PROPAGATION OF LASER RADIATION IN NONLINEAR COUPLER IN THE CASE OF TWO-PHOTON EXCITATION OF BIEXCITONS

Khadzhi Piotr[1], Korovai Olesya[2], Nosenko Olga[2], Kordonskaya Nadejda[2]

[1]Institute of Applied Physics, Academy of Sciences of Moldova,

Academy str. 5, Kishinev, Moldova, 2028.

[2] Dniester State University Tiraspol,

25 October str. 128, Tiraspol, Moldova, MD 3300.

e-mail: tdsu4@idknet.com

Abstract: The propagation peculiarities of coherent laser radiation in two identical semiconductor waveguides are investigated. The system of the nonlinear differential equations is derived, which describes the intensity of propagating pulses. The periodic, quasiperiodic and chaotic energy transfer is predicted, considering the pulse portraits on two connected Poincare spheres.

The propagation features and the interaction of laser radiation in two identical parallel semiconductor waveguides are considered. Waveguides form a nonlinear optical coupler. We suppose that two pulses of laser radiation with the frequencies ω_1 and ω_2 and the field amplitudes of the pulse envelopes E_1 and E_2 incident on the end face of one of the waveguides (Fig. 1). The sum of the frequency of both pulses is in the exact resonance with the self-frequency of the biexciton state in the medium of waveguides (Fig. 1). Propagating along the waveguides the photons of these pulses in pairs excite the biexcitons with which they interact. Due to the tunnel effect the energy of propagating pulses is transferred periodically from one waveguide to another and vise versa. The main problem is the determination of the spatial distribution of the fields of both pulses in the waveguides and the possibility of the realization of the nonlinear self-switching phenomenon.

In the frame of steady–state and of the slowly varying in space envelopes approximations we have obtained the system of nonlinear equations for the fields f_1 and f_2 in the first guide and g_1 and g_2 for the fields in the second guide of the coupler:

$$df_1/dx = -i\alpha I_2 f_1 + i\gamma g_1, \qquad (1)$$

$$df_2/dx = -i\alpha I_1 f_2 + i\gamma g_2, \qquad (2)$$

$$dg_1/dx = -i\alpha J_2 g_1 + i\gamma f_1, \tag{3}$$

$$dg_2/dx = -i\alpha J_1 g_2 + i\gamma f_2, \tag{4}$$

where x is the coordinate, α is the constant of two–photon biexciton excitation and γ is the linear coupling constant and

$$I_1 = |f_1|^2,\ I_2 = |f_2|^2,\ J_1 = |g_1|^2,\ J_2 = |g_2|^2 \tag{5}$$

are the intensities.

We can form the components of polarizations

$$Q_1 = i\left(g_1^* f_1 - g_1 f_1^*\right),\ Q_2 = i\left(g_2^* f_2 - g_2 f_2^*\right),$$

$$R_1 = g_1^* f_1 + g_1 f_1^*,\ R_2 = g_2^* f_2 + g_2 f_2^*, \tag{6}$$

and we obtain the set of nonlinear equations for the intensities

$$I_1' = -\gamma Q_1,\ I_1' = -\gamma Q_1,\ J_1' = \gamma Q_1,\ J_2' = \gamma Q_2, \tag{7}$$

$$Q_1' = \alpha\left(I_2 - J_2\right)R_1 + 2\gamma\left(I_1 - J_1\right), \tag{8}$$

$$Q_2' = \alpha\left(I_1 - J_1\right)R_2 + 2\gamma\left(I_2 - J_2\right), \tag{9}$$

$$R_1' = -\alpha\left(I_2 - J_2\right)Q_1, \tag{10}$$

$$R_2' = -\alpha\left(I_1 - J_1\right)Q_2, \tag{11}$$

where the prime at the variables is the derivative on x.

From (7)–(11) we obtained the following integrals of motion

$$I_1 + J_1 = I_{10}, \qquad I_2 + J_2 = I_{20}, \tag{12}$$

$$Q_1^2 + R_1^2 = 4I_1J_1, \quad Q_2^2 + R_2^2 = 4I_2J_2, \tag{13}$$

$$R_1 + R_2 + \alpha/\gamma\left(I_1J_2 + I_2J_1\right) = 0, \tag{14}$$

where I_{10} and I_{20} are the intensities of two waves incident of the front endfase of the first waveguide, i.e.

$$I_{1|x=0} = I_{10},\ I_{2|x=0} = I_{20},\ J_{1|x=0} = J_{2|x=0} = 0. \tag{15}$$

Introducing new normalized variables

$$x_1 = \alpha_1\left(1 - 2\frac{J_1}{I_{10}}\right), \quad x_2 = \alpha_2\left(1 - 2\frac{J_2}{I_{20}}\right),$$

$$y_1 = \alpha_1\frac{Q_1}{I_{10}}, \qquad y_2 = \alpha_2\frac{Q_2}{I_{20}}, \tag{16}$$

$$z_1 = \alpha_1\frac{R_1}{I_{10}}, \qquad z_2 = \alpha_2\frac{R_2}{I_{20}},$$

where $\alpha_1 = \frac{\alpha I_{10}}{2\gamma}$, $\alpha_2 = \frac{\alpha I_{20}}{2\gamma}$, we have obtained the system of six nonlinear equations for new variables

$$\begin{aligned} x_1' &= -y_1, & x_2' &= -y_2, \\ y_1' &= x_1 + z_1 x_2, & y_2' &= x_2 + z_2 x_1, \\ z_1' &= -y_1 x_2, & z_2' &= -y_2 x_1 \end{aligned} \tag{17}$$

together with three integrals of motion

$$\begin{aligned} & x_1^2 + y_1^2 + z_1^2 = \alpha_1^2, \\ & x_2^2 + y_2^2 + z_2^2 = \alpha_2^2, \\ & x_1 x_2 - z_1 - z_2 = \alpha_1 \alpha_2, \end{aligned} \tag{18}$$

where the only normalized parameters of our theory are α_1 and α_2. From (18) we can see that that the evolution of the system is represented as the bound motion of two displayed points on the surfaces of two spheres enclosed each other, the radii of which α_1 and α_2 are determined by the initial conditions. We obtained the exact analytical solutions of the system of equations only for the case when the radii of the spheres are equal $\alpha_1 = \alpha_2 = \alpha$. At the high level of excitations of the system from the end face of one of waveguides it takes place the periodic complete energy transfer of the propagating pulses and the connection length (the minimal distance on which the maximal energy transfer takes place) slowly increases with the increase of the pump intensity. In Fig.2 we presented the solutions (spatial variation of variables) $x_1 = x_2 = x$, $y_1 = y_2 = y$ and $z_1 = z_2 = z$ for different values of parameter α. We can see, that every variable x, y and z exhibits the periodical spatial change. The period of oscillations depend only on the parameter α. The increase of α leads to the increase of spatial period for $0 \le \alpha \le \alpha_{cr} = 2$ and for $\alpha > 2$ the period decreases.

If the level of excitations approaches the critical one the connection length increases rapidly and all energy of pulses is transferred. For the case of critical pump intensity it takes place the aperiodic transferring regime and the half of energy is transferred. At the high level of excitation more than the critical one the connection length rapidly decreases and the part of transferred energy is small. We predicted the self-switching phenomenon, which consists in the strong change of the output in the case of small change of the input intensity. The numerical investigations of the system of equations shows the existence of the complex propagations regimes depending on the parameters, the periodic, quasiperiodic and chaotic solutions, pulling–out and pushing–in of phase trajectories from the definite regions of the phase space.

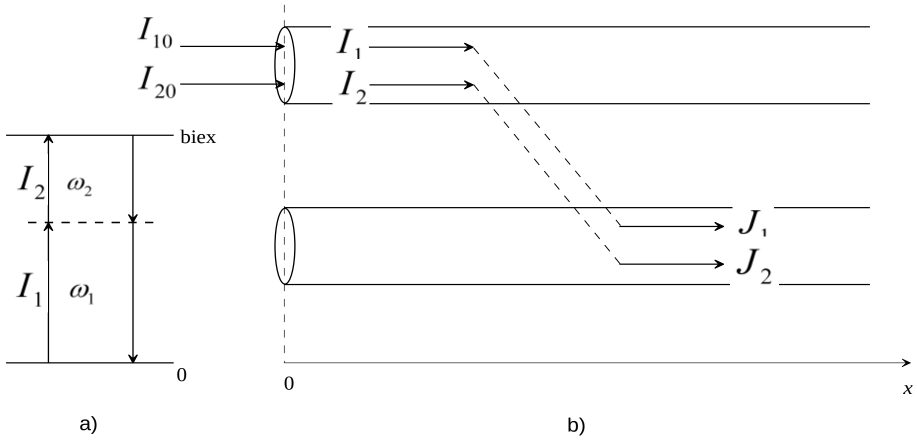

Fig 1. Diagram of the two–photon quantum transitions *a)* and scheme of the coupler under investigation *b)*.

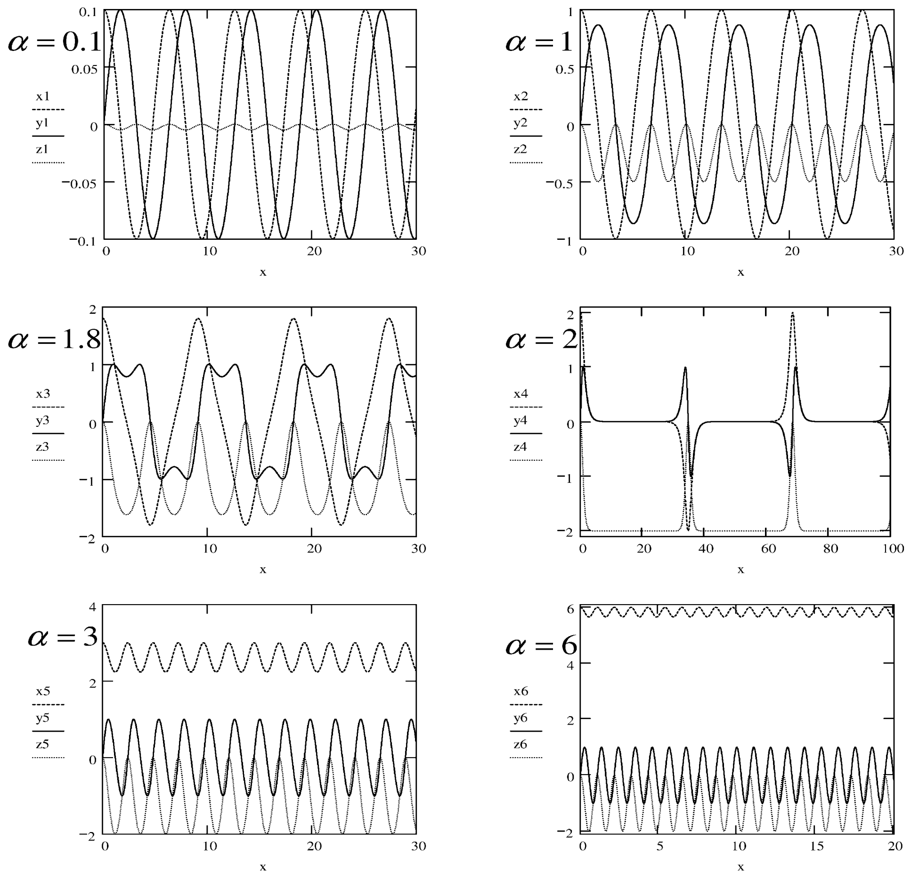

Fig. 2 Spatial variation of variables x, y and z.