Packaging consideration of two dimensional polymer-based photonic crystals for laser beam steering

Xinyuan Dou[a], Xiaonan Chen[a], Maggie Yihong Chen[b], *IEEE Senior Member*, Alan Xiaolong Wang[b], Wei Jiang[c], Ray T. Chen[a*], *IEEE Fellow*

[a] Microelectronics Research Center, Department of Electrical and Computer Engineering, University of Texas at Austin, Austin, TX, 78758, USA

[b]Omega Optics, Inc. Austin, TX 78758

[c]Department of Electrical and Computer Engineering, and Institute for Advanced Materials, Devices, and Nanotechnology, Rutgers University, Piscataway, NJ 08854

*Email: chen@mail.utexas.edu

ABSTRACT

In this paper, we report the theoretical study of polymer-based photonic crystals for laser beam steering which is based on the superprism effect as well as the experiment fabrication of the two dimensional photonic crystals for the laser beam steering. Superprism effect, the principle for beam steering, was separately studied in details through EFC (Equifrequency Contour) analysis. Polymer based photonic crystals were fabricated through double exposure holographic interference method using SU8-2007. The experiment results were also reported.

Key words: photonic crystals, beam steering, superprism effect, holographic interference

1. INTRODUCTION

Photonic crystals are artificial periodic dielectric structures to control light propagation[1]. Recently a method has been demonstrated for controlling the propagation of light inside a photonic crystal, involving the manipulation of the anisotropy of the bands[2,3]. Due to this anisotropy, the propagation direction of light inside a photonic crystal can be extremely sensitive to the parameters such as the wavelength or the incident angle of the light beam. This effect, known as the superprism phenomenon, is observed, where anisotropy in photonic band structure is strongest and it behaves like negative refraction. Superprism effect is one of the unusual properties of the photonic crystals, which could lead to a large change of propagation direction of the light beam within the photonic crystals due to a small change of the incident beam, such as its direction or the wavelength. A prism made up of a photonic crystal would have a dispersion capability 500 times stronger than a prism made of a conventional crystal[2]. Various theoretical predictions and experimental studies have been reported regarding anomalous angular deviation at high frequencies near the photonic band gap[4-6]. In this work, we will consider a superprism configuration where the input and

Photonics Packaging, Integration, and Interconnects IX, edited by Alexei L. Glebov, Ray T. Chen,
Proc. of SPIE Vol. 7221, 722104 · © 2009 SPIE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.811708

output surfaces are perpendicular to each other. Here we give a detailed theoretical study of this effect through EFC (Equi-frequency Contour) analysis for the polymer based photonic crystals. The fabrication procedures of the photonic crystals are illustrated and the superprism effect-based beam steering is demonstrated.

2. MODELING AND SIMULATION

The layout of the polymer based 2D photonic crystals with an area of $100a\times100a$ is shown in Fig. 1a, where a is the lattice constant of the PC structures. In our simulation, the input beam wavelength λ is 1.55μm and the lattice constant a is 1.0μm (a/λ=0.6452), the material index n is assumed to be 1.6, which corresponds to the index of the SU8 polymer we use at the wavelength of interest. The 50° angle corresponds to the recording result during the experiment.

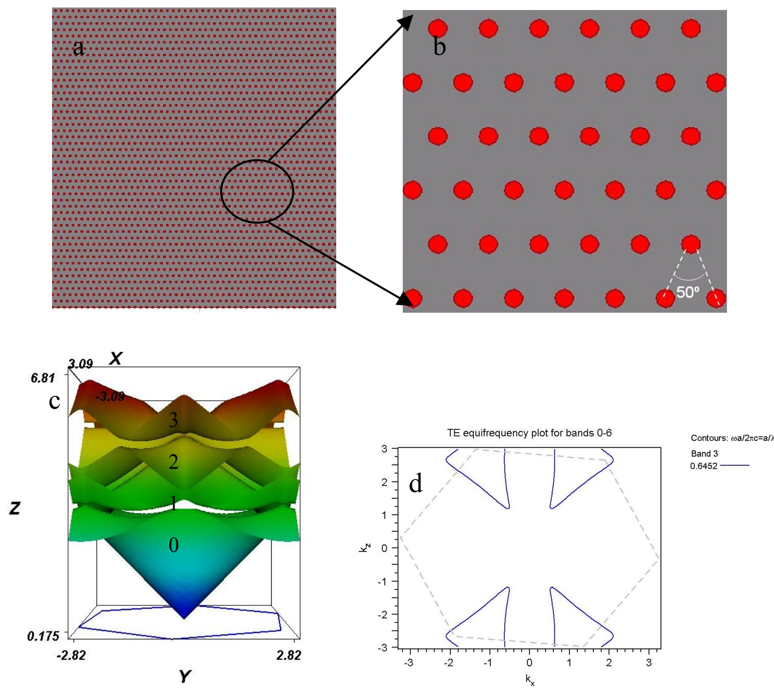

Fig.1. (a) (b) Layout of the photonic crystals in xoz plane. (c) 3D band structure of the polymer based photonic crystals. The x,y axis represents k_x and k_z, respectively. z represents the frequency. (d) The EFC (Equi-frequency Contour) at certain freqeuency($\omega a/2\pi c=a/\lambda$=0.6452) for band 3.

Fig.1c shows 3D view of the first four bands of the two dimensional polymer based photonic crystals. The lowest band is band 0, then band 1, band 2 and so on, indicated by numbers in Fig.1c. The EFC (Equi-frequency Contour) can be achieved by intercepting the 3D band structure by a certain frequency plane which is perpendicular to the Z-axis. In the EFC analysis (Fig.1d) we are interested in the band 3(Fig.1d) because it corresponds the beam wavelength at 1.55μm and it has the highest possibility of superprism effect.

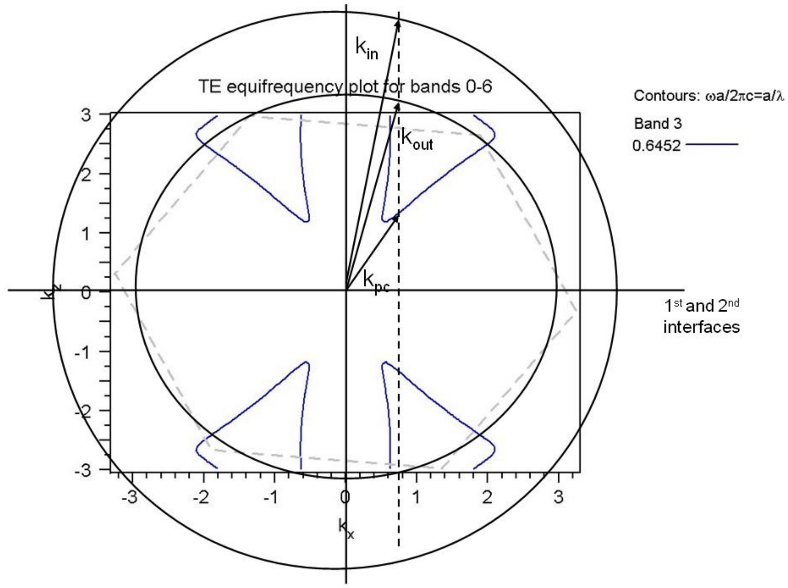

Fig. 2. Analysis of the refraction process when the input and output surfaces are parallel.

In Fig.2, we show the EFC analysis for the two parallel interfaces. k_{in} is the input wave vector, k_{pc} is the wave vector inside the photonic crystals, k_{out} is the output wave vector. The small and big circles are the air contour and medium contour, respectively. If the medium is also air, then the two circles are the same. The output wave vector is given by the conservation law of the tangential wavevector component at the interfaces [5]. Therefore the final results of the input and output wave vectors satisfy the Snell's Law. In this way, the photonic crystal superprism effect is cancelled by the two parallel interfaces. To avoid this effect, we have to use the photonic crystal effect using two nonparallel interfaces of the photonic crystals.

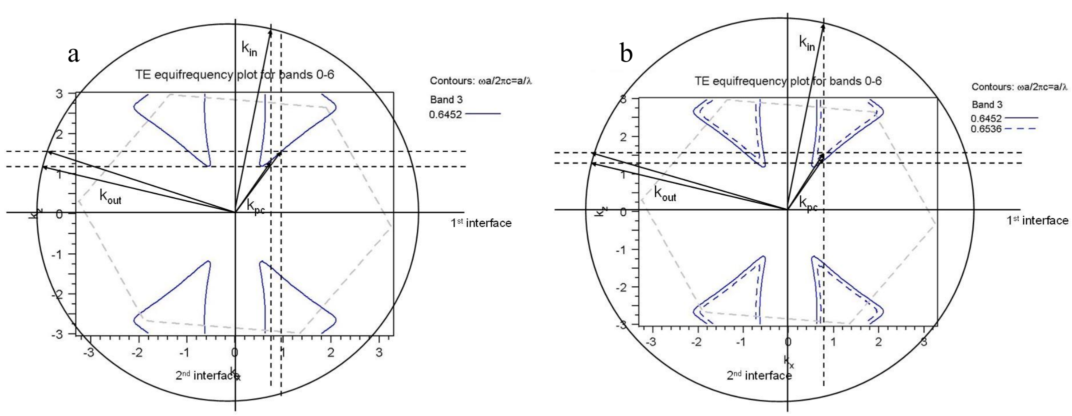

Fig.3 EFC analysis for (a) the input angle change and (b) input wavelength change

In Fig.3, we show the EFC analysis of the refraction process, or the superprism effect process with two perpendicular interfaces. The laser beam first enters the photonic crystals area from the air or medium. After two refractions, the laser beam enters the air or medium again. The input or 1st and the output or the

2nd interfaces are perpendicular to each other. k_{in} is the input wave vector, k_{pc} is the wave vector inside photonic crystals. k_{out} is the output wave vector after the 2nd interface. k_{in} and k_{pc} have equal k_x component due to the momentum conservation at the 1st interface. k_{pc} and k_{out} have equal k_z component due to the momentum conservation at the 2nd interface. Momentum conservation is indicated by the dashed line in the figure. When the input angle or wavelength is changed, the corresponding wave vector k_{in} will be changed, so will k_{pc} be changed. k_{out} will also be changed according to the momentum conservation. In this analysis, we can find the exact cross point of EFC contour with the conservation dashed lines, so we can find the output angle change. That is also the beam steering principle. In Fig.4, we gave the simulated beam steering angle curves with respect to the input angle and input wavelength. Both of these two curves are achieved at around 1.55μm wavelength, 10º input angle. From these two curves, we can see when the input angle changes 2º, the output angle can change around 2.5º. When the input wavelength changes around 30nm, the output angle can change around 4º.

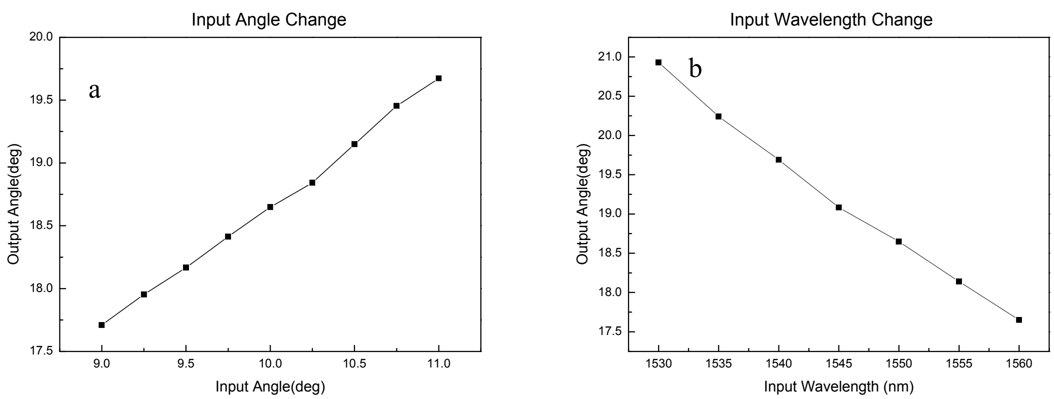

Fig.4 The output angle change vs (a) input angle change and (b) input wavelength change.

3. PHOTONIC CRYSTAL FABRICATION

In order to demonstrate the laser beam steering, we fabricated the two dimensional polymer based photonic crystals through double-exposure holographic interference method[7-8]. The photoresist we used in the fabrication is photoresist SU8-2007 and the laser is He-Cd laser at 325nm. A mirror was used to create the interference pattern. In order to carry out the beam steering test using a large collimated beam(1-2mm diameter), we made the photonic crystals parallel stacked with respect to the glass substrate. The scheme in Fig. 5 shows the complete fabrication process for the horizontally stacked photonic crystals. A pattern of Cr was deposited to block UV light to open trenches for the developing process. First Cr-patterned glass substrate was prepared using photolithography and lift-off technique. After coating the adhesion promoter, a film of 10μm thick SU8-2007 was spin-coated on the glass substrate. After baking the sample by ramping the hotplate from 65ºC to 95ºC, the double exposure was carried out at 325nm laser beam. Post exposure bake was at the same condition as the pre-bake. At last the sample was developed at room temperature.

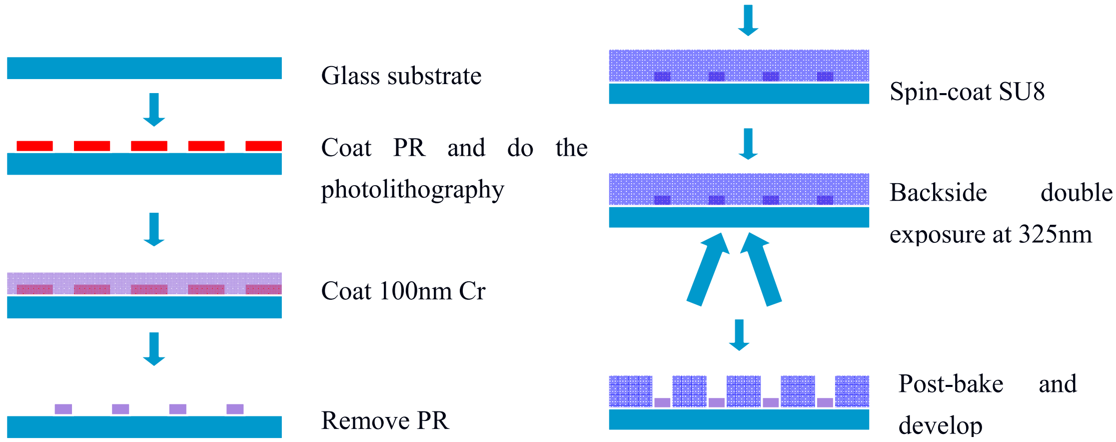

Fig.5 The scheme of fabrication of horizontally stacked photonic crystal on the glass substrate.

Fig.6 shows the SEM pictures, which show the period of 2D photonic crystal structures with a feather size around 1.0μm.

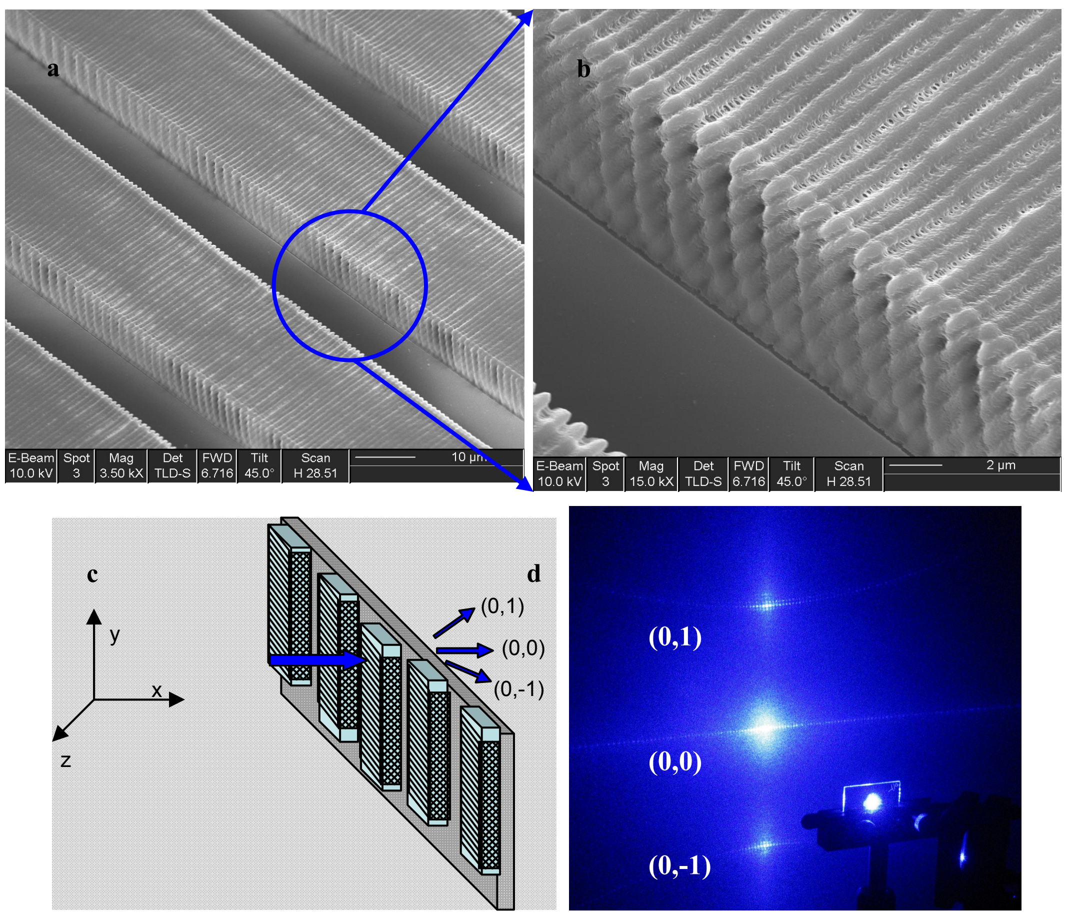

Fig. 6 (a) low and (b) high magnification view SEM pictures of the horizontally stacked photonic crystal structures fabricated using SU8. (c) The schematic laser diffraction setup. (d) The 442nm laser diffraction pattern of the fabricated photonic crystals.

Fig.6c shows the schematic view of the laser diffraction setup. Fig.6d shows the 442nm laser diffraction pattern. From the diffraction pattern, we can clearly see the center spots, which is corresponding with the zero order (0,0) beam diffraction and the two first orders (0,1) and (0,-1) order. The first order diffraction angle at 27.2º indicates the period of the photonic crystals to be 0.97µm, which is consistent with the simulation. The periodical photo polymer belts with a period of 30um also have a grating effect, which produces the discrete spots horizontally in *z* direction (Fig.6c,d). The photonic crystal diffraction effect is in the vertical *y* direction, which appears in a line of weaker spots on the top (0,1) and bottom(0.-1) of the screen. Beams (0,1) and (0,-1) are symmetrical around the input beam and have the same intensity. In this way, we have successfully achieved the horizontally stacked 2D polymer based photonic crystals structures through double-exposure holographic interference. Note that this diffraction experiment with input and output surfaces parallel to each other was solely intended for the confirmation of photonic crystal lattice structure. The superprism effect must be investigated with perpendicular input and output surfaces and the details will be presented in the next section.

4. MEASUREMENT RESULTS

The beam steering experiment was carried out at 1.55µm. The setup is shown in Fig.7. Fig.7a is the schematic view of the optical beam steering setup. First, the input beam enters the glass substrate, and then the photonic crystal region. Some part of the beam will be reflected at the glass/air interface and some part will directly pass through the photonic crystal. The beam which has refractions at the glass/PC interface and the PC/air interface at the edge can be captured by the IR camera. Fig.7b is the actual experimental setup. We observed three output beams, the transmitted beam, reflected beam and the superprism steering beam. The steering beam was observed by IR camera.

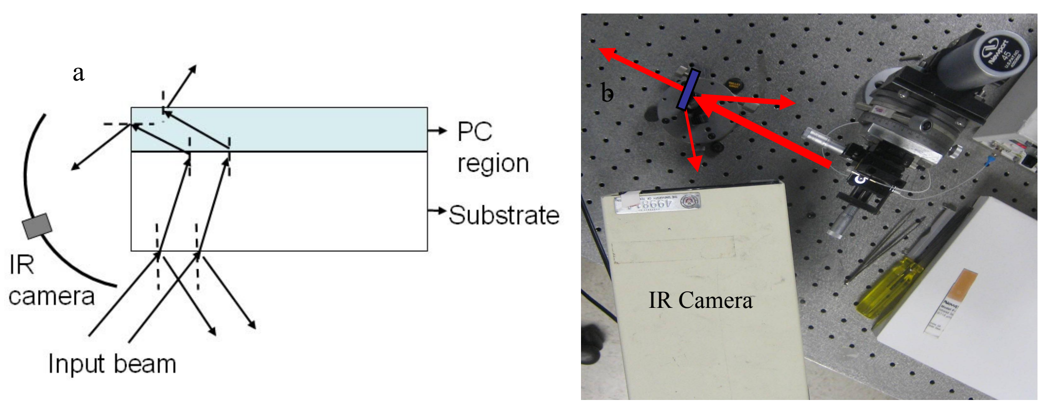

Fig.7 (a) Schematic view and (b) experimental setup of the beam steering test

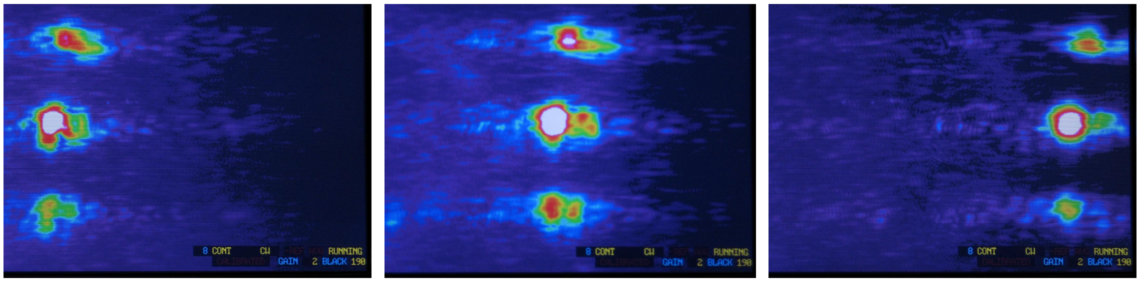

Fig.8 Typical IR camera view of the steering output beams for three different input angles at 1.55μm wavelength.

In Fig.8, we show the typical output steering beam image capture by the IR camera at three different input angles or three different input wavelengths. The vertical discrete spots are due to the polymer belts or bars grating effect. When the input angle or input wavelength changes, the steering discrete beam spots move simultaneously in horizontal direction, which corresponds to the output angle change. Fig.9 shows the measured optical beam steering experiment results for the input wavelength change and the input angle change. The steering angle is around 10º for 30nm input wavelength change and 6º for 1.5º input angle change. Comparing with the simulations, the experiment results have some difference because the photonic crystals in the simulation are for ideal configurations and shapes.

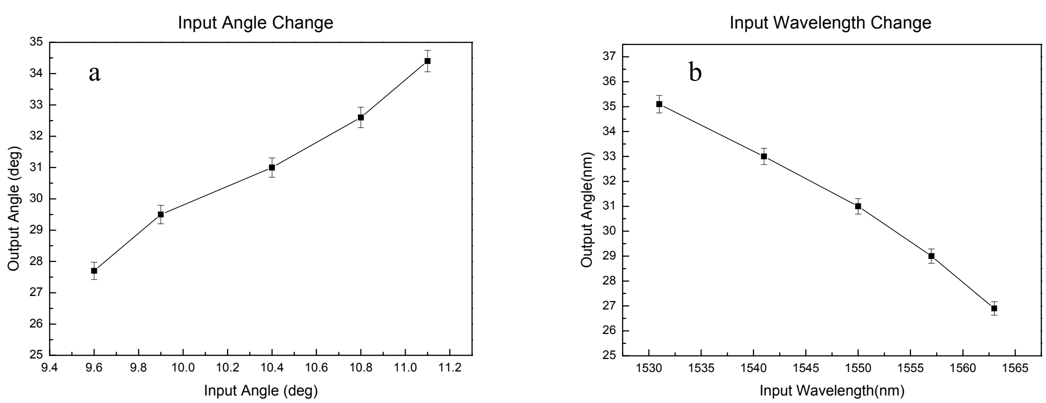

Fig.9. The beam steering experiment result based on the (a) input angle change and (b) input wavelength change.

4. CONCULUSION

In conclusion, we reported the polymer-based photonic crystal beam steering simulation and the fabrication of horizontally stacked photonic crystal structures through holographic interference method using photo polymer SU8. The beam steering was studied in detail using EFC (Equi-frequency Contour) method. SEM pictures and laser diffraction pattern of the fabricated photonic crystal were also shown. Optical beam steering at 1.55μm was carried out for the input angle change and the input wavelength change. The experimental results show strong superprism effect. This research is supported by AFRL. Helpful discussion with Jiaqi Chen, Dr. Lanlan Gu and Dr. Robert Nelson is acknowledged.

REFERENCES

1. E. Yablonovitch, Phys. Rev. Lett. 58, 2059 (1987)
2. H. Kosaka, T. Kawashima, A. Tomita, M. Notomi, T. Tamamura, T. Sato and S. Kawakami, Phys. Rev. B 58, R10096 (1998)
3. H. Kosaka, T. Kawashima, A. Tomita, M. Notomi, T. Tamamura, T. Sato and S. Kawakami, Appl. Phys. Lett. 74, 1370 (1999)
4. S. Lin et al., Opt. Lett. 21, 1771 (1996)
5. W. Jiang, R. T. Chen, and X. Lu, Phys. Rev. B 71, 245115 (2005)
6. W. Jiang and R. T. Chen, Phys. Rev. B 77, 075104 (2008)
7. JQ Chen, W. Jiang, XN Chen, L. Wang, SS Zhang, and R. T. Chen, Appl. Phys. Lett. 90, 093102(2007)
8. T. Kondo, S. Juodkazis, V. Mizeikis and H. Misawa, Optics Express, 14, 7943 (2006)