Propagation of the Gaussian Beam in Bessel Optical Lattices

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Abstract The numerical analysis of the dynamics of a Gaussian beam in Bessel lattices which are induced by transvering the focusing photorefractive nonlinearity crystal is presented. The propagation properties of the Gaussian beam can be different with and without the lattices. In the absence of the lattice, the beam will present linear diffraction and nonlinear focusing in a homogeneous medium. The beam can overcome these effects in a homogeneous medium after transfering in a crystal with lattices. With different initial input conditions in the case of lattices, the input beam can overcome these effects and form a ring-shaped soliton or a circle-shaped soliton.

Key words nonlinear optics; Gaussian beam; Bessel lattice; photorefractive crystal; soliton

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贝塞尔晶格中高斯光束的传输

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摘要 通过数值仿真研究了高斯光束在贝塞尔晶格中的传输特性,贝塞尔晶格是在光折变晶体中通过光诱导产生的。在有晶格和无晶格的情况下,高斯光束的传输特性有很大差别。高斯光束在均匀介质中传输时会呈现出线性衍射和自聚焦现象,当晶体中存在晶格时,光束可以克服光在均匀介质中的衍射和自聚焦效应,在不同的初始输入条件下,高斯光束在传输的过程中会演变成一个环形孤子或者圆形孤子。

关键词 非线性光学;高斯光束;贝塞尔晶格;光折变晶体;光孤子

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1 Introduction

Gaussian beams are the general and often the most desirable type of beam provided by a laser source[1] whose propagation usually is analysed based on an optical paraxial ABCD system[2].

Self-trapping of light beams in nonlinear self-focusing Kerr media has been explored intensively during the past years[3]. Periodic photonic structures and photonic crystals recently attracted a lot of interest due to the unique ways they offer for controlling light propagation[4]. If the waveguide array is embedded in a nonlinear medium, more fantastic propagation phenomenon is expected to occur. Gaussian beams propagating in optically-induced linear lattices with appropriate nonlinearity will form a two-dimensional (2D) discrete soliton[5]. In nonlinear optics, discrete solitons were first demonstrated in one-dimensional (1D) AlGaAs semiconductor waveguide arrays in 1998[6-7]. Various soliton phenomena have been studied in square lattices. In recent years, vortex solitons and discrete solitons in

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本文电子版彩色效果请详见中国光学期刊网 www.opticsjournal.net non- square lattice have been studied, among them, there is another important optical lattice with unique symmetry, which is called the Bessel lattice[8]. A Bessel beam is associated with a solution of the wave equation so that any cross-section of the beam intensity distribution remains independent of the propagation variable z, and can be presented as a superposition of an infinite number of plane waves[9]. So far, several kinds of solitons have been found supported by Bessel lattices, such as multipeaked vortex solitons[10], necklace solitons[11], spatial-temporal solitons[12] and so on.

The dynamics of the Gaussian beam launched into the focusing photorefractive nonlinear crystal that imprinted the optically induced Bessel optical lattices are discussed. The linear diffraction and nonlinear propagation in a homogeneous medium without the lattices are studied, then the propagation of the Gaussian beam in the presence of it with different input conditions is analysed. The input beam is well restrained and can evolve into a three- rings- shaped soliton seated in the first channel of the lattices. What's more, the energy mainly gather in the outer ring when most of the energy of the input beam are in the lattice dark space. While in the other two situations, such as a small part of the energy of the input beam distribute on the lattice dark field and a part of the energy of the input beam overflow the centre ring of the lattices, it can support a circle-shaped soliton. These results may pave the way for the observation of similar phenomena.

2 Propagation

Within the approximation of isotropic photorefractive nonlinearity, the evolution of paraxial optical beams in the media with a periodically modulated refractive index is described by the nonlinear Schrödinger equation[4] for the slowly varying envelope u ,

$$\mathrm{i}\frac{\partial u}{\partial z}+\frac{1}{2}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{V_0 u}{1+I_{\mathrm{g}}(x,y)+|u|^2}=0, \tag{1}$$

where $V_0=\gamma_{\mathrm{nl}}x_0^2/2$, $\gamma_{\mathrm{nl}}=k_0^2 n_{\mathrm{e}}^4 r_{33}E_0$, n_{e} is the refractive index for extraordinary polarized beams, k_0 is the wave number, r_{33} is the electro-optic coefficient of the crystal, and for our choice of polarity of the bias field E_0 , nonlinearity exhibited by the probe beam is self-focusing. The transverse coordinates x,y are measured in the units of x_0 , and z is the propagation distance, in units of $k_0 n_{\mathrm{e}} x_0^2$. Consequently, $x=1$ corresponds to 15 μm , one z unit corresponds to 6.73 mm, $V_0=1$ corresponds to 85.6 V/cm .

A two- dimensional Bessel lattice created by ordinary polarized beams can be described by the intensity pattern as

$$I_{\mathrm{g}}(x,y)=I_0\mathrm{J}_{n_{\mathrm{J}}}^2\left[b_{\mathrm{lin}}r\right], \tag{2}$$

where I_0 is the maximum lattice intensity, n_{J} denotes the order of the Bessel function, $r=\left(x^2+y^2\right)^{1/2}$ is the radius, and b_{lin} defines the transverse lattice scale. To understand stable ring- like solitons generated from a radially symmetric input Gaussian beam, the input beam is described as $u(x,y)=2\exp(-x^2-y^2)$, where (x,y) are the transverse coordinates [Fig.1(a)]. Here, $n_{\mathrm{J}}=1$ is chosen, the lattice energy distribution given by Eq.(2) is shown in Fig.1(b), Fig.1(c) and Fig.1(d), and the corresponding value of b_{lin} is equal to 1, 3, 5, respectively. As b_{lin} increasing, the channel distribution is more and more intensive in the same scale.

Now the situation in the presence of the Bessel lattice is taken into consideration. Without the lattice, the beam diffracts in linear regime and self- focuses in the nonlinear part. When the natural broadening is balanced by a nonlinear effect, in which light-induced lensing counteracts diffraction(or dispersion), the wavepacket forms an optical spatial (or temporal) soliton. However, the behavior can be dramatically different from the case with lattices. As the beam propagating through, it is governed by Eq.(1). Here the lattice depth $I_0=24$, and the bias nonlinearity $V_0=50$. Typical simulated results are presented in Fig.2, where Fig.2(a1) shows most of the energy of the input beam focusing on the lattice dark field, and its propagation for about $z=3$ corresponds to 20.19 mm. It is well restrained and sufficient to form a three- rings- like soliton, and the energy mainly gathered in the outer ring, as demonstrated in Fig.2(a2). Absolutely, Fig.2(b1) contains a small part of the energy of the input beam distributed on the lattice dark field, meanwhile, all the others are consist in the inner ring, then a bright

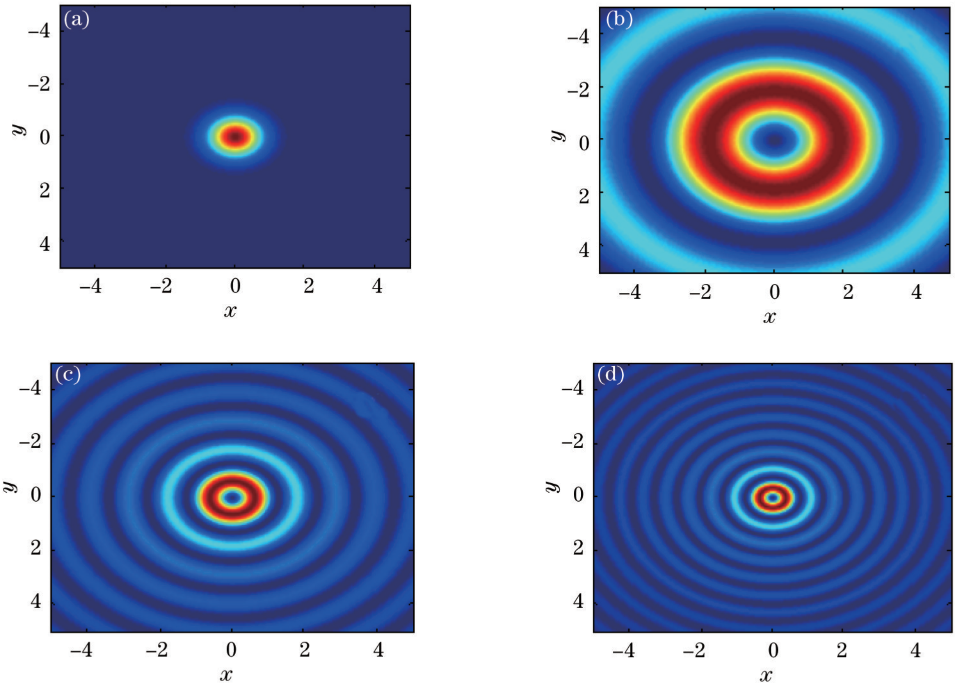

Fig. 1 Numerical results. (a) Gaussian beam intensity distribution in $x-y$ plane; lattice energy distribution for (b) $b_{\text{lin}} = 1$, (c) $b_{\text{lin}} = 3$ and (d) $b_{\text{lin}} = 5$

circle- shape soliton just right on the the first channel of the Bessel lattice [Fig.2(b2)] can be got. In addition, this provides that the whole intensity is staied within the first ring. In comparison, when part of the energy of the input beam overflowes the centre ring of the lattices [Fig.2(c1)], then it also takes shape in a circle solition similar to that in Fig.2(b2), the difference is that most of the soliton energy concentrates on the first channel, while there still be some energy[Fig.2(c2)] between the first and the second rings.

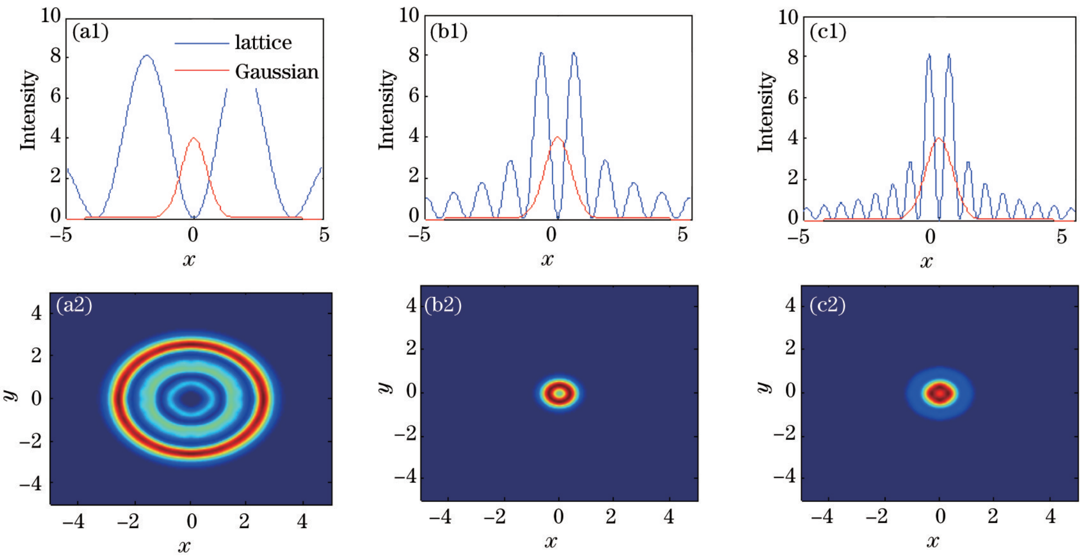

Fig.2 Locations of the input beam and the lattice for (a1) $b_{\text{lin}} = 1$, (b1) $b_{\text{lin}} = 3$ and (c1) $b_{\text{lin}} = 5$, respectively; (a2), (b2) and (c2) propagation results at $z = 3$ corresponding to Fig.(a1), (b1), (c1)

3 Conclusion

The dynamics of the Gaussian beam launched into optical lattices induced by nondiffracting first-order Bessel beam in media with the focusing photorefractive nonlinearity is reported. In the absence of the lattice, the Gaussian beams have diffraction in linear region and nonlinear self- focusing in a homogeneous medium. Bessel lattices imprinted in photorefractive media have been shown to be able to support stable ring- shaped solitons and bright circle- shaped solitons. The results are suitable for Bose-Einstein condensates trapped in Bessel lattices with repulsive interatomic interactions.

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