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Variation of focal switch with spectrum of a broadband laser

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ABSTRACT

Effects of the spectrum on focal switch of a broadband laser in a dispersion dual-focus system are presented in this paper. The numerical results show that the two maximum intensities of the broadband laser on the z-axis vary when the central frequency of the broadband laser shifts and the spectrum shape changes, and the variations affect the generation of the focal switch. It is also found that difference of the two maximum intensities tends to increase when the absolute value of central wavelength increases. According to the results in this paper, the generation of the focal switch can be controlled by choosing the shift of the central frequency, the bandwidth, the distance between the two lenses, and the spectrum shape of the broadband laser.

1. Introduction

Focal switch effect is found by Martinez and Climent in 1996. It is a phenomenon that for certain axially super-resolving diffracting screens illuminated by a converging spherical wave an effective permutation of the focal point can take place [1]. In the following decades, the focal switch has been investigated in lots of systems [2–11]. A focal shift and accompanying focal switch of flattened Gaussian beams passing through an aperture bifocal lens is presented by Ji in 2003 [4]. They found that by suitably choosing the parameters of the optical system and beam, the focal switch can take place. In 2007, the effects of focal shift and focal switch have been found when a generalized astigmatic elliptical Gaussian beam (EGB) propagates in a focusing optical system with an elliptical aperture [8].

We found almost all previous papers about the focal switch were about monochromatic or quasi-monochromatic light. It is well known that, in comparison with the monochromatic and quasi-monochromatic waves, the broadband laser has different propagation properties. Thus we regard the broadband laser as our research object to try to found some interesting phenomenon in recent years. It has been found that the focal shift and focal switch can take place in a broadband laser and the bandwidth is an important role to affect the focal shift and focal switch [12–14]. In this paper, variations of focal switch with spectrum of a broadband laser in a dispersion dual-focus system are studied. Influences of position of the central frequency and the spectrum shape of the broadband laser on the focal switch are analyzed in detail.

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2. Fields of a broadband laser passing through a dispersion dual-focus system

Consider a broadband laser passing through a dispersion dual-focus system as depicted in Fig. 1 in Ref. [14]. Using the Huygens–Fresnel diffraction integral, the field of each frequency component of the broadband laser is obtained by as

$$E(x,y,z,\omega)=\frac{\exp(ikz)}{i\lambda}\sqrt{\frac{1}{B_xB_y}}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}E_0(x_0,y_0,0,\omega)\exp\left[-\frac{ik}{2B_x}\left(A_xx_0^2-2x_0x+D_xx^2\right)\right]\times\exp\left[-\frac{ik}{2B_y}\left(A_yy_0^2-2y_0y+D_yy^2\right)\right]\mathrm{d}x_0\mathrm{d}y_0 \tag{1}$$

$E_0(x_0, y_0, 0, \omega)$ is the field of the incident pulse in the frequency domain at the plane of Lens 1 and it is obtained by Fourier transform of the field of the incident pulse $E_0(x_0, y_0, 0, t)$ in time domain. Assuming the space and time field of the initial pulse can be separated, i.e. $E_0(x_0, y_0, 0, t)$ is rewritten as $E_0(x_0, y_0, 0)s(t)$, where $s(t)$ is the field distribution at $x=y=z=0$ in the time domain. Thus, $E_0(x_0, y_0, 0, \omega)$ can be written as $E_0(x_0, y_0, 0)s(\omega)$, where $s(\omega)$ is the Fourier transform of $s(t)$. The field of any point behind the lens system in time domain is derived from inverse Fourier transform of

$$E(x,y,z,t)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}E(x,y,z,\omega)\exp(\mathrm{i}\omega t)\mathrm{d}\omega. \tag{2}$$

The transfer matrices of the dispersion dual-focus system in Eq. (1) are the same Eq. (5) in Ref. [14].

Assume that the spatial mode $E_0(x_0, y_0, 0)$ is also a Gaussian

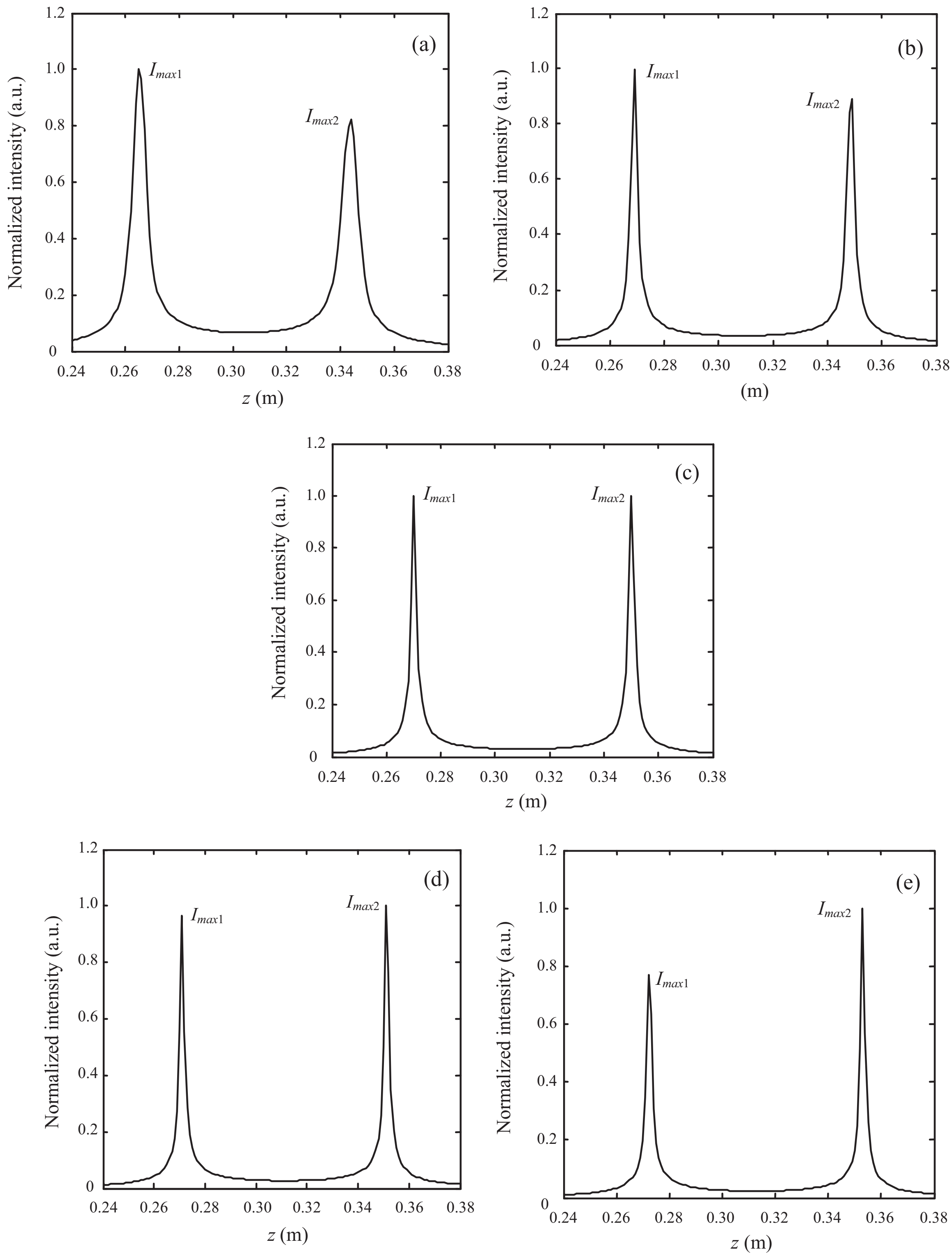

Fig. 1. Axial intensity profiles of broadband laser in dual-focus system with $N_{0wx}=395$, $N_{0wy}=1071$, $d=0$, and $\Delta\lambda=91$ nm. (a) $\lambda_s=-300$ nm; (b) $\lambda_s=-100$ nm; (c) $\lambda_s=0$ nm; (d) $\lambda_s=100$ nm; (e) $\lambda_s=300$ nm.

profile written as

$$E_0(x_0, y_0, 0) = \exp\left[-\left(\frac{x_0^2}{w_{0x}^2} + \frac{y_0^2}{w_{0y}^2}\right)\right], \tag{3}$$

where w_{0x} and w_{0y} are the beam waists in the x direction and y direction, respectively. We also consider that the temporal form of the pulse is a Gaussian shape as

$$s(t) = \exp\left(-a_g^2\frac{t^2}{T_P^2}\right)\exp(-i\omega_0 t), \tag{4}$$

where T_P is pulse duration (full width at half maximum, FWHM), ω_0 is the carrier frequency, $a_g=(2\ln 2)^{1/2}$ and the initial phase φ is