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Optical Phase Conjugation in One-Dimensional Photonic Crystals

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Photon modes in photonic crystal structures are greatly modified from those in vacuum. In one-dimensional photonic crystals with a structural defect, there is a localized mode where the field is localized around the position of the defect. If the defect is made of nonlinear optical material, the effective nonlinearity of the photonic crystal is largely enhanced by the enhanced light intensity at the defect. We observed a large enhancement of degenerate four-wave mixing efficiency in a one-dimensional photonic crystal with a defect. Since the total thickness of the whole structure is only a few micrometers, it was successfully used to form an optical phase-conjugated image.

Keywords: photonic crystal; one-dimensional photonic crystal; photonic defect state; degenerate four-wave mixing; optical phase-conjugation

INTRODUCTION

Much interest has been devoted to photonic crystals since the formal similarity between Schrödinger equation for electrons and Maxwell equation for photons was clearly recognized. Control of photon modes by using photonic crystal structures is expected to be a key technology for future photonic devices. It is expected that spontaneous emission is completely inhibited in photonic band gaps, and optical nonlinearities can be enhanced by using the photonic defect states. But at present it is not easy to fabricate three-dimensional photonic crystals with desired structures, since the control of dielectric constant with spatial precision higher than the wavelength of light is very difficult.

In many applications, however, the control of laser beams is required where laser beams are close to plane wave. In this case we don't need to have

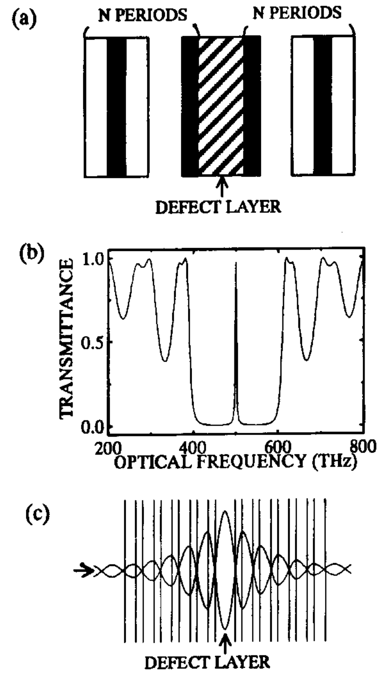

FIGURE 1 (a)Model structure of 1-D PC with a defect. (b)Transmission spectrum of 1-D PC. (c) Field pattern of light in 1-D PC.

three dimensional photonic crystals but one-dimensional photonic crystals (1-D PC) or dielectric multi-layers are sufficient. Quarter-wave stacks of dielectrics with different refractive indices, a kind of 1-D PCs, have a wide photonic band gap at the wavelength where Bragg reflection takes place. By placing a structural defect in the center of the stacks, a photonic state, which is localized around the defect, can be made. The defect state induces a sharp transmission peak in the band gap, and the wavelength of the transmission peak can be changed by changing the thickness or refractive index of the defect layer. Figure 1(a) shows a model structure of the 1-D PC with a defect in the center of the stacks, and Figure 1(b) and (c) show the simulated transmission spectrum and the field pattern of light at the transmission peak wavelength, respectively. From the figure we see that effective optical nonlinerity of the defect material in the center can be greatly enhanced by the enhanced light intensity at the defect.

DEGENERATE FOUR-WAVE MIXING

We fabricated a 1-D PC with a defect in the center. The defect layer was a spin-coated polyvinyl alcohol film doped with eosin Y, and this film was placed between 5-periods quarter wave stacks of SiO_2 and TiO_2.

The efficiency of degenerate four-wave mixing (DFWM) of the 1-D PC

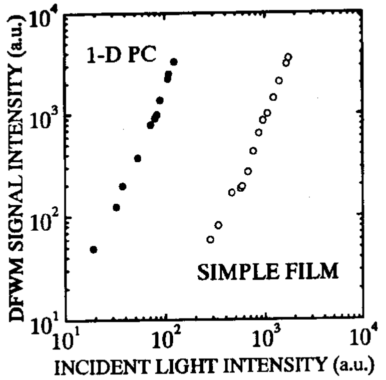

FIGURE 2 Incident intensity dependence of the DFWM signal intensity.

was compared with that of a simple polyvinyl alcohol film doped with eosin Y. The excitation light was second harmonics of a Q-switched YAG laser with 5ns pulse widths at 532nm. Since the wavelength of the transmission peak of the 1-D PC depends on the angle of incidence, we used box-CARS configuration of DFWM where the angles of incidence of all the three excitation beams and the output beam were the same, 2 degrees.

The refractive indices of SiO_2 and TiO_2 are 1.46 and 2.35, respectively, and the ratio of the two is 1.6. Therefore, if all the materials in the 1-D PC are transparent, the enhancement factor of DFWM efficiency in the 1-D PC against a simple film is calculated to be $(1.6)^{4N}$, where N is the number of periods of dielectric stacks on one side of the defect layer[1]. By substituting N=5, we obtain the enhancement factor of 12,000 for the DFWM efficiency in the 1-D PC against a simple film made exactly the same with the defect layer.

In the present 1-D PC, however, we used absorptive nonlinearity of eosin Y dye molecules at the defect layer, therefore the enhancement of the light intensity at the defect was reduced by the absorption, and so was the enhancement of the DFWM efficiency. Figure 2 shows the comparison between the relative efficiencies of the 1-D PC and a simple polyvinyl alcohol film doped with eosin Y where the simple film was made exactly the same as the defect layer in the 1-D PC. From Figure 2, we see about 1000 times of enhancement of the DFWM efficiency for the present 1-D PC against the simple film. When the transmittance at the transmission peak of the 1-D PC is 0.1, the calculated value of the enhancement factor is 1300. The agreement between the experiment and the calculation is fairly good.

OPTICAL PHASE CONJUGATION

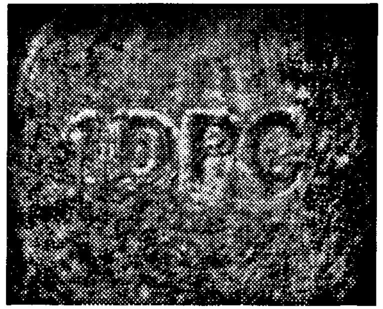

FIGURE 3 Optical phase-conjugated image of "1DPC" by the 1-D PC.

Dye doped polymer films are good media for phase conjugation optics and image processing. Although the present 1-D PC has complicated structure, the total thickness is only a few micrometers. This point is very much different from ordinary nonlinear etalons used for bistability or optical switching [2,3]. Therefore the present 1-D PC can be used to form an optical phase-conjugated image.

For the demonstration of image construction, a cw Ar laser at 514.5nm was more convenient as the excitation source. The defect layer in this case was a polyvinyl alcohol film doped with methyl orange. The dielectric stacks on both sides of the defect layer were the same as the previous experiment. Since the wavelength of the transmission peak depends on the angle of incidence on the 1-D PC, optical systems are aligned so as that all the three incident beams and the phase-conjugated beam have the same angle of incidence. The acceptance angle of the peak transmission of the 1-D PC was about 80 mrad, therefore the beam divergence of the image beam was limited by this angle. The incident beams were focused on the 1-D PC to the spot diameter of about 1 mm, and the power of each incident beam was a few mW. Figure 3 shows the formed phase-conjugated image "1DPC" by the present 1-D PC. Because of the optical imperfection of the defect layer in the 1-D PC, the formed image is not so clear. But it was apparently shown that 1-D PC structures can be used for phase conjugation optics and image processing.

References

[1.] T.Hattori, N.Tsurumachi and H.Nakatsuka, *J.Opt.Soc.Am.B*, **14**, 348 (1997).
[2.] H.M.Gibbs, S.L.McCall and T.N.C.Venkatesan, *Phys.Rev.Lett.*, **36**, 1135 (1976).
[3.] R.Quintero-Torres and M.Thakur, *Appl.Phys.Lett.*, **66**, 1310 (1995)