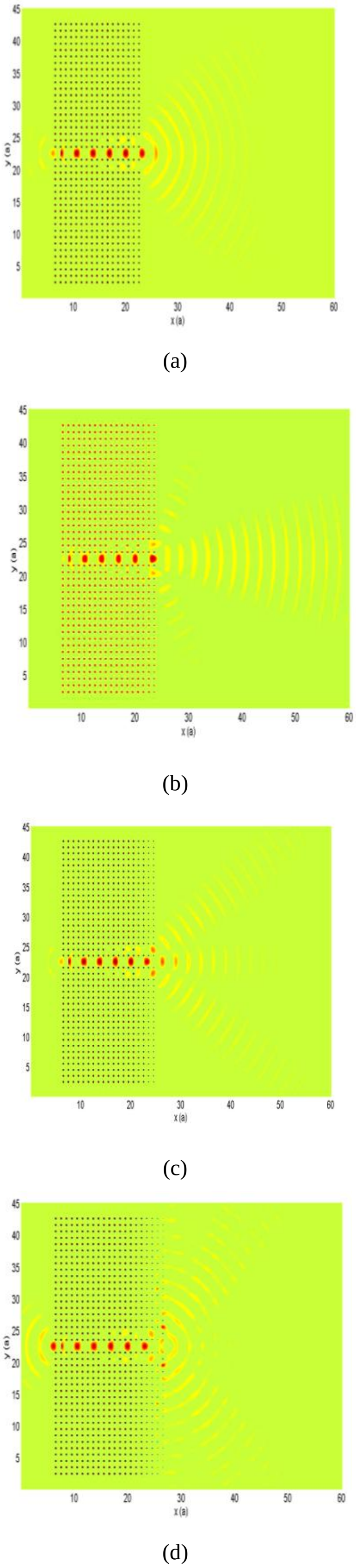
(a)

(b)

(c)

(d)

Fig. 2. Electric field distribution of the correspond structure shown in Fig.1 with $L_x = 5$. *（a）* $L_y = 1$, *(b)* $L_y = 3$, *(c)* $L_y = 5$, *(d)* $L_y = 7$.



(a)

(b)

(c)

(d)

Fig. 3. Electric field distribution of the correspond structure shown in Fig.1 with $L_y = 3$.（a） $L_x = 2$, (b) $L_x = 3$, (c) $L_x = 4$, (d) $L_x = 6$.

It is shown in Fig. 2 that while the CCWs are inserted and the surface is modified in the structure, a Y shaped spatial beam splitter with excellent performance can be achieved in the case of $L_x = 5, L_y = 3$. The PC structure is shown in Fig. 1 (b). A plane wave of TM modes light source propagating along x-axis is place at input port of $(0, 22.5a)$ and the width is $2a$.

The electric field distribution of correspond structure for different L_x is shown in Fig. 3, with $L_y = 3$.（a） $L_x = 2$, (b) $L_x = 3$, (c) $L_x = 4$, (d) $L_x = 6$. We compare Fig. 2 (b) with Fig. 3, they clearly show perfect spatial Y beam splitter prosperities with $L_x = 5, L_y = 3$.

In order to know the prosperities of the Y shaped beam splitter with $L_x = 5, L_y = 3$; we measure the Poynting vector S_r as a function of azimuthal angle θ in Fig. 4.

The poynting vector S_r is calculated with the electromagnetic from the 2D FDTD method, using the Eq. 1.

$$S(\omega) = 1/2\,\mathrm{Re}[E(\omega)\times H^*(\omega)] \qquad (1)$$

In the FDTD method, all the fields are obtained in the time domain. Thus, one needs to transform the calculated filed u (e.g., E_Z, H_y) from the time domain to the frequency domain by the fast Fourier transform (FFT). It can be performed on the fly concurrently with the FDTD time stepping using the following formula,

$$u(\omega) = \int_0^{N_t} u(t)e^{-i\omega t}dt \approx \sum_{n=0}^{N_t} u(n\Delta t)e^{-in\omega\Delta t}\Delta t \qquad (2)$$

where N_t is the total time steps, and n is the current time step.

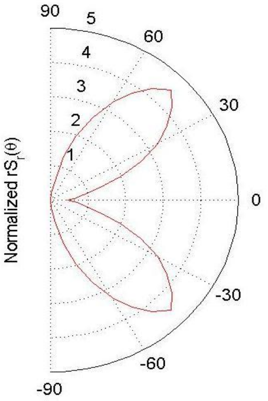


Fig. 4. Far-field radial component of the pointing vector S_r as a function of azimuthal angle θ, in the case, we take $L_x = 5, L_y = 3$ correspond to the well Y beam splitter shown before.

Namely, a Y shaped beam splitter with symmetrical energy distribution is achieved. The measured transmittance of the structure we proposed is 90.64%.

3. Conclusions

In conclusion, we accomplish the highly transmission spatial Y beam splitter design and consider the coupled multi-channel taper waveguide with L_x (the number of cylinders along x) and L_y (the number of waveguides along y) compact on the behavior of the beam splitter we supposed. The plane wave expansion is employed to calculate the band gap, and the FDTD method is used to demonstrate distribution of the electric field. All those structures have symmetrical energy distribution. While L_x and L_y are designed suitable, highly transmittance can be achieved. The enhancement of the light splitter transmittance may have potential applications in integrated optical and micro-photonic circuit.

Acknowledgments

The author would like to acknowledge the financial support of the National Natural Science Foundation of China through Grant No. 60588502.

References

[1] H. A. Bethe, Phys. Rev. **66**, 163 (1994).
[2] E. Yablonovitch, Phys. Rev. Lett. **58**, 2059 (1987).
[3] S. John, Phys. Rev. Lett. **58**, 2486 (1987).
[4] K. M. Leung, Y. F. Liu, Phys. Rev. Lett. **65**, 2646 (1990) 3. Esteban Moreno, F. J. Garcı´a-Vidal, L. Martı´n-Moreno, Phys. Rev. B. **69,** 121402 (R) (2004).
[5] Z. H. Zhu, W. M. Ye, J. R. Yuan, C. Zen, Appl. Phys. B. **86**, 327 (2007).
[6] A. Yariv, Y. Xu, R. K. Lee, A. Scherer, Opt. Lett. **24**, 711 (1999).
[7] M. Bayindir, B. Temelkuran, E.Ozbay, Phys. Rev. B **61**, R11855 (2000).
[8] M. Bayindir, B. E. Ozbay, Phys. Rev. B. **62**, R2247 (2000).
[9] M. Bayindir, B. Temelkuran, E. Ozbay, Phys. Rev. Lett. **84,** 2140 (2004).
[10] A. Mekis, J. C. Chen, I. Kurland, S. H. Fan, P. R. Villeneuve, J. D. Jiannopulos, Phys. Rev. Lett. **77**, 3787 (1996).

---

*Corresponding author: xuquanwww@163.com