Self-deflection characteristics of bright photovoltaic spatial solitons in closed-circuit realization*

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Abstract: The self-deflection process of bright photovoltaic spatial solitons in photovoltaic photorefractive media is investigated by taking into account diffusion effects. By using perturbation techniques, it is found that the center of the optical beam moves on a parabolic trajectory and, moreover, the central spatial frequency component shifts linearly with the propagation distance. Both the spatial deflection and the angular deviation are proportional to the product of two dimensionless quantities which are associated with the diffusion and the photovoltaic process, respectively. The photovoltaic solitons have a similar way to screening solitons in self-bending process.

Key words: spatial optical solitons photorefractive effects photovoltaic effects self-deflection

闭路光伏明空间光孤子的自偏转特性

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摘要: 利用微扰方法,通过考虑扩散效应的影响,分析了闭路光伏光折变晶体中的光伏明空间光孤子的自偏转特性。结果表明,光伏明孤子的中心沿着一条抛物线轨迹偏转,中央空间频率分量随传播距离线性移动。无论是空间位移还是偏向角都正比于分别同漂移效应和光伏效应相关的两个无量纲量的积。闭路光伏明孤子具有同屏蔽明孤子相类似的自偏转特征。

关键词: 空间光孤子 光折变效应 光伏效应 自偏转

Photorefractive spatial solitons have attracted much interest in the past few years[1~10]. At present, several generic types of scalar solitons are known: quasi-steady-state solitons[1~3], screening solitons[4~8] and photovoltaic solitons[9,10]. Whereas planar screening solitons have been predicted to occur in a photorefractive material with an external applied field at steady-state when the field is nonuniformly screened[4~8], photovoltaic solitons have been predicted to occur and have been observed in photorefractive materials with a strong photovoltaic current($LiNbO_3$) and refractive-index perturbation associated with photovoltaic field is used to guide and confine the planar photovoltaic soliton[9~11].

As previously pointed out[12], the diffusion process introduces an asymmetric tilt in the light-induced photorefractive waveguide, which in turn is expected to affect the propagation characteristics of photorefractive solitons. The effect of diffusion on the screening solitons has been

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studied, which result in a self-bending process of bright screening solitons in a biased non-photovoltaic photorefractive crystal[13]. In this paper, we investigate the effect of diffusion on the photovoltaic solitons in closed-circuit realization, which has not been revealed ever. By using perturbation methods which involve the conservation laws of the nonlinear wave equation, we find that the bright photovoltaic solitons have a similar way to the bright screening solitons in self-bending process, that is, the beam center shifts quadratically with the propagation distance, whereas the angle between the central wavevector and the propagation axis varies linearly.

In order to analyze the self-deflection process of a planar bright photovoltaic soliton, let us consider an optical beam that propagates in a photovoltaie-photorefractive material along the z axis and is permitted to diffract only along the x direction. Moreover, let us assume that the optical beam is linearly polarized along x direction. Under these conditions, the perturbed extraordinary refractive index is given by $(\hat{n}_e)^2 = n_e^2 - n_e^4 r_{33} E_{SC}$[14], where r_{33} is the electro-optic coefficient, n_e is the unperturbed extraordinary index of refraction, and E_{SC} is the space-charge field induced in this crystal. In typical photovoltaie-photorefractive media and for relatively broad beam configurations, under the case of taking into account diffusion effects, the value of the induced space-charge electric field can be directly obtained from the Kukhtarev-Vinetskii model[15] and it is approximately given by

$$E_{SC} = -E_p[I/(I+I_d)] - (k_B T/e)\cdot(\partial I/\partial x)/(I+I_d) \tag{1}$$

where k_B is Boltzmann's constant, T is the absolute temperature, and I_d is the so-called dark irradiance that phenomenologically accounts for the rate of thermally generated electrons. In Eq. (1), $I = I(x, z)$ is the power density profile of the optical beam and it is related to the slowly varying envelope φ through Poynting's vector, i. e. $I = (n_e/2\eta_0)|\varphi|^2$, where $\eta_0 = (\mu_0/\varepsilon_0)^{1/2}$, and $E_p = k\gamma_R N_A/(e\mu)$ is the photovoltaic field constant, where k is the photovoltaic constant, N_A is the acceptor density, μ and e are, respectively, the electron mobility and the charge, and γ_R is the carrier recombination rate.

In turn, the envelope propagation equation can be obtained by substituting the expression on the perturbed refractive index (induced by the space-charge field) into the paraxial wave equation. After appropriate normalization, the envelope U obeys the following dynamically evolution equation:

$$iU_\xi + U_{ss}/2 + \alpha|U|^2 U/(1+|U|^2) + \gamma(|U|^2)_s U/(1+|U|^2) = 0 \tag{2}$$

where $U = (n_e/2\eta_0 I_d)^{1/2}\varphi$ is the power density normalized with respect to the dark irradiance, and $U_\xi = \partial U/\partial\xi$, etc. In Eq. (2), $s = x/x_0$, where x_0 is an arbitrary spatial width, and $\xi = z/(k_0 n_e x_0^2)$ is the normalized coordinate, where $k_0 = 2\pi/\lambda_0$ is the free-space wavevector of the light wave employed. The dimensionless quantities α and γ are associated with the photovoltaic and diffusion processes, respectively, and they are given by $\alpha = (k_0 x_0)^2 (n_e^4 r_{33}/2) E_p$ and $\gamma = (k_B T/2e)(k_0^2 x_0 n_e^4 r_{33})$. For the purpose of simplicity, loss effects have been neglected in Eq. (2).

When the diffusion process is neglected, we can obtain the bright solitary wave solutions of Eq. (2) with $\gamma = 0$. That is, by expressing the beam envelope U in the usual fashion: $U = r^{1/2} \times y(s)\exp(i\nu\xi)$, substituting this latter form of U into Eq. (2) and integrating Eq. (2) (with $\gamma = 0$), we can obtain the bright photovoltaic solitons as following

$$\nu = -(\alpha/r)\ln(1+r) + \alpha \tag{3}$$

$$(\dot{y})^2 = (2\alpha/r)[\ln(1+ry^2) - y^2\ln(1+r)] \tag{4}$$

where ν represents a nonlinear shift of the propagation constant, $y(s)$ is a normalized real function bounded between $0 \leqslant y(s) \leqslant 1$ and r is defined as $r = I_{max}/I_d > 0$ ($I_{max} = I(0)$). In obtaining Eqs. (3) and (4), we have employed the y-boundary conditions, that is $y(0) = 1$, $y(s \to \pm\infty) = 0$, $dy/ds = 0$ at $s = 0$. The functional form $y(s)$ of these self-trapped waves can then be determined by numerically integrating Eq. (4).

In order to investigate the effects of diffusion on the propagation of these photovoltaic solitons, we solve Eq. (2) by using perturbative procedures previously employed within the context of nonlinear fiber optics[16,17]. Keeping in mind that the beam evolution under the action of diffusion is approximately adiabatic[13], we make the following ansatz for the solution of Eq. (2):

$$U = r^{1/2} y[s + u(\xi)]\exp\{i[\nu\xi + \omega(\xi)(s + u(\xi)) + \sigma(\xi)]\} \tag{5}$$

where $U = r^{1/2} y(s)\exp(i\nu\xi)$ is the steady-state bright screening soliton of Eq. (2) whit $\gamma = 0$. In Eq. (5), $u(\xi)$ represents a shift in the position of the beam center, $\omega(\xi)$ is associated with the angle between the central wavevector of this beam and the propagation axis ξ, and $\sigma(\xi)$ is a phase factor which is allowed to vary during propagation. The equations of motion of these real variables is obtained by substituting Eq. (5) into the two complex conservation laws of Eq. (2)[16,17]. These are established by multiplying Eq. (2) with U^* and U_s^* and integrating over the coordinate s. A straightforward calculation yields following results:

$$du(\xi)/d\xi = -\omega(\xi) \tag{6}$$

$$d\sigma(\xi)/d\xi = \omega^2(\xi)/2 \tag{7}$$

$$d\omega(\xi)/d\xi = 4\gamma\alpha k(r) \tag{8}$$

where the dimensionless function $k(r)$ is given by

$$k(r) = \int_{-\infty}^{+\infty} ds \frac{2y^2(s)}{1 + ry^2(s)} \times \{y^2(s)\ln(1+r) - \ln[1 + ry^2(s)]\}\left(\int_{-\infty}^{+\infty} ds\, y^2(s)\right)^{-1} \tag{9}$$

Fig. 1 gives the dependence of the $k(r)$ function on r, and this function reaches a maximum close to $r = 10$.

Integrating Eqs. (6), (7) and (8), we have the following equation of motion for $\omega(\xi)$, $u(\xi)$ and $\sigma(\xi)$:

$$\omega(\xi) = 4\gamma\alpha k(r)\xi \tag{10}$$

$$u(\xi) = -2\gamma\alpha k(r)\xi^2 \tag{11}$$

$$\sigma(\xi) = 8[\gamma\alpha k(r)]^2\xi^3/3 \tag{12}$$

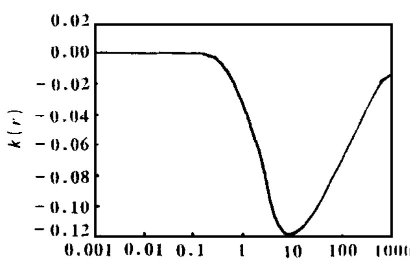

Fig. 1 Dependence of the $k(r)$ function on r

Eqs. (10), (11) and (12) demonstrate that in the absence of diffusion, i. e. $\gamma = 0$, the variables $\omega = u = \sigma = 0$. On the other hand, be taking diffusion effects into account, Eq. (11) shows that the beam center follows a parabolic trajectory, whereas Eq. (10) implies that the center spatial frequency component shifts linearly with the propagation distance. From these latter results, one quickly finds that the beam has suffered a lateral displacement distance given by

$$x_d = 2\gamma\alpha k(r)z^2/(k_0^2 n_e^2 x_0^3) \tag{13}$$

where z is the actual propagation distance. Moreover, the angular deflection, i. e. the angle between the central wavevector of this solitary beam and the z-axis can also be evaluated from Eq. (10) and is given by

$$\theta_d = 4\alpha\beta k(r)z/(k_0^2 n_e^2 x_0^3) \qquad (14)$$

It is to point out that whether $\omega(\xi)$, $u(\xi)$, $\sigma(\xi)$ or x_d, θ_d is proportional to the produce of γ and α which are associated with the diffusions and photovoltaic processes, respectively. As expected, Eqs. (10) ~ (14) similar to Eqs. (6) ~ (10) in Ref. 13 and the reference describes the self-bending process of screening solitons.

From Eqs. (10~ (11), we can define the normalized spatial and angular frequency shifts as following $\Delta s = -u(\xi)/(2\gamma\alpha)$ and $\Delta k_s = \omega(\xi)/(4\gamma\alpha)$, respectively. Fig. 2 and Fig. 3 give the dependence of Δs and Δk_s function on r, respectively. These figures show that the center of the optical beam moves on a parabolic trajectory and, moreover, the central spatial frequency component shifts linearly with the propagation distance.

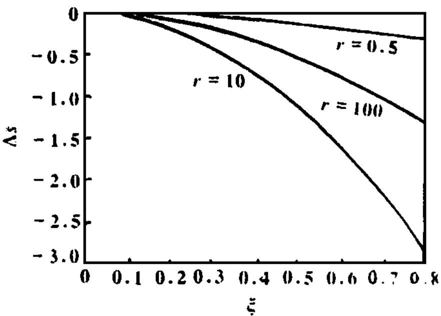

Fig. 2　Dependence of the normalized spatial shift Δs function on r

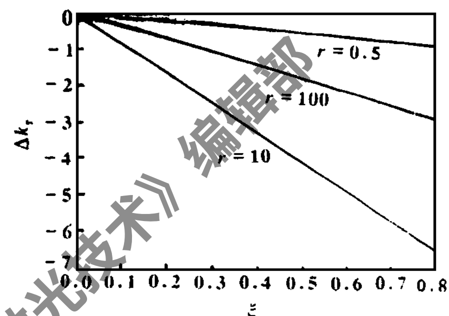

Fig. 3　Dependence of the normalized angular frequency shift Δk_s function on r

In summary, the self-deflection of bright photovoltaic spatial solitons arising from diffusion effects has been investigated by using a perturbation model. We have found that the center of the solitary beam moves on a parabolic trajectory, whereas its central spatial frequent component shifts linearly with the propagation distance. Obviously, in the absence of diffusion, the self-bending process can not occur. The photovoltaic solitons have a similar way to the screening solitons in self-bending process.

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带有金环的 CO_2 激光器的着火及放电特性研究

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摘要: 将金环置于 CO_2 激光器的放电毛细管中, 是近几年出现的一种新的 CO_2 催化再生方法, 以 He, Ne 两种气体为放电气体, 对带有金环的 CO_2 激光器的着火及放电特性进行了实验研究, 结果表明: 与普通的 CO_2 激光器相比, 加入金环的激光管中两种气体的着火电压及放电时的端电压都明显地提高了。

关键词: CO_2 激光器 放电特性 着火特性 金环

Study on discharge and break-down characteristic of CO_2 laser with distributing of gold rings

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Abstract: In order to study the discharge and break-down characteristics of CO_2 laser with distributing of gold rings, a comparison experiment has been carried out with CO_2 laser tubes-one was typical, the other was improved by putting a series of gold rings in the discharge capillary. Two kinds of gases-helium and neon have been used in the experiment. The results showed that both the break-down voltage and the terminal voltage of the laser tube with gold rings are increasing significantly in comparison with the tube without gold rings.

Key words: CO_2 laser discharge characteristics break-down characteristics gold rings

引 言

对于放电激励的 CO_2 激光器, 始终存在着工作物质 CO_2 由于电子碰撞而分解的问题:

$$CO_2 + e \rightarrow CO + O + e$$

这一反应通常在 CO_2 分解达 60% 时才能最终达到平衡[1]。1985年, 王欲知、刘建生采用玻璃微孔对激光器早期过程进行了直接质谱诊断[2,3], 结果表明, 对于纯 CO_2 放电, 5min 内的分解

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