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The diffraction propagation properties of double-half inverse Gaussian hollow beams

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A B S T R A C T

In the paper, double-half inverse Gaussian hollow beams, which are a new type of hollow beams, have been proposed. In the paraxial approximation, the propagation model of double-half inverse Gaussian hollow beams in free space is deduced by utilizing the Collins formula. The distribution of the optical field is simulated with different initial spot sizes (ω_0=1 mm and 5 mm) and different propagating distances (z=10 mm, 6×10^2 mm, 1.5×10^3 mm, 1×10^4 mm and z=10 mm, 1.5×10^4 mm, 3×10^4 mm and 10×10^4 mm). And the simulated results demonstrate that the Airy pattern is derived after propagating some distance. Meanwhile, the focusing property appears visibly and the energy is redistributed intricately. In the research, the focusing distance could be controlled by transforming the initial spot size and the intensity inequality is also shown.

1. Introduction

With the development of laser technology, high-energy laser is playing an important role in military and civilian fields [1,2]. When high-energy laser propagates through the atmosphere, it is generally limited by linear and non-linear phenomena such as scattering of aerosol particles and thermal blooming. Aerosol particles absorb energy from high-energy laser beams, heat the air through thermal conduction, form the uneven distribution of air in the beams, affect the laser wave, and finally affect the propagation of high-energy laser [3]. Thermal blooming is a very important nonlinear effect in which the medium density is changed because of the laser energy, and thus the cross-sectional energy distribution of the laser beam is transformed, the propagation direction deviates from a predetermined direction, the spot size increases, the spot shape distorts and so on [4]. Hollow laser beams could reduce the effect of thermal blooming in atmosphere propagation and are a special kind of laser beams [5,6]. With the development of laser, various hollow laser beams with different intensity distributions have been proposed [7–11], such as bottle beams, hollow Gaussian beams and half-Gaussian hollow beams. In this paper, we present double-half inverse Gaussian hollow beams of which the intensity in edge is higher than that in center. The propagation model of double-half inverse Gaussian hollow beams in free space is deduced by utilizing the Collins formula in the paraxial approximation, and the simulations are implemented in the condition of different initial laser waists. The result shows that the double-half inverse Gaussian hollow beams have specific propagation model. It means that the double-half inverse Gaussian hollow beams transforms to an Airy pattern during the process of propagation, with the focusing property appearing visibly and the energy being redistributed intricately. We also find that the focusing distance could be controlled by adjusting the initial spot size. Through the theoretical study, we can better master the diffraction propagation properties of the double-half inverse Gaussian hollow beams. It is clearly a theoretical work that could be beneficial to the field of high-energy laser beam propagation Table 1.

Table 1
The values of A_j and B_j

A_j	B_j
11.428 + 0.95175i	4.0697 + 0.22726i
0.06002 − 0.08013i	1.1531 − 20.933i
− 4.2743 − 8.5562i	4.4608 + 5.1268i
1.6576 + 2.7015i	4.3521 + 14.997i
− 5.0418 + 3.2488i	4.5443 + 10.003i
1.1227 − 0.68854i	3.8478 + 20.078i
− 1.0106 − 0.26955i	2.5280 − 10.310i
− 2.5974 + 3.2202i	3.3197 − 4.8008i
− 0.14840 − 0.31193i	1.9002 − 15.820i
− 0.20850 − 0.23851i	2.6340 + 25.009i

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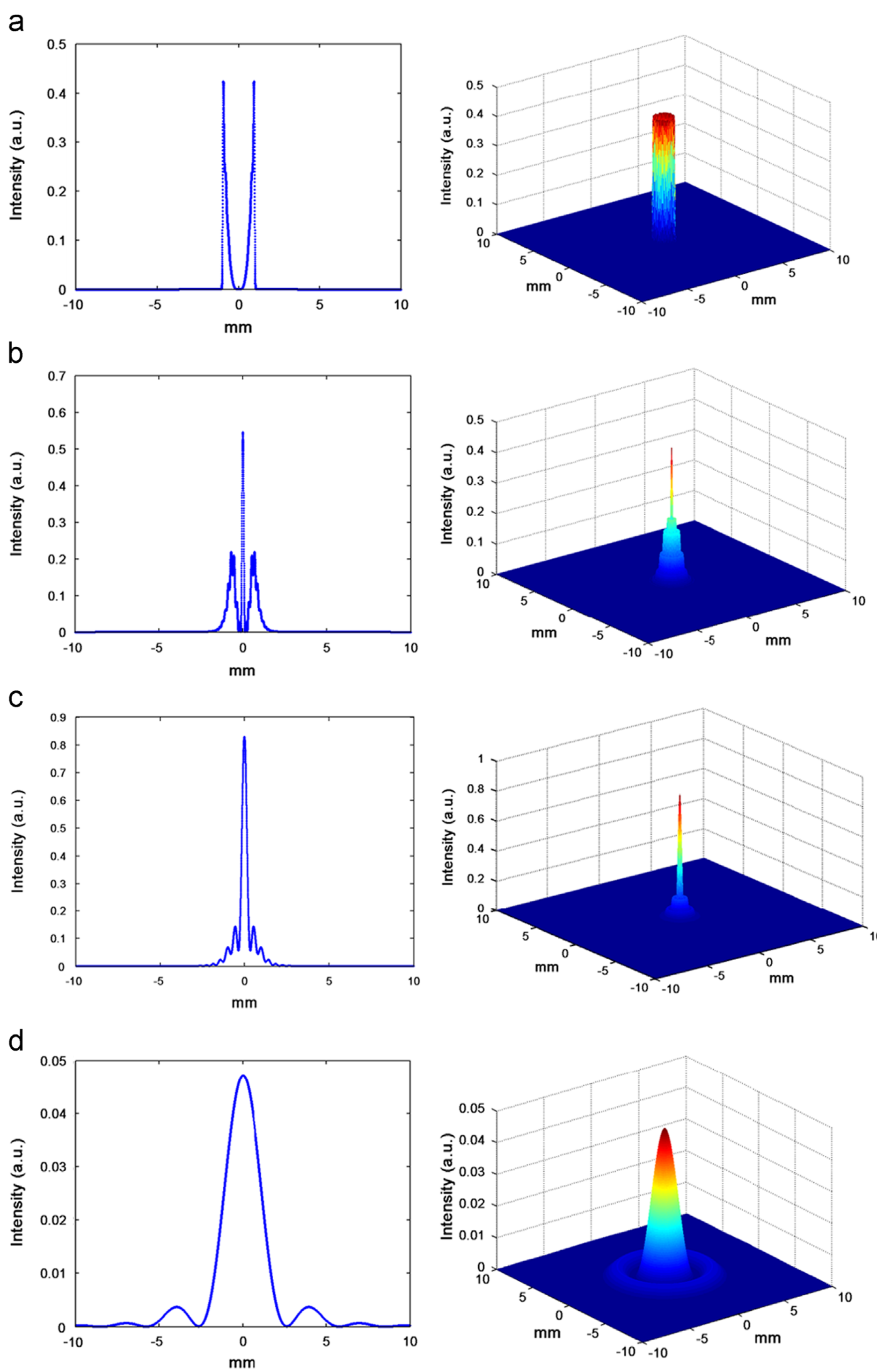

Fig. 1. The propagation properties of the double-half inverse Gaussian hollow beams in free space when $\omega_0 = 1$ mm, (a) $z = 10$ mm (b)$z = 6 \times 10^2$ mm (c)$z = 1.5 \times 10^3$ mm and (d)$z = 1 \times 10^4$ mm.

2. The propagation model of double-half inverse Gaussian hollow beams in free space

The Gaussian hollow beams at the original plane of $z = 0$ is

$$E(r,0) = \left[1 - \exp\left(-\frac{r^2}{\omega_0^2}\right)\right] circ\left(\frac{r}{\omega_0}\right) \tag{1}$$

where, r is radial radius and ω_0 is spot radius.

$$circ\left(\frac{r}{\omega_0}\right) = \begin{cases} 1 r \le \omega_0 \\ 0 r > \omega \end{cases} \tag{2}$$

The equation above could be expanded as follows [12,13]

$$circ(\frac{r}{a}) = \sum_{j=1}^{m} A_j \exp(-\frac{B_j}{\omega^2} r^2) \tag{3}$$