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Original Scientific Paper

LIGHT CAPTURING WITHIN THE DEFECT LOCATED IN LINEAR ONE-DIMENSIONAL PHOTONIC LATTICE

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ABSTRACT

Numerically investigated the light beam propagation through one-dimensional photonic lattice possessing one linear defect. It is shown how capturing of light depends on lattice characteristics as well as the width and wavelength of input light beam. Results may be useful for all-optical control of transmission of waves in interferometry.

Keywords: Photonic lattices, Linear defect, Trapping efficiency, Optical control.

INTRODUCTION

Wave propagation in periodic optical lattices has been intensively studied in the last years. Photonic lattices (PL) are periodic structures that are widely used for light manipulation in photonic devices (Song et al., 2003). Their periodic structures enable the study as discrete diffraction (Eisenberg et al., 2000) the existence of Bloch oscillations (Peschel et al., 1998) discrete and gap solitons (Christodoulides et al., 2003; Neshev et al., 2007; Garanovich et al., 2012). Localized modes can be formed inside the lattice and are influenced by the very geometry of photonic systems, such as modulated lattices (Cao et al., 2012) and flat-band lattices (Vicencio et al., 2015; Beličev et al., 2015). The periodicity enables formation of zonal structure. The zonal structure consists of permitted and forbidden zones which can allow or stop light beam propagation. The zonal structure can be changed by introducing defect into the lattice (Yablonovitch, 1993; Meade et al., 1993). Control of light propagation in one-dimensional (1D) photonic crystals is possible by changes system parameters, such as refractive index, lattice period and the width of defect (Suntsov et al., 2006; Matias et al., 2003; Kuzmanović, 2016; Stojanović Krasić et al., 2017). The defects disrupt translational symmetry and enables the formation of localized defect modes (Gupta et al., 1997, Tsai et al., 1998). Defects in PL may stop light (Goodman et al., 2002), trap or deflect the incident beam (Molina et al., 2006). Can be used for all-optical switching and routing (Wang et al.; 2009, Ye et al., 2008). Defects be formed by changing the value of refractive index in certain WG or by changing the width of the WG or the distance between WGs (Meier et al., 2005, Morandotti et al., 2003). Lattice defects increase the complexity of the zonal structure by creating defect levels within the gaps (Beličev et al., 2010; Fedele et al., 2005; Molina et al., 2008).

The propagation of waves in periodic systems with linear and nonlinear defects were investigated (Mak et al., 2003; Molina et al., 2006) and the scattering of linear and nonlinear waves in series with a PT-symmetric defect (Dimitriev et al., 2011). Structural defect significantly influences the propagation of light beams in the vicinity of lattices compound and enables the existence of various localized components.

In this work, we numerically analyze how light capturing is affected by lattice parameters and by light characteristics such as wavelength and full width at half maximum.

THEORETICAL PART

We analyze the linear one-dimensional PL which contains a linear defect (LD) embedded (Figure 1).

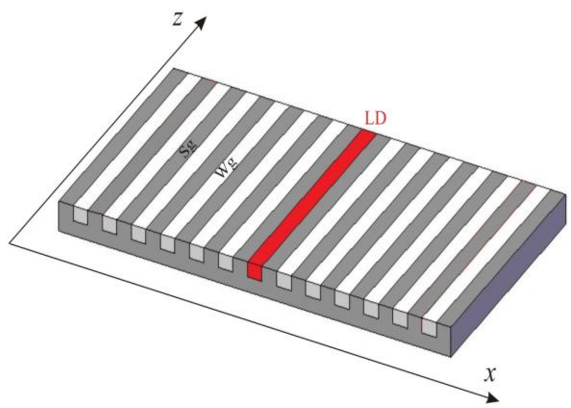

Figure 1. Schematic representation of the system. red line shows the position of the linear defect.

The light propagation through PL consisting of the linear waveguide array with embedded single linear waveguide. Mathematically, the model can be described with the paraxial time-independent Helmholtz equation (Kuzmanović et al., 2015):

$$i\frac{\partial E}{\partial z}+\frac{1}{2k_0n_0}\frac{\partial^2 E}{\partial x^2}+k_0n_0n(x)E=0 \qquad (1)$$

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where z is the propagation coordinate, $E(x,z)$ is the component of the light electric field in the z-direction, $k_0 = 2\pi/\lambda$ is the wave number, n_0 is the refractive index of the substrate, and λ is the wavelength of light. The lattice is prepared along the transverse x direction and there are 49 WGs in each lattice. Functional dependence of the refractive index on system parameters (Kuzmanović et al., 2016) given by in the form:

$$n_l(x) = \Delta n \left(\begin{array}{l} \sum_{j=1}^{k-1} G(w_g, s, x) + G_k(w_{gk}, s_k, x) \\ + \sum_{j=k+1}^{m} G(w_g, s, x) \end{array} \right) \quad (2)$$

where k is the position of the LD which is arbitrary placed in the lattice, m is the number of WGs in lattice Δn is the lattice potential depth. Parameters w_g mark the width within lattice. The parameter w_{gk} represents the width of the LD, while parameters s represents the spacing between WGs in the lattices. Functions $G(w_g, s, x)$ represent Gaussians corresponding to the WGs of the lattice, whereas function $G_k(w_{gk}, s_g, x)$ corresponds to the LD. Lattice potential depth is 0.011.

The explicit form of Gaussians is:

$$G_n(x, w_g, s) = \sqrt{\frac{4\ln 2}{\pi w_g^2}} \exp\left(-\left(\frac{x - ns}{w_g} \right)^2 4\ln 2 \right) \quad (3)$$

that models the waveguides refractive index profile (Kuzmanović et al., 2015).

The position of the center of the nth component Gaussian is marked ns, and it is shifted from the middle of the waveguide along the x axis. The respective width w_g represents the full width at half maximum.

Introducing dimensionless variables $\xi = k_0 x$ and $\eta = k_0 z$, the equation (1) obtained the following dimensionless form:

$$i\frac{\partial E}{\partial n} + \frac{1}{2n_0}\frac{\partial^2 E}{\partial \xi^2} + n_0 n(\xi) E = 0 \quad (4)$$

The light propagation across the lattice is initiated by the Gaussian light beam with wavelength λ = 450 nm and λ = 550 nm with the FWHM as a variable parameter. In the following, we use either Gaussian light beam with the FWHM = 1,5 μm, 2 μm, 3,5 μm, 4 μm and 6 μm. The light propagation is simulated numerically by the split-step Fourier method (Fisher & Bischel 1973).

NUMERICAL RESULTS

The aim of the numerical results is to compare how lattice parameters, as well as beam characteristics, affect light capturing at the 2 μm and 6 μm wide defect. The width of the LD is either 2 or 6 μm and further in the paper they will be marked as narrow and wide defect, respectively. The width of the WG within the lattice is variable parameter and we analyse $w_g = 3.5$ μm, 4 μm, 4.5 μm and 5 μm and the distance between neighboring WGs is $s_g = 3.5$ μm, 4 μm and 4.5 μm. LD is fixed in the middle of the lattice and its position does not change.

In general, the trapping efficiency in a lattice with a coupling defect depends on the wavelength of used light (please see Fig. 3 below) and the coupling strength of the defect compared to the rest of the lattice. Keeping the size of the defect and the wavelength of used light constant, the coupling strength may be changed either by changing the parameters of the uniform lattice (please see Figs. 2a and 2b) or by varying the FWHM of the input beam (please see Fig. 2, 3).

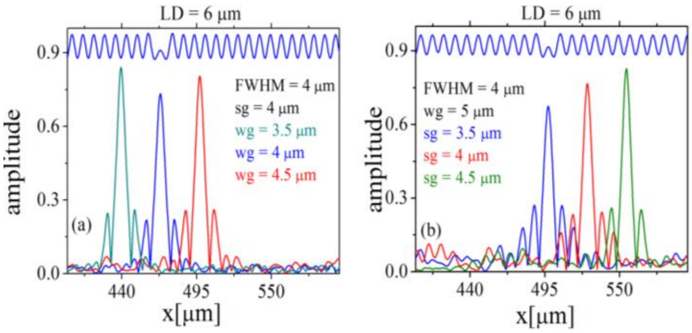

Figure 2. Amplitude profiles of the output light beams. Light (FWHM = 4 μm) is captured at the 6 μm wide LD in the lattice: a) The separation between waveguides is constant, while their width is the changeable parameter: 3.5 μm - green, 4 μm - blue and 4.5 μm – red colour. b) The width of the waveguides is constant and the separation between them is the varying parameter: 3.5 μm – blue, 4 μm – red, 4.5 μm – green colour. The potential of the lattice is schematically represented within the plots – blue curve in Figs. 2. a, b.

Light capturing at the 6 μm wide LD within the lattice, where the distance between the waveguides is constant (s_g) and where the width of the waveguides (w_g) is the varying parameter, is shown in Fig. 2a. Because of the different periods of the lattices, caused by diverse widths of the waveguides (3 μm, 4 μm, 4.5 μm), the positions of the LDs are shifted along the x – axis (see the positions of the green, blue and red curve). The potential of one of the lattices ($w_g = 4$ μm) is schematically represented in Fig. 2, 3, for the better readability. One may see that the different widths of the waveguides influence the amplitudes of defect modes (green, blue and red curve).

Light capturing at the 6 μm wide LD within the lattices where the width of the waveguides is constant and where the separation between the waveguides is the changeable parameter, is presented in Fig. 2b. It is obvious that different separations between the waveguides influence the trapping efficiency of the observed defect modes (see blue, red and green curve in the Fig. 2b).

Capturing of light at the 6 µm wide LD for two different wavelengths is presented in Fig. 3. There is a slightly difference between the amplitudes' heights when the wavelength of the used light is 450 nm or 550 nm (see red curve and red curve in Fig. 3).

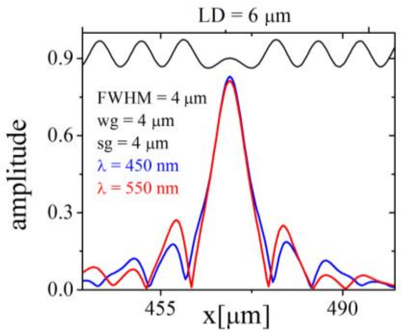

Figure 3. Amplitude profiles of the output light beams. Light (FWHM = 4 µm) is captured at the 6 µm wide LD in the lattice with $w_g = 4\,\mu\text{m}$ and $s_g = 4\,\mu\text{m}$. The blue curve denotes a light beam with the wavelength of 450 nm, while the red one marks the light beam with the wavelength of 550 nm. The potential of the lattice is schematically represented within the plots – black curve in Fig. 3.

In Fig. 4a and Fig. 4b it can be seen that the input of 4 µm gives the best capturing effect at the 6 µm wide LD (see red curve in Fig. 4a). In Fig. 4b, it can be seen that at the 2 µm wide LD the narrower input beam (2 µm FWHM) enables slightly better capturing (see – green colour in Fig. 4b).

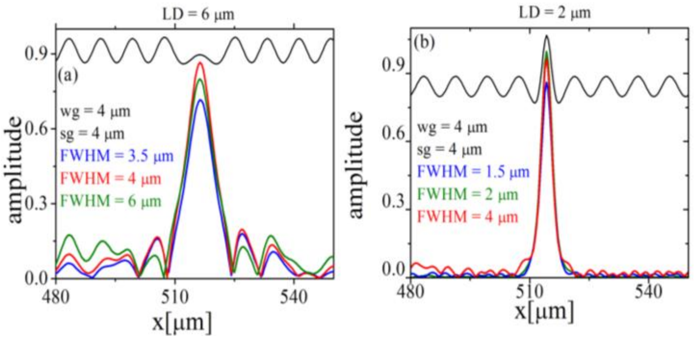

Figure 4. Amplitude profiles of the output light beams. Light is launched in the lattice where $w_g = 4\,\mu\text{m}$ and $s_g = 4\,\mu\text{m}$, at the: a) 6 µm wide LD. FWHM of the input beam is: 3.5 µm – blue, 4 µm – red, 6 µm – green. b) 2 µm wide LD. FWHM of the input beam is: 1.5 µm – blue, 2 µm – green, 4 µm – red. The potential of the lattice is schematically represented within the plots – black curve in Fig. 4.

CONCLUSION

We have numerically explored how LDs of different widths affect light beam propagation through a PL system with a LD. The chosen set of system parameters, the narrower LD is more efficient in light entrapment. The difference of light capturing is analyzed through varying the system parameters, waveguide width and separation between waveguides, and also by changing the characteristics of the light beam such as FWHM and waveguide.

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