Three-Dimensional Photonic Crystal for Spatial Filtering

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Abstract

It is well known that photonic crystals exhibit frequency band gaps. The main application of that property is that one can utilize it for a frequency filtering. Recently it has been proposed that angular band gaps in two and three-dimension photonic crystals can be similarly applied for a spatial filtering of light beams [1]. The purpose of this paper is to experimentally demonstrate that photonic crystals can spatially filter the light.

1. Introduction

For improving of spatial quality of light beams spatial filtering technique is broadly used [2]. The conventional technique of spatial filtering consists of a confocal system of lenses and a diaphragm of the appropriate diameter at the focal point. In the present paper another alternative method using Photonic Crystals (PCs) for spatial filtering is described and proved experimentally.

PCs are the materials with periodically spatially modulated refraction index on a wavelength scale. They are widely studied due to their temporal dispersion properties, especially due to the band gaps in frequency domain. Recently it has been predicted that spatial dispersion can be also modified in Photonic crystals [1]. In paper we show experimental results which prove the effect of spatial filtering. We present the advanced results from the first experimental demonstration of spatial filtering method in [3].

2. Photonic crystals

In order to create periodic refraction index modulation (longitudinal and transverse period - $d_{\parallel} = 5.8\ \mu m$ and $d_{\perp} = 1.5\ \mu m$, the modulation of the index was of the order of 10^{-3}) in a glass bulk we used femtosecond laser pulses. The mechanism responsible for the spatially dependent index change is not completely understood; the magnitude of the index change depends on material and exposition conditions [4]. For fabrication we used $\tau = 300\ fs$ duration, $f = 50\ kHz$ repetition rate pulses at the wavelength of $\lambda = 1030\ nm$. The laser beam was focused using $f = 4{,}03\ cm$ aspheric lens with numerical aperture *of* $NA = 0{,}62$, which allows to focus the incident laser beam to the spot of 1 μm. The average laser power of $P = 100\ mW$ corresponds to $\Phi_w = 130\ \mathrm{J/cm^2}$ energy density at the focal point.

This particular geometry (Fig. 1) was chosen in order to demonstrate spatial filtering for wavelength $\lambda = 532\ nm$.

Here ellipsoids indicate the areas illuminated by femtosecond pulses and correspond to areas with enhanced refraction index. Different colours of the ellipsoids indicate odd and even layers of photonic crystal which are half-period shifted one with respect to another. Green pointers correspond to light beam propagation direction.

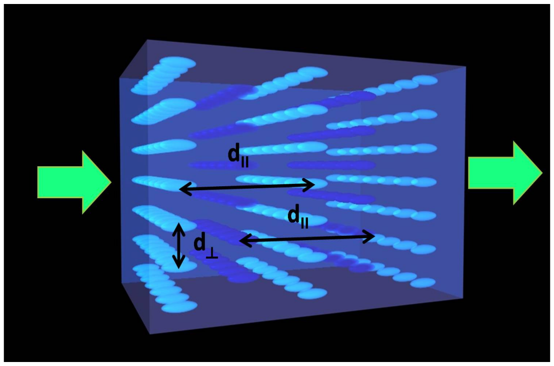

Fig. 1: The geometry of the PC used.

3. Results

We illuminated the PC with a focused beam of CW Nd:YAG laser with wavelength $\lambda = 532\ nm$ and power up to $P = 100\ mW$. The PC was located in the focus of the beam so that the waist of the beam would fit inside the PC. The spatial distribution of the intensity of the beam behind the PC (far field) was observed on a screen (Fig. 2.a)) and recorded by CCD camera (Fig. 2.b)).

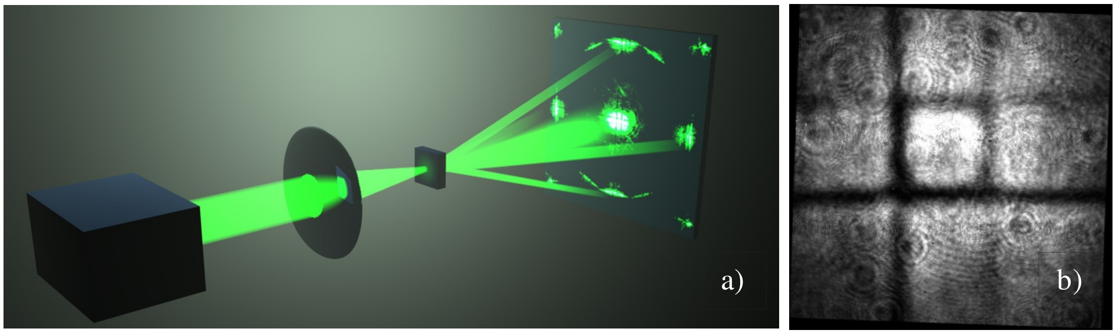

Fig.2: a) The experiment consisting of a focused laser beam, PC and a remote screen for the observation of the far-field. b) The CCD image of the central part of the beam with particular beam components filtered out (dark lines crossing each other and making a square around the centre).

The results we have obtained show the expected effect of the spatial filtering in PCs. Fig. 2 b) shows the structure of the central maximum of transmited beam which consists of the crossing dark lines which corresponds to the filtered out angular components of the spatial spectra. The structure of the dark lines in the central maximum is in a good agreement to the theory [1].

3. Theory

We consider light propagation in a material with spatially modulated refraction index, as described by paraxial model:

$$\left(2ik_0\, \partial/\partial z + \nabla_{\perp}^2 + 2\Delta n(x, y, z)k_0^2\right)A(x, y, z) = 0 \qquad (1)$$

Here $A(x, y, z)$ is the slowly varying complex envelope of the electromagnetic field in 3D space and $\Delta n(x, y, z)$ is the fabricated profile of refraction index. The numerical study of (1) allows to reproduce the experimentally recovered distributions in far field, i.e. four crossing lines in $k_\perp$ space, as shown in Fig. 3. Physically speaking the radiation from each of the resonance lines is efficiently transported to their "own" diffraction components.

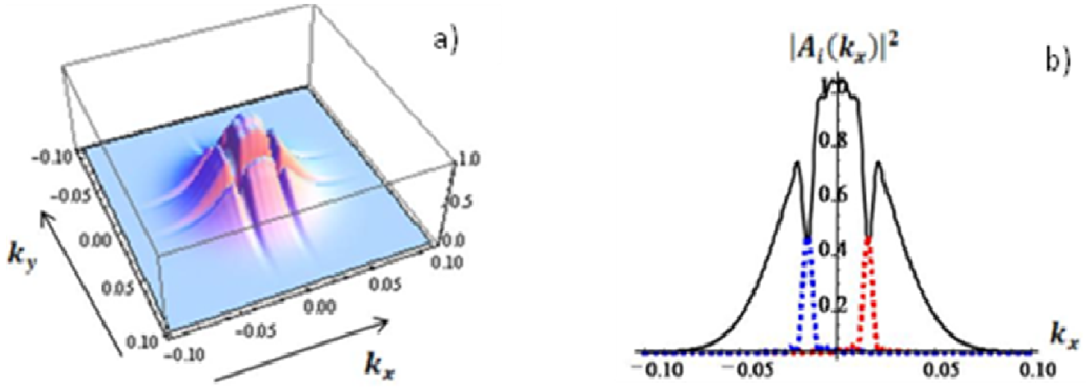

Fig. 3: The 2D transmission profile (a) as well as the distribution on a horizontal cut (b), as obtained by numerical integration.

4. Conclusion

We give first experimental demonstration of the signatures of spatial filtering of light beams by three-dimensional photonic crystals according to the recent theoretical predictions [1]. These signatures are the modification of the angular spectra of the propogating beams when particular angular components are deflected, i.e. removed from the central maximum, or in other words filtered out. The reported effect of spatial filtering is relatively weak, and carries a demonstrational character only, as the dark lines are relatively narrow. In order to obtain a technologically utile spatial filter the higher index contrast PCs are necessary, which are to be based on new materials and new fabrication technologies.

References

[1] K. Staliunas and V.Sanchez-Morcillo, Spatial filtering by chirped photonic crystals, Phyical Reiew A, vol. 79, p. 053807, 2009.
[2] A. E. Siegman, Defining, measuring, and optimizing laser beam quality, Proceedings SPIE, vol. 1868, p. 2, 1993.
[3] L.Maigyte, K. Staliunas, et al., Signatures of light-beam spatial filtering in a three-dimensional photonic crystal, Physical Review A, vol. 82, p. 043819, 2010.
[4] R.R. Gattas and E. Mazur, Femtosecond laser micromachining in transparent materials, Nature photonics, vol. 2, p. 219, 2008.