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# EFFECT OF A GEOMETRIC DEFECT ON LIGHT PROPAGATION THROUGH A COMPOSITE LINEAR PHOTONIC LATTICE

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**Abstract**. *In this paper we investigated numerically light beam propagation through a one-dimensional composite photonic lattice composed of two structurally different lattices, with a geometric defect emerging at the interface between the two of them. Depending on the initial light beam position with respect to the geometric defect and the transverse tilt of the input beam, different dynamical regimes have been identified. Presented results may be useful for different applications, such as blocking, filtering and transporting light beams through optical media.*

**Key words**: *composite photonic lattice, transparency, reflection, trapping at defect*

## 1. INTRODUCTION

Photonic lattices (PL) represent a special kind of photonic crystals which consist of periodic arrays of evanescently coupled dielectric waveguides. In such structures, light can be confined at discrete sites inside the waveguides and at the same time it can propagate between channels via evanescent coupling (Garanovich et al., 2012). Due to their properties and structure, PLs represent a suitable system for investigation of wave propagation in periodic systems (Denz et al., 2010). In these periodic structures, different defects may arise in the process of their fabrication or are results of misusage, accidental damage, etc. These imperfections break the translation symmetry of the system but at the same time they allow for different types of stable, localized defect modes (Beličev et al., 2010; Chen et al., 2010; Fedele et al., 2005).

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Defects in PLs can be linear or nonlinear. The influence of a singular nonlinear defect, which may be formed by changing the value of the refractive index in a respective waveguide on the motion of the light beam across a uniform one-dimensional PL, has been investigated previously (Kuzmanović et al., 2015a). In this paper, we numerically investigate the dynamics of the light beam propagating through a composite PL consisting of two structurally different one-dimensional lattices. The interface between them represents a linear defect (i.e. geometric defect in the following). Depending on the input parameters, different dynamical regimes have been identified, including full transparency, blockade of light propagation by reflection from geometric defect (GD), as well as the trapping of the light on the GD.

The paper is organized as follows. The mathematical model of the wave propagation through the system is formulated in Section 2. By varying the initial beam position with respect to the position of the GD and the transverse tilt of the input beam (i.e. the inclination to the central waveguide), different regimes have been obtained and these numerical findings are presented and discussed in Section 3. In Section 4, conclusions are briefly summarized.

## 2. Model Equations

We consider a composite PL consisting of two different linear waveguides arrays, i.e. two PLs A and B, an interface layer between them presenting a geometric (structural) defect. The light propagation in this composite PL is modeled by the paraxial time-independent Helmholtz equation (Radosavljević et al., 2014):

$$i\frac{\partial E}{\partial z}+\frac{1}{2k_0 n_0}\frac{\partial^2 E}{\partial x^2}+k_0 n_0 n(x)E=0 \tag{1}$$

wherez is the propagation coordinate, $k_0=2\pi/\lambda$ is the wave number, $n_0$ is the refractive index of the substrate and $\lambda$ is the wavelength of light. The lattice is prepared along the transverse $x$ direction and the lattice system properties are modeled by functional dependence of the refractive index on system parameters which is defined in the form (Kuzmanović et al., 2015b):

$$n(x)=\sum_{i=1}^{m_A}G_i(w_{gA},s_A,x)+\sum_{i=1}^{m_B}G_i(w_{gB},s_B,x) \tag{2}$$

where $m_A$ ($m_B$) is the number of waveguides in lattice A (B). Parameters $w_{gA}$ and $s_A$ , and $w_{gB}$ and $s_B$ represent width and distance between neighboring WGs in the first lattice A and the second lattice B, respectively. The distance between lattices A and B, denoted by parameter $w$, represents the width of the geometric defect. Functions $G_i(w_{gA}, s_A, x)$ and $G_i(w_{gB}, s_B, x)$ represent Gaussians centered at $x=(i\text{-}1)(w_{gA}+s_A)+w_{gA}/2$ with the full width at half maximum (FWHM) $w_{gA}$, and $x=m_A(w_{gA}+s_A)+w+(i\text{-}1)(w_{gB}+s_B)+w_{gB}/2$ with FWHM $w_{gB}$ , respectively.

By introducing the dimensionless variables$\xi$=$k_0x$,$\eta$=$k_0z$Eq. (1) can be rewritten in the following dimensionless form:

$$i\frac{\partial E}{\partial \eta}+\frac{1}{2n_0}\frac{\partial^2 E}{\partial \xi^2}+n_0 n(x)E=0 \tag{3}$$

The light propagation along the lattice is initiated by the Gaussian-shaped input light beam and simulated numerically by the split-step Fourier method (Radosavljević et al., 2014). The light beam intensity was kept at the fixed value, while the position of the injection with respect to the defect and the value of the transverse tilt were the variable parameters in this study.

## 3. Results and Discussion

In order to demonstrate propagation of light through the composite lattice we have performed numerical simulations by using experimentally attainable lattice parameters (Chen et al., 2005, Smirnov et al., 2006). The length of the composite lattice, comprising two lattices A and B, is $z$=20 mm. The widths of the waveguides are 5 μm and 4 μm in the PL A and PL B, respectively, while the distances between the waveguides are the same in both PLs and they are set to 4 μm. The interface layer between the two lattices A and B is 3.3 μm wide and it represents a geometric defect. We will refer to the coupling of this interface layer with its first neighbors in lattices A and B, as the area of GD. In experiments, the composite lattice can be fabricated ona lithium niobate ($LiNbO_3$) undoped substrate using the standard photolithographic technique (Kanshu et al., 2009).

The intensity of the initial light beam is set to be weak enough in order not to affect the PLs characteristics during the propagation. The FWHM of this initial (Gaussian) beam is set to 4.3 μm.

The position of the initial beam with respect to the position of the geometric defect ($n$) and the inclination of the beam to the GD, i.e. the initial transverse tilt ($\alpha$), are changeable parameters in this study. The Input position of the incident beam was varied from the first neighbor of the GD till the ninth waveguide from the defect, while the initial tilt was changed from π/24 to π/3 (the case with a zero tilt was considered as well).

Since our composite lattice is composed of two structurally different PLs, i.e. the lattice is asymmetric with respect to GD, the starting point of the study was to investigate the influence of this asymmetry on the propagation of the beam through the composite lattice.

We have performed two numerical simulations, launching a Gaussian beam in the second waveguide left from the GD-area (lattice PL A) and right from it (lattice PL B), there was no initial transverse tilt ($\alpha$=0). In the case of the lattice composed of two identical PLs (i.e. the lattice is symmetric), one can observe partial reflection and transmission of the beam injected in the waveguide either left or right from the GD. i.e. the beam dynamic is symmetric with respect to the interface layer (Fig. 1).

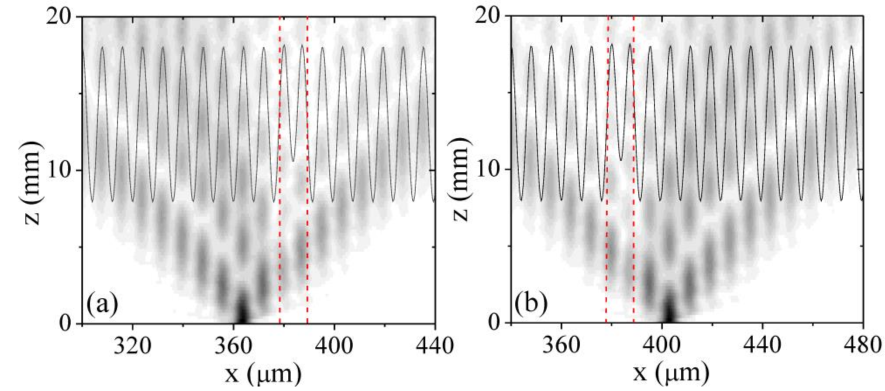


**Fig.1** Reflection and transmission of the Gaussian beam injected in the second waveguide left from the GD (a) and right from the GD (b). There is no initial transverse tilt. The composite lattice is composed of two identical PLs. The widths of the waveguides as well as distances between the waveguides are 4 μm, while the interface layer between the two lattices is 3.3 μm wide.

However, when the lattice is asymmetric, that being the case in our study, partial trapping and reflection of the beam from the area of GD is observed when the beam is injected in the waveguide right from the GD (Fig. 2(b)). On the other hand, the beam is predominately reflected when initiated in the waveguide left from the GD (Fig. 2(a)).Due to the structural difference of two PLs that compose the lattice, this difference being most pronounced in the interface layer, the composite lattice is 'deeper' on the right hand side (PL B side) and this leads to the trapping of the beam. This asymmetric behavior is observed for those beam injection positions close to the GD-area and small initial transverse tilt, i.e. these input settings lead to the trapping of the beam when launched in the lattice B. On the contrary, trapping is not observed for the beam launched in the lattice A with the same initial settings ($n$, $\alpha$). Otherwise, no qualitative difference regarding the propagation of the beam initiated left or right from the GD is observed (Fig. 3).

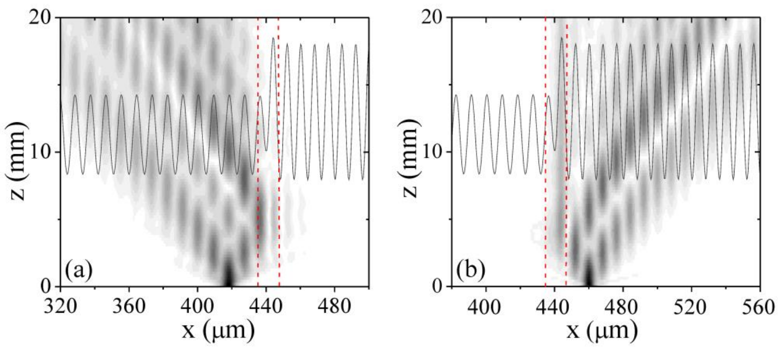


**Fig. 2** (a) Reflection of the Gaussian beam injected in the second waveguide left from the GD; (b) Reflection and trapping of the beam injected in the second waveguide right from the GD. In both cases, there is no initial transverse tilt. Composite lattice is composed of two structurally different PLs. Dashed red lines mark the area of GD.

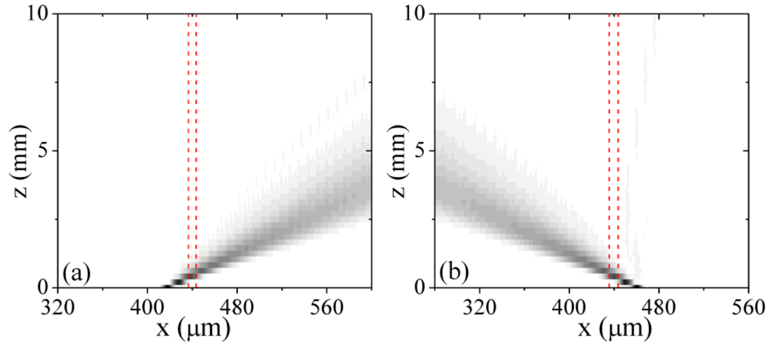


**Fig. 3** Symmetry in dynamical evolution of the beam launched in the second waveguide (with respect to the GD-area) in the lattice A (a) and lattice B (b), with $\alpha=\pi/6$. Transmission of the beam through the GD-area is observed.

Having all of this in mind we investigated propagation of the beam launched in the lattice B while changing parameters $n$ and $\alpha$. With the previous reasoning, we could consider the obtained dynamical regimes to be symmetrical/identical to those that would be found for the beam launched in the lattice A (with corresponding $n$ and $\alpha$) except for those values of parameters discussed above.

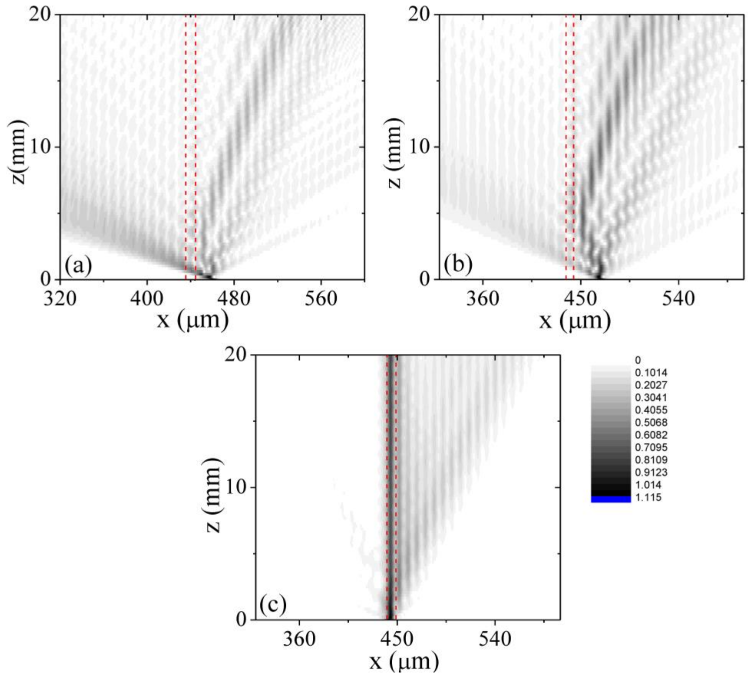


**Fig. 4** (a) Regime of partial reflection and transmission of the beam obtained for $n$=2 and $\alpha=\pi/12$; (b) reflection of the beam for $n$=3 and $\alpha=\pi/22$; (c) trapping of the beam and significant diffraction through the lattice B, $n$=0 (the beam is initiated in the GD area), $\alpha$=0.

When the beam is launched under higher angles ($\alpha > \pi/10$), it freely traverses across the PL (this corresponds to the parameter settings of Fig. 3(b)) for every initial beam position ($n$) - this regime is identified as total transmission of the beam. The decrease in the transverse tilt will lead to the kind of transient regime where the light is partially reflected and partially transmitted (Fig. 4(a)) i.e. the GD acts as a beam splitter.

If we continue to decrease the tilt ($\alpha<\pi/13$), transmission of the beam becomes negligible and reflection is now a dominant regime (Fig 4(b)). This is valid for all input positions except for $n$=1 where trapping of the beam accompanied with the beam diffraction through the lattice B is observed; the smaller the angle, the more pronounced the diffraction gets. A further decrease of $\alpha$ will allow for the weak (partial) trapping to occur for $n$=2 as well, together with the partial reflection of the beam. Trapping is maximal when there is no initial transverse tilt of the beam launched in the GD area(Fig 4(c)).

Comparing these results with those obtained in the case of the light beam propagating across a linear, one-dimensional photonic lattice possessing one nonlinear defect (Kuzmanović et al., 2015a), we can see some similarities as well as differences. In both cases, there is a general tendency for the transmission of the beam launched under higher angles, whereas the beam initiated under smaller angles gets reflected (except in the case of the very low nonlinearity where no reflection is detected). Also, in the case studied here, trapping of the beam is observed when the beam is launched under small angles, close to the GD. However, in the case of the lattice with one nonlinear defect (and depending of the strength of the nonlinearity) trapping can be observed for higher angles and for a variety of input beam positions, but it is always accompanied with reflection or transmission, or with both of these regimes.

## 4. Conclusion

In this paper we investigated the influence of a geometric defect on the propagation of the light beam across a linear composite lattice composed of two structurally different PLs. It is the interface between the two lattices that represents the geometric defect. The influence of the asymmetric structure of the composite lattice, which is most pronounced in the interface layer, is recognized in the evolution of the beam launched close to this layer (i.e. close to the area of GD) when it gets trapped when launched in the lattice B. On the other hand, the trapping is not observed (or is less pronounced) for initialization of the beam in the lattice A. Otherwise, no qualitative difference regarding the propagation of the beam initiated left or right from the GD is observed.

Depending on the initial beam parameters, i.e. its initial position and inclination to the GD, different regimes of the light propagation have been identified: reflection of the beam, transmission, trapping, partial reflection and transmission, reflection and trapping. Regimes of reflection and reflection and trapping, i.e. blocking of the light by the GD can be phenomenologically associated with the Fano resonance (Miroshnichenko et al., 2010, Naether et al., 2009). Also, simulations show that the transition between regimes is not abrupt. Results presented here could be useful for different applications, such as blocking, filtering and transporting light beams through the optical medium.

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# UTICAJ GEOMETRIJSKOG DEFEKTA NA PROSTIRANJE SVETLOSTI KROZ KOMPOZITNU LINEARNU FOTONSKU REŠETKU

*U ovom radu, numerički je proučavano prostiranje svetlosnog snopa kroz jednodimenzionalnu fotonsku rešetku sastavljenu od dve strukturno različite rešetke. Spoj te dve rešetke je predstavljao geometrijski defekt. U zavisnosti od početnog položaja snopa i njegovog nagiba u odnosu na geometrijski defekt, prepoznati su različiti dinamički režimi. Rezultati predstavljeni ovde mogu biti korisni u različitim oblastima primene, kao što je blokiranje, filtriranje i prenošenje svetlosnog signala kroz optičke sredine.*

Ključne reči: *kompozitna fotonska rešetka, transmisija, refleksija, zarobljavanje na defektu*