Diffraction-induced laser pulse splitting in a linear photonic crystal

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We demonstrate analytically a linear optical property of photonic crystals—diffraction-induced incident optical pulse splitting in two pulses propagating with different group velocities in a linear photonic crystal. The reason of this phenomenon is in spatially inhomogeneous field localization within the photonic crystal in case of the Bragg diffraction at the Laue scheme. The field of the fast first pulse is mainly localized within low refractive index layers, whereas the slow second pulse field is mostly in high refractive index layers. Changing optical properties of either high-index or low-index layers of periodical multilayer structure, it is possible to control parameters of each propagating pulse separately. The distance between two transmitted and two diffractively reflected output pulses can be controlled by varying the crystal thickness and modulation depth of the refractive index.

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I. INTRODUCTION

Short laser pulse propagation dynamics and its stability and decay in linear and nonlinear media are studied extensively in modern optics and laser physics [1]. Usually a process of optical solitary wave decay on their constituents is investigated in the case of nonlinear light-matter interaction. It is well known that the phenomena of high-order soliton decay are induced by high-order nonlinear effects [2,3], as well as by third-order dispersion [4] in optical fibers. When a large area coherent optical pulse propagates in a resonant two-level medium, it separates into train of steady state 2π pulses of self-induced transparency [5]. In a resonant photonic crystal (RPC), which is formed by the periodically distributed thin layers of two-level atoms in uniform host dielectric medium [6], nonlinear diffraction-induced laser pulse splitting arises at nonlinear Borrmann effect [7]. In this case radiation propagates in the structure under condition of the Laue transmission scheme [8] of the Bragg diffraction and incoming optical pulse decays near the RPC boundary on two pulses, which propagate in resonantly absorbing structure without absorption and with different group velocities. The first pulse linearly interacts with the structure because it is formed by two coupled Borrmann modes and its wave nodes are localized on resonant layers of RPC. The second pulse propagates as slow nonlinear Laue soliton of self-induced transparency because it consists of two anti-Borrmann modes with the field maxima on the resonant layers and it strongly interacts with two-level atoms [7]. Although the RPC is a convenient model to study theoretically nonlinear optical phenomena in photonic crystals, experimental work with the RPC still is a difficult problem until now and so nonlinear diffraction pulse splitting still has not been observed experimentally.

Here a *linear* effect of diffraction-induced pulse splitting (DIPS) in a linear photonic crystal (PC) at the Laue scheme of the Bragg diffraction has been predicted theoretically. In the simplest one-dimensional (1D) case, a PC is a multilayer periodic structure (Fig. 1). By means of analytical solution of a boundary problem for 1D PC with low refractive index contrast, we show that an input picosecond laser pulse brakes up within the structure on two pulses propagating with different group velocities. The DIPS effect is explained by spatially inhomogeneous light localization in the PC at the Laue geometry of diffraction. One pulse field is mainly localized within low-index layers of the structure, but another pulse field is localized in the high-index layers. Therefore parameters of these pulses can be changed separately by means of changing the high-index or low-index layer optical properties. Such structure of field localization in the PC bulk is caused by wave diffraction. In the PC, each spectral component of a pulse incident at the Bragg angle with respect to the PC layers splits up into a coherent superposition of two transmitted and two diffracted (diffractively reflected) waves. These waves propagate in the PC with two different effective refractive indices and, as a result, with two different velocities. With an increase in the propagation depth in the PC bulk, these waves are divided into two pulses, propagating

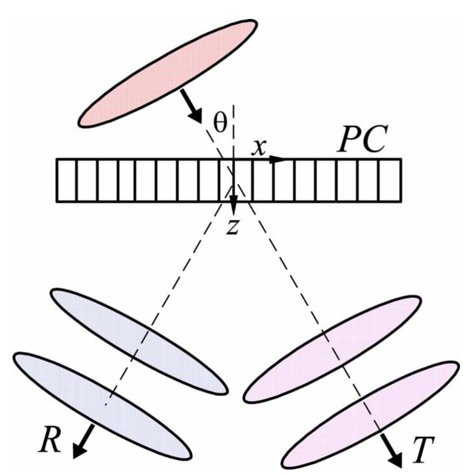

FIG. 1. (Color online) Schematic diagram of doubling of the number of laser pulses caused by splitting of an incident pulse within PC at the Bragg diffraction in the Laue geometry; T and R are transmitted and diffractively reflected pairs of pulses at the PC output.

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with different group velocities. Each pulse is a wave packet consisting of pairs of coupled waves for each spectral component: one transmitted and one diffracted waves moving with the same velocity. At the PC output, a pair of transmitted (T) and a pair of diffractively reflected (R) pulses are emitted (Fig. 1). The time interval between the pulses emerging from the PC is proportional to the crystal thickness and the Fourier component of the difference between the refractive indices $\Delta n(x)=n_2-n_1$ of the PC layers. Calculations show that to observe the DIPS effect for the pulse with radiation wavelength $\lambda_0\sim 500-1000$ nm and duration $\tau_0\sim 0.1-10$ ps, one should use PC with the period $d\sim\lambda_0$, the refraction index modulation depth $\Delta n\sim 0.1-0.3$, and the thickness $L\sim 0.1-3$ cm.

II. OPTICAL PULSE PROPAGATION UNDER LAUE SCHEME OF DIFFRACTION

Consider a linear PC composed of periodically alternating layers with thicknesses d_1 and d_2 and refractive indices n_1 and n_2. The layers are oriented perpendicularly to the PC surface (Fig. 1), and the period of the structure is $d=d_1+d_2$. A light pulse in the form of a planar wave packet is incident on a PC along a fixed direction $\boldsymbol{s}_0$ at an angle θ to the normal to the surface,

$$\boldsymbol{E}_{in}(\boldsymbol{r},t)=\boldsymbol{e}_{in}A_{in}(t-\rho/c)\exp(i\boldsymbol{k}_0\boldsymbol{r}-i\omega_0 t), \tag{1}$$

where envelope of the wave packet A_{in} is generally a complex slowly varying function; c is the speed of light in vacuum; ω_0 is the central signal frequency; $k_0=|\boldsymbol{k}_0|=\omega_0/c=2\pi/\lambda_0$, where λ_0 is the central wavelength, $k_{0x}=k_0\sin\theta$, and $k_{0z}=k_0\cos\theta$; and $\rho=\boldsymbol{r}\boldsymbol{s}_0=x\sin\theta+z\cos\theta$, where the x axis is directed along the PC surface and the z axis is directed into the bulk of the crystal along the normal to the surface.

The dependence of the refractive index on the transverse coordinate x is represented in the form

$$n(x)=n_e+\Delta n(x), \tag{2}$$

where $n_e=(n_1d_1+n_2d_2)/d=n_2+\delta_0\xi$ is the average refractive index, d is the period of the structure, $\delta_0=n_1-n_2$, and $\xi=d_1/d$. In the layers with the thickness d_1, the function $\Delta n(x)=\delta_0(1-\xi)$ and in the layers with thickness d_2, $\Delta n(x)=-\delta_0\xi$.

The complex electric field in a PC composed of optically isotropic layers with small $\Delta n(x)$ obeys the wave equation

$$\Delta\boldsymbol{E}(\boldsymbol{r},t)-c^{-2}\varepsilon(x)\partial^2\boldsymbol{E}(\boldsymbol{r},t)/\partial t^2=0, \tag{3}$$

where $\varepsilon(x)=n^2(x)$ is the complex permittivity and $\Delta=\partial^2/\partial x^2+\partial^2/\partial z^2$ is the Laplace operator.

Following Ref. [9] we will represent field (1) of the incident wave packet as a spectral expansion, i.e., in the form of a set of plane monochromatic waves with spectral amplitudes $A_{in}(\Omega)$, frequencies $\omega=\omega_0+\Omega$, and wave vectors $k=\omega/c$,

$$\boldsymbol{E}_{in}(\boldsymbol{r},t)=\boldsymbol{e}_{in}\int_{-\infty}^{\infty}A_{in}(\Omega)\exp(i\boldsymbol{k}\boldsymbol{r}-i\omega t)d\omega, \tag{4}$$

where the frequency spectrum of the pulse envelope has the form

$$A_{in}(\Omega)=(1/2\pi)\int_{-\infty}^{\infty}A_{in}(t)\exp(i\Omega t)dt.$$

The field $\boldsymbol{E}(\boldsymbol{r},t)$ in the PC will also be represented as a spectral expansion,

$$\boldsymbol{E}(\boldsymbol{r},t)=\int_{-\infty}^{\infty}\boldsymbol{E}(\boldsymbol{r},\omega)\exp(-i\omega t)d\omega. \tag{5}$$

For definiteness, we will restrict ourselves to consideration of a PC with a small modulation depth of the refractive index ($\delta_0\ll n_e$) and the light diffraction will be considered in the two-wave approximation, which implies existence of two strong coupled waves in a crystal: transmitted (E_0) and diffracted (E_h). In this case, the field $\boldsymbol{E}(\boldsymbol{r},\omega)$ for each spectral component in Eq. (5) can be written as

$$\boldsymbol{E}(\boldsymbol{r},\omega)=\boldsymbol{E}_0(\omega)\exp(i\boldsymbol{q}_0\boldsymbol{r})+\boldsymbol{E}_h(\omega)\exp(i\boldsymbol{q}_h\boldsymbol{r}), \tag{6}$$

where $\boldsymbol{q}_h=\boldsymbol{q}_0+\boldsymbol{h}$; $\boldsymbol{h}$ is the reciprocal lattice vector and $h=2\pi/d$. In our symmetric case, $h_x=-h$ and $h_z=0$.

The field amplitudes $E_{0,h}$ and the wave vectors $\boldsymbol{q}_0$ and $\boldsymbol{q}_h$ in Eq. (6) are found from Eq. (3) and the boundary conditions. From the condition of continuity of the tangential projections of wave vectors in vacuum and in the medium, the projection of $\boldsymbol{q}_0$ on the x axis is $q_{0x}=k_x=k\sin\theta$. The projection of $\boldsymbol{q}_0$ on the z axis is $q_{0z}=k(\gamma_0+\beta)$, where $\gamma_0=(n_e^2-\sin^2\theta)^{1/2}$ and the quantity β, which is to be determined, describes the change in the wave vector $\boldsymbol{q}_0$ along the normal to the surface, caused by the Bragg diffraction.

The permittivity $\varepsilon(x)$ in the two-wave approximation has the form

$$\varepsilon(x)=\chi_0+\chi_h\exp(-ihx)+\chi_{-h}\exp(ihx), \tag{7}$$

where χ_0, χ_h, and χ_{-h} are the Fourier components of the permittivity, determined by the relation

$$\chi_g=(1/d)\int_0^d\varepsilon(x)\exp(igx)dx, \tag{8}$$

where $g=0$, h, and $-h$. Hence, taking into account the relation $\varepsilon(x)=[n_e+\Delta n(x)]^2\approx n_e^2+2n_e\Delta n(x)$, we find that $\chi_0=n_e^2$,

$$\chi_h=i(n_e\delta_0/\pi)[1-\exp(i2\pi\xi)],$$

$$\chi_{-h}=-i(n_e\delta_0/\pi)[1-\exp(-i2\pi\xi)].$$

Obviously, in a medium without absorption $(\chi_h)^*=\chi_{-h}$. Let us now substitute Eqs. (5)–(7) into the wave equation (3) and equate the expressions with identical exponentials. As a result, we obtain the following system of equations for the scalar amplitudes of the transmitted (E_0) and diffracted (E_h) waves:

$$2\gamma_0\beta E_0 - C\chi_{-h}E_h = 0,$$

$$(2\gamma_0\beta - \alpha)E_h - C\chi_h E_0 = 0, \tag{9}$$

where the polarization factor $C=1$ and $C=\cos 2\theta$ for s- and p-polarized radiations, respectively. System (9) is obtained on the assumption that $\beta \ll \gamma_0$, which is valid in the case of weak modulation of refractive index (2). The quantity α in the second equation in Eq. (9) determines deviation of the frequency ω and the angle of incidence θ from the exact diffraction condition $\alpha=0$, where

$$\alpha = [k^2 - (\boldsymbol{k}+\boldsymbol{h})^2]/k^2 = h(2k_x - h)/k^2. \tag{10}$$

System (9) has the same form as the system of equations of the dynamic diffraction theory in the x-ray optics [8], which was obtained for a plane monochromatic wave, where the parameter α is determined by the deviation of the angle of incidence of a wave from the Bragg angle. In our case, system (9) describes the diffraction of a pulse with an arbitrary time dependence, and the parameter α is determined both by the detuning of the radiation frequency from the so-called Bragg frequency and by the deviation from the Bragg angle.

Let us determine the Bragg angle $\theta=\theta_B$ for radiation with the central frequency ω_0 using the relation $2(\omega_0/c)\sin\theta_B = h$ or, what is the same, $\sin\theta_B=\lambda_0/2d$. Let now the spectral component of field (4) with the frequency $\omega=\omega_0+\Omega$, where $\Omega\ll\omega_0$, be incident on a PC at the angle $\theta=\theta_B+\Delta\theta$, where $\Delta\theta\ll\theta_B$. Then, the projection of the wave vector k_x in Eq. (10) has the form $k_x=(k_0+\Omega/c)\sin(\theta_B+\Delta\theta)$. Substituting this relation into Eq. (10), we obtain the following expression for the diffraction parameter $\alpha(\Delta\theta,\Omega)$:

$$\alpha = 2\sin 2\theta_B[\Delta\theta + (\Omega/\omega_0)\tan\theta_B]. \tag{11}$$

The condition for nontriviality of the solution to system (9) leads to a square equation with respect to the desired quantity β, whose roots have the form

$$\beta_{1,2} = (1/4\gamma_0)[\alpha \pm (\alpha^2 + 4C^2\chi_h\chi_{-h})^{1/2}]. \tag{12}$$

It follows from the first equation in Eq. (9) that the amplitudes of the transmitted and diffracted waves in a PC are related by a simple expression $E_{hj}=R_jE_{0j}$, where $R_j=2\gamma_0\beta_j/C\chi_{-h}(j=1,2)$.

Taking into account the specular reflection from the PC input surface with an amplitude E_r, the boundary conditions for continuity of the electric and magnetic fields in the plane $z=0$ for the s polarization have the form

$$A_{in} + A_r = E_{01} + E_{02},$$

$$k_z(A_{in} - A_r) = q_{0z}^{(1)}E_{01} + q_{0z}^{(2)}E_{02},$$

$$R_1E_{01} + R_2E_{02} = 0, \tag{13}$$

where $q_{0z}^{(j)}=k(\gamma_0+\beta_j)$ and the quantities β_j are determined by relations (11) and (12).

As a result, we derive from Eqs. (6) and (13) the following expression for the spectral components of the fields in Eq. (5) at an arbitrary point in the PC bulk:

$$E_g(\boldsymbol{r},\omega) = A_{in}(\Omega)B_g(\boldsymbol{r},\omega), \tag{14}$$

where $g=0$, h; B_0 and B_h are the amplitude coefficients of transmission and diffractive reflection, respectively,

$$B_g(\boldsymbol{r},\omega) = \sum_{j=1,2} F_{gj}\exp(iq_{gx}x + iq_{0z}^{(j)}z). \tag{15}$$

Here, $q_{0x}=k_x$, $q_{hx}=k_x-h$,

$$F_{01} = -2R_2k_z/D, \quad F_{02} = 2R_1k_z/D, \quad F_{hj} = R_jF_{0j},$$

$$D = R_1(k_z + q_{0z}^{(2)}) - R_2(k_z + q_{0z}^{(1)}). \tag{16}$$

The final expressions for the fields $E_g(\boldsymbol{r},t)$ at a depth z at an instant t have the following integral form:

$$E_g(\boldsymbol{r},t) = \int_{-\infty}^{\infty} A_{in}(\Omega)B_g(\boldsymbol{r},\omega)\exp(-i\omega t)d\omega. \tag{17}$$

These fields can also be written as wave packets, similarly to Eq. (1),

$$E_g(\boldsymbol{r},t) = A_g(\boldsymbol{r},t)\exp(ik_{gx}x + ik_0\gamma_0 z - i\omega_0 t). \tag{18}$$

Here, $k_{0x}=k_0\sin\theta$, $k_{hx}=k_{0x}-h$, and the envelopes of the wave packets have the form

$$A_g(\boldsymbol{r},t) = \int_{-\infty}^{\infty} A_{in}(\Omega)\sum_{j=1,2}F_{gj}(\Omega)\exp(i\varphi_j)d\Omega,$$

$$\varphi_j(\Delta\theta,\Omega) = k\beta_j z + (\Omega/c)(x\sin\theta + \gamma_0 z) - \Omega t, \tag{19}$$

where φ_j are the complex phases of the waves in the case of an absorbing medium.

The intensities of the transmitted ($g=0$) and diffracted ($g=h$) pulses at an arbitrary depth of the PC are $I_T(z,t)=|E_0(z,t)|^2$ and $I_R(z,t)=|E_h(z,t)|^2$, respectively.

III. DIFFRACTION-INDUCED SPLITTING OF AN OPTICAL PULSE

Consider the dynamics of propagation and splitting in PC of incident pulse with the Gaussian envelope $A_{in}(t)=\exp[-(t/\tau_0)^2]$ and with the width τ_0 (Fig. 2). It follows from Eqs. (12), (15), and (16) that the region of strong diffractive interaction of radiation with a PC is determined by the relation $|\alpha|\le 2C|\chi_h|$. If a pulse is incident on a PC at an exact Bragg angle ($\Delta\theta=0$), the spectral range of diffractive reflection and transmission is determined by the so-called spectral Bragg width $\Delta\Omega_B=\omega_0|\chi_h|/2\sin^2\theta_B$. This width increases with a decrease in the Bragg angle and with an increase in the modulation depth δ_0 of the PC refractive index, reaching a maximum at $\xi=0.5$. In order to use the two-wave approximation correctly, the pulse spectral width $\Delta\Omega_0=2/\tau_0$ is assumed to be smaller than the spectral Bragg width, i.e., $\Delta\Omega_0\ll\Delta\Omega_B$. Figure 2 shows spatial-temporal dynamics of evolution of transmitted and diffracted fields in the PC under exact Bragg condition calculated by Eq. (17). For convenience, the plots are shown as functions of the coordinate $t_z=t-z\gamma_0/c$ in dynamical frame of reference which is rigidly related to the transmitted pulse in an homogeneous

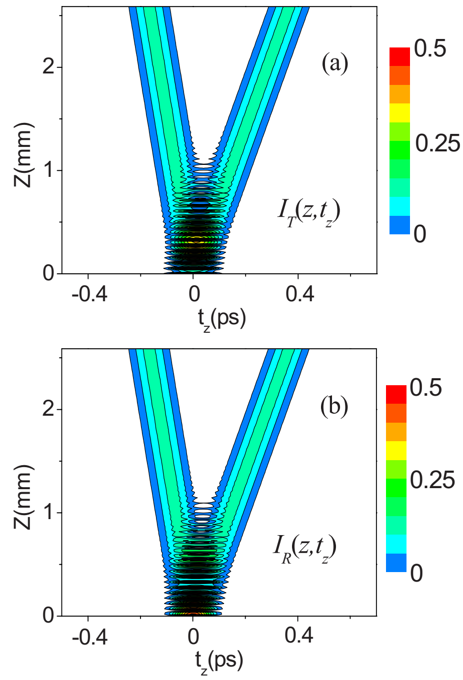

FIG. 2. (Color online) Spatial-temporal dynamics of the incident pulse evolution inside a PC, one pulse splits on two pulses. Intensities of (a) transmitted $I_T(z,t_z)=|E_0(z,t_z)|^2$ and (b) diffracted $I_R(z,t_z)=|E_h(z,t_z)|^2$ waves calculated by expression (17) (arb. units). The parameters of the incident pulse and PC are as follows: $\tau_0=0.1$ ps, $\lambda_0=0.8$ μm, $\xi=0.5$, $n_1=1.5$, $\delta_0=0.1$, and $d=3$ μm.

medium with a maximum at $t_z=0$. During some time, the pulse propagates inside PC as a single "refracted" pulse. It means that all four waves, two transmitted $E_{01,2}$ and two diffracted $E_{h1,2}$, exist in any point of the PC simultaneously. The superposition of these waves leads to periodical total transfer of energy from the transmitted to the diffracted waves and vice versa. This pendular solution represents in Fig. 3. The extinction depth Λ, at which complete transfer occurs, is obtained from Eq. (15), $\Lambda=\lambda_0\gamma_0/2C|\chi_h|$.

As it follows from Eqs. (14) and (15), the one pair of transmitted E_{01} and diffracted E_{h1} coupled waves and second

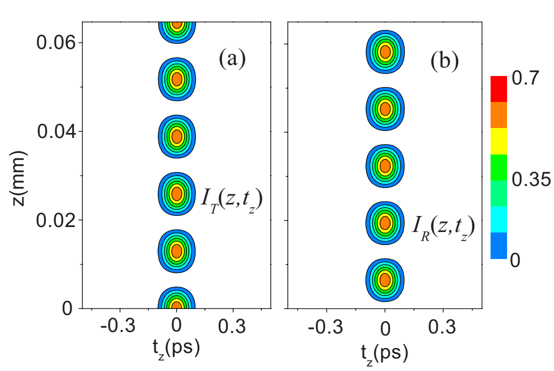

FIG. 3. (Color online) Initial stage of pulse evolution represented in Fig. 2. The superposition of four waves $E_{01,2}$ and $E_{h1,2}$ leads to so-called pendular solution when energy is periodically completely transferred from (a) the transmitted $I_T(z,t_z)$ to (b) the diffracted $I_R(z,t_z)$ waves and vice versa (arb. units).

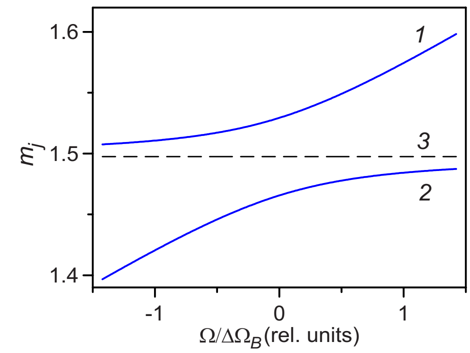

FIG. 4. (Color online) Frequency dependences of the effective refractive indices (1) m_1, (2) m_2, and (3) Re(γ_0) for a PC with the period $d=1$ μm, $\xi=0.5$, $n_1=1.5$, and $\delta_0=0.1$; the wavelength $\lambda_0=0.8$ μm.

pair (E_{02} and E_{h2}) propagate in the PC with different effective refractive indices $m_j=\text{Re}(\gamma_0+\beta_j)$ (Fig. 4) and, hence, with different velocities. The wave velocity difference gives rise to the splitting of the propagating pulse into two pulses with different group velocities (Fig. 2). The first pulse is formed by the waves E_{01} and E_{h1}, whereas the second one is formed by waves E_{02} and E_{h2}. We call this phenomenon the diffraction-induced pulse splitting. In Fig. 5, the space distribution of the field amplitude inside a PC in the case of the DIPS has been shown. It can be seen that the field has a strong spatially inhomogeneous localization. The fields of different pulses are localized in different space areas in the PC. The field of the first propagating pulse is mainly localized in low-index layers, therefore the pulse is faster, while the second pulse field is in the high-index layers and this pulse moves slower. Actually, these two pulses propagate in effectively different optical media and, consequently, the parameters of each pulse (amplitude, width, velocity, and polarization) are independently determined by optical properties (material dispersion, nonlinearity, anisotropy, refraction index sign, and so on) of either low-index or high-index layers. For instance, if the high-index layers are chosen as nonlinear but the low-index layers are linear, the slow pulse will demonstrate the properties of nonlinear wave, whereas the fast pulse will be a linear one. This effect has been de-

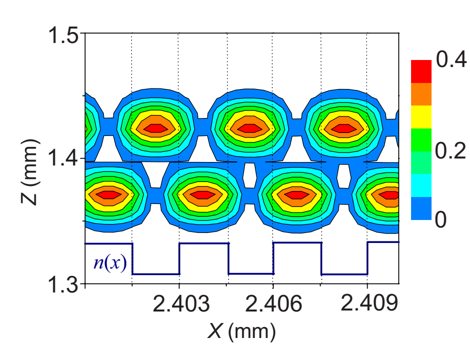

FIG. 5. (Color online) Spatial distribution of the field module $|E_0(x,z)+E_h(x,z)|$ (arb. units) inside a PC at the point of time when the pulse splitting has occurred, calculated in Eq. (17). The stepped line at the bottom of the figure shows schematically the refraction index profile $n(x)$.

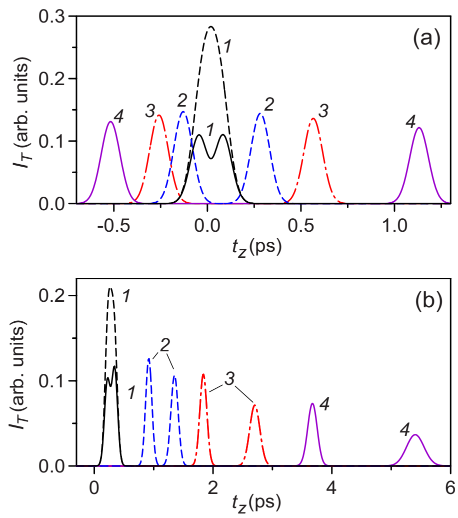

FIG. 6. (Color online) Dynamics of the transmitted pulse intensity $I_T(z,t_z)$ at PC thicknesses $z=(1)$ 0.05, (2) 0.2, (3) 0.4, and (4) 0.8 mm. The parameters of the incident pulse and PC are as follows: $\tau_0=0.1$ ps, $\lambda_0=0.8$ μm, $\xi=0.5$, $n_1=1.5$, and $\delta_0=0.1$; the period $d=$(a) 3 and (b) 0.8 μm. The dashed curves 1 are related to the diffracted pulse at $z=0.05$ mm.

scribed earlier for the special case of ultrathin resonant nonlinear layers in a RPC [7]. Our calculations show also that if material dispersion of the low-index layers, for example, is larger in comparison with high-index material of a linear thick PC, then the fast pulse will be greatly broader than the slow one.

Let us now discuss the conditions necessary for DIPS. It is easy to estimate the distance z_0 at which split pulses will be spaced by a time interval $2\tau_0$. If the exact Bragg condition $\alpha=0$ is satisfied, it follows from Eq. (12) that $z_0=2c\tau_0\gamma_0/C|\chi_h|$. This distance decreases with a decrease in the pulse width and with an increase in the modulation depth of the refractive index in the PC. At the same time, the distance z_0 should not strongly exceed the photoabsorption length $L_a=1/[2k_0\,\mathrm{Im}(\gamma_0)]$. It is noteworthy that the depth z_0, measured in units of the extinction depth Λ, is determined only by the pulse wavelength and width: $z_0/\Lambda=4c\tau_0/\lambda_0$. For example, for the pulse width $\tau_0=0.1$ ps, $\lambda_0=0.8$ μm, $d=1$ μm, $\xi=0.5$, $n_1=1.5$, the modulation parameter $\delta_0=0.1$, $\Lambda=6.3$ μm, and the pulse becomes noticeably split in a fairly thin PC: $z_0=0.93$ mm. Figure 6 shows the temporal dynamics of pulse transmission through different cross sections z of a PC. It can be seen that at small thicknesses ($z<z_0$) the pulse is not yet split; however, with an increase in z DIPS occurs and the time interval between the split pulses increases with the distance z.

Outside of the structure, i.e., in homogenous medium, the earlier coupled transmitted and diffracted waves of either pulse will propagate independently and, as result, the incident pulse will split by PC on four pulses: two transmitted and two diffracted (Figs. 1 and 6). In view of the symmetry of the problem at $\Delta\theta=0$, the amplitudes and shapes of transmitted and reflected pulses completely coincide at $z>z_0$. Due to the features of the effective frequency dispersion of the refractive indices $m_j(\Omega)$, the pulse propagation velocities differently depend on the period d, i.e., on the angle of incidence θ_B. For example, at almost normal incidence [$\theta_B=7.7°$; Fig. 6(a)], one of the pair of pulses advances beyond the pulse in a continuous medium, while the second pulse lags behind. With an increase in the angle of incidence [$\theta_B=30°$; Fig. 6(b)] both pulses propagate faster than a pulse in a homogeneous medium. In this case, the first pulse stronger decreases in amplitude and broadens in time in comparison with the second pulse. It should be noted that the frequency dispersion $dn_{1,2}/d\omega$ of the PC refractive indices, which is disregarded here, is generally smaller by more than 1 order of magnitude than the dispersion $dm_j/d\omega$ of the effective refractive indices and does not affect the pulse propagation in thin PCs.

IV. CONCLUSION

The diffraction-induced picosecond laser pulse splitting in a linear PC under condition of the Bragg diffraction in the Laue geometry, which we have described, is a linear effect. The DIPS is independent of the field intensity and can be implemented even for weak pulse. Therefore, even a simple linear thin 1D PC can be used as miniature-type device to transform arbitrary power laser pulses into double pulses with controlling delay, amplitudes, durations, and polarizations, which could be useful, for instance, for pump-probe spectroscopy and laser physics. Moreover, the DIPS effect allows us to double the laser pulse repetition rate.

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