Simulation of incoherent interaction between bright-bright screening soliton in an unbiased series two-photon photorefractive crystal circuit

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***Abstract*— Incoherently interaction between bright-bright screening soliton pairs under steady-state condition in an unbiased series two-photon photorefractive crystal circuit in one dimension are simulated numerically.**

Keywords-component; Nonlinear optics; Photorefractive soliton; Screening soliton

I. INTRODUCTION

Spatial soliton in photorefractive (PR) crystals have attracted considerable attention during the past decade. Growing interests in optical spatial solitons in PR media are because of properties of these solitons and their possible applications for many optical subjects for example switching and routing [1-4]. These solitons in steady state consist of three types. One of them are screening solitons which require the application of an external bias field in photorefractive-non-photovoltaic materials and result from non-uniform screening of the external field [5]. Recently, Liu *et a*l studied these solitons in PR crystal in a chain to form a series PR crystal circuit which two solitons are known collectively as separate spatial soliton pairs [4]. Coherent and incoherent soliton interaction is also one of the most interesting theoretically and experimentally [6-8].

In this paper we have investigated the simulation of the incoherent interaction of screening soliton pairs in an unbiased two-photon PR crystal circuit.

II. THEORICAL MODEL

We consider two optical beams with the same polarization, wavelength, which are mutually incoherent, propagate collinearly in the two-photon SBN photorefractive crystal (P) in a close-circuit condition with the other crystal (p'); at least one of them should be photovoltaic. We suppose that another beam with the same condition illuminate this crystal. The beams propagate along the z-axis and are permitted to diffract only along the x direction, coincide to the optical c-axis. Moreover, let us assume that the polarizations of the incident optical beams are parallel to the c-axis. We have considered the incoherent solitons interaction in crystal P as shown in Fig.1.

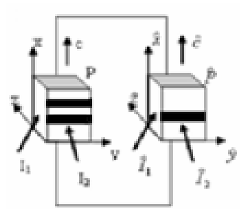

Fig. 1. Illustration of the series two-photon PR crystal circuit consists of two PR crystals.

As usual, we express the optical field of the incident beams in terms of slowly varying envelopes $\phi(x,z)$ and $\psi(x,z)$, i.e. $\vec{E}_A = \hat{x}\psi(x,z)e^{ikz}$, $\vec{E}_B = \hat{x}\phi(x,z)e^{ikz}$ where $k = k_0 n_e = (2\pi/\lambda_0)n_e$ that λ_0 and n_e are the free-space wavelength and the unperturbed extraordinary index of refraction respectively. Under these conditions, the two optical beams satisfy the following envelope evolution equations [6]:

$$i\phi_z + \frac{1}{2k}\phi_{xx} - \frac{k_0 n_e^3 r_{33} E_{sc}}{2}\phi = 0\,, \tag{1}$$

$$i\psi_z + \frac{1}{2k}\psi_{xx} - \frac{k_0 n_e^3 r_{33} E_{sc}}{2}\psi = 0\,, \tag{2}$$

where $\phi_z = \partial\phi/\partial z$, $\phi_{xx} = \partial^2\phi/\partial x^2$, $\psi_z = \partial\psi/\partial z$, $\psi_{xx} = \partial^2\psi/\partial x^2$ and r_{33} is the electro-optic coefficient. E_{sc} is the induced space charge field in the medium. In the steady-state and under close-circuit condition, the space charge field can be obtained from the Castro-Camus model [9], and introduced as

$$E_{sc} = E_0 \frac{(I_\infty + I_{2d})(I + I_{2d} + \gamma_1 N_A/s_2)}{(I + I_{2d})(I_\infty + I_{2d} + \gamma_1 N_A/s_2)} + \\ - \frac{D\gamma_1 N_A}{\mu s_2 (I + I_{2d} + \gamma_1 N_A/s_2)(I + I_{2d})}\frac{\partial I}{\partial x}\,, \tag{3}$$

where the parameters introduced in Ref.[1,3].

According to Poynting's theorem, the total intensity of the two mutually incoherent optical beams can be obtained by

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$I = I_A + I_B = (n_e / 2\eta_0)\left(|\phi|^2 + |\psi|^2\right)$ Where $\eta_0 = (\mu_0 / \varepsilon_0)^{1/2}$ and $I_\infty = I(s \to \pm\infty, z)$. Note that the values of the fields in two crystals depend on the parameters of both crystals [1]. For convenience, we use the dimensionless coordinates and appropriate normalization according to [1]. Under these conditions, we obtained the normalized envelopes U and V of the two optical beams that satisfy the following dynamical evolution equations:

$$iU_\xi + \frac{1}{2}U_{ss} - \frac{\beta(1+\rho)}{(1+\rho+\sigma)}\left(1 + \frac{\sigma}{1+|U|^2+|V|^2}\right)U \quad , \qquad (5)$$
$$+\delta \frac{\sigma(|U|^2+|V|^2)_s}{\left(|U|^2+|V|^2+1\right)\left(|U|^2+|V|^2+1+\sigma\right)}U = 0$$

and the same equation for V. Where parameters introduced in Ref. [1]. We consider bright-bright soliton pairs. In this case, the intensity is expected to vanish at infinity $(s \to \pm\infty)$ and thus $I_\infty = \rho = 0$. Soliton solutions and the normalized envelopes U and V can be converted in the following form:

$$\left(\frac{dy}{ds}\right)^2 = [\ln(1+ry^2) - y^2\ln(1+r)]\left(\frac{2\beta\sigma}{r(1+\sigma)}\right) \qquad (6)$$

As we know, can be shown for $0<y^2<1$, $\ln(1+ry^2) - y^2\ln(1+r) > 0$. Therefore for bright soliton in this case is $\beta > 0$ i.e. $E_0 > 0$. By integrating once we found:

$$s = \pm\int_y^1 \left\{\left[\frac{2\beta\sigma}{r(1+\sigma)}\right]\left[\ln(1+r\tilde{y}^2) - \tilde{y}^2\ln(1+r)\right]\right\}^{-1/2} d\tilde{y} \qquad (7)$$

We will discuss the interaction of the incoherent bright–bright screening soliton pairs solutions due to two-photon PR media in the next section.

III. NUMERICAL SIMULATION

We have used the numerical method for simulation of propagation of soliton pairs and solved the differential equations by using some modification of Crank-Nicholson iteration and Runge-Kutta methods by taking boundary conditions into account [8]. A relevant example is provided for the bright–bright soliton pairs formed in SBN crystal that used with the parameters that mentioned in [9].

We have taken incoherent interaction of this pair by changing the distance between the two soliton without changing other parameters also the diffusion term δ is ignored. The results are shown in Fig.2 for $\Delta s = 0.8, 1.2, 1.8, 2.4$. As it can be seen in Fig. 2(a), solitons overlap with each other completely and they propagate as a beam with periodical and slightly changes in amplitude. Fig. 2(b) and 2(c) indicate that by increasing the length of separation, solitons attract each other but the attraction is decreased by increasing the separation. Also in Fig. 2(d), the attraction goes to zero and approximately beams propagate independently. Solitons have greater tendency to preserve their profiles and period of attraction occurs in further distance. We found that the strength of attraction, and the point of collision depends on primary separation distance between solitons and also the biased field E_0, so by increasing the separation distance and decreasing the biased field, collisions occur in the longer distance.

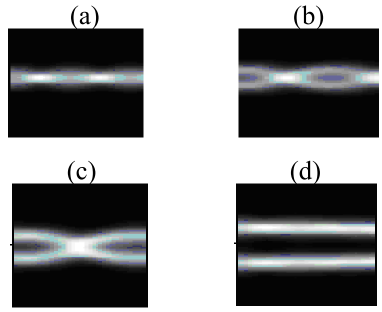

Fig. 2. Incoherent interaction between two bright soliton pairs in crystal P with the same polarization and intensity for $r=1$ and (a) $\Delta s=0.8$, (b) $\Delta s=1.2$ (c) $\Delta s=1.8$ (d) $\Delta s=2.4$.

IV. CONCLUSION

We studied the incoherent interaction of the bright-bright screening soliton pairs in PR crystals under steady-state condition in an unbiased series of two-photon PR crystal. We numerically simulated the effect of the separation distance on the interaction. We found that for one-dimensional interaction between these screening solitons, attraction always occurs. In fact, the two input beams propagate straight through the soliton wave channel induced by them. Additionally, their output position can be controlled by changing the initial separation and biased field E_0 that can be changed the relative initial separation. That is what we need in real switching applications and planar waveguides in photonics. For example, the realization of a cross-junction switch can be considered based on the above results.

REFERENCES

[1] X. Ji, Q. Jiang, J. Yao, J. Liu, " Separate spatial soliton pairs in an unbiased series two-photon photorefractive crystal circuit" Opt. Laser. Technol, vol. 42, 2009, pp.322-327.
[2] A. Keshavarz, L. Sadralsadati, M. Hatami, " Simulation of soliton propagation in photovoltaic photorefractive two- photon materials and study the switching behavior", PIERS Proceeding, Moscow, Russia, August18-21, 2009, pp. 1823-1826.
[3] G. Zhang, J. Liu, " screening-photovoltaic spatial solitons in biased two photon photovoltaic photorefractive crystals" J. Opt. Soc. Am. B, vol. 26, 2009, pp. 113-120.
[4] J. Liu, Phys, Lett. A, " Separate spatial soliton pairs and solitons interaction in an unbiased series photorefractive crystal circuit", vol. 300, 2002, pp.213-220.
[5] L. Keqing, Zh. Yanpeng, T. Tiantong, L. Bo, " Incoherently coupled steady-state soliton pairs in biased photorefractive-photovoltaic materials", Phys. Rev. E, vol. 64, 2001, 056603-1.
[6] Y. Zhang, Ch. Hou, K. Zhan, Xi.Sun, Optik Int. J. Light. Electron, " incoherently coupled bright-dark photovoltaic soliton pairs based on two-photon photorefractive effect", 2010, In Press, Corrected Proof.
[7] E. Castro-Camus, L. F. Magana," Prediction of the physical response for the two-photon photorefractive effect" J. Opt. Soc. Am, vol. 28, 2003, pp.1129-1131.
[8] G. Evans, J. Blackledge, P. Yardley, "Numerical methods for partial differential equation", Springer Verlag, Berlin, 2000.
[9] Y. Zhang, Ch. Hou, F. Wang, Xi. Sun, " Incoherently coupled grey-grey spatial soliton pairs due to two-photon photorefractive media" Optik,. vol. 119, 2008, pp.700-704.