Propagation of beams with a power-law dependence on the radius

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Introduction

Optical traps [1] are widely used to capture, manipulate, and study molecules, atoms, and biological cells. For conventional light traps, when a microparticle is attracted to the region of maximum intensity, the destructive effect of heating on the trapped objects is one of the main problems. An alternative is to capture in the area with minimum intensity, in the so-called "light bottles" [2], which are an area of zero intensity surrounded by a high intensity area, which are light barriers.

Many works are devoted to the construction of a trap based on Airy beams formed by the cubic phase, since they have the property of abruptly autofocusing [3]. To create optical traps, it is logical to use beams with large intensity and phase gradients using diffractive optical elements or optical light modulators [4].

We consider beams with a power-law dependence on the radius, combined with a binary axicon [5], and with an additional apodization aperture, which provides a variation in the properties of self-focusing beams and the possibility of creating optical traps of different sizes and shapes.

Modelling

In this work, optical beams of the following form are considered:

$$f(r) = c_0 \exp(-ik\alpha_1 (r-r_0)^n) cos(\alpha_2 (r-r_0)),$$

where $k = 2\pi/\lambda$ is the wave number for laser radiation with wavelength λ, α_1 is a positive real number less than one.

The Fresnel transform is used to simulate the paraxial propagation of a beam in space. Input function can be represented as $f(r,\varphi) = A(r)e^{im\varphi}$, where m is an integer, and has axial symmetry $(m = 0)$, therefore the generated field will not depend on the angle:

$$F_0(\rho,z) = \frac{k}{z}\exp(ikz)\exp\left(\frac{ik\rho^2}{2z}\right) * \int_a^b A(r)\exp\left(\frac{ikr^2}{2z}\right) J_0\left(\frac{kr\rho}{z}\right) r dr.$$

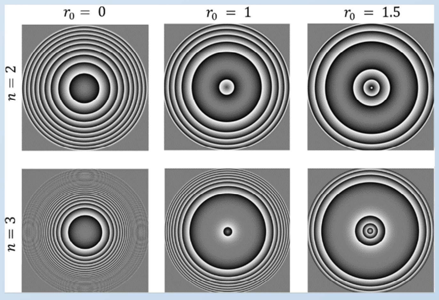

Fig. 3. Phase of the input beam without axicons as the radius of the inner diverging region changes.

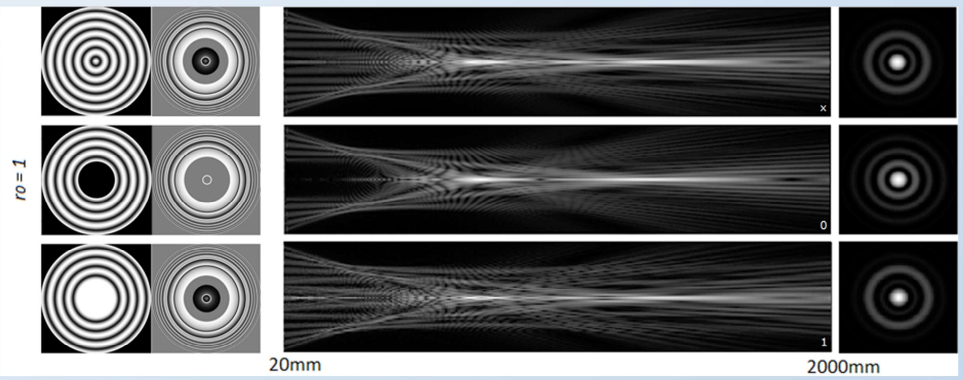

Fig. 1. Longitudinal intensity pattern for $n = 3$. (x) - the amplitude of the function does not change; (0) $- r < r_0$, and the amplitude in this region becomes equal to 0; (1) $- r < r_0$, and the amplitude in this region becomes equal to 1.

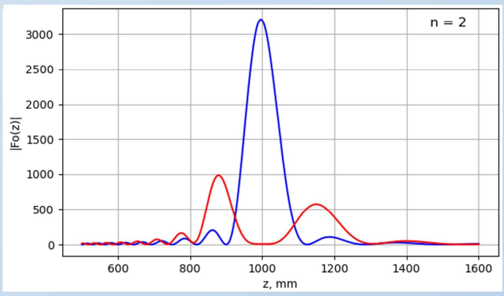

Fig. 4. Intensity distribution along the optical axis for $n = 2$. The blue color shows the case without the use of axicons, the red color shows the case with the use of axicons.

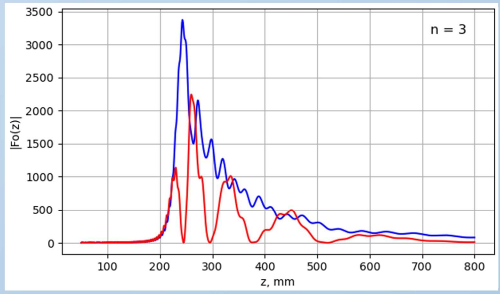

Fig. 5. Intensity distribution along the optical axis for $n = 3$. The blue color shows the case without using axicons, the red color shows the case with using axicons.

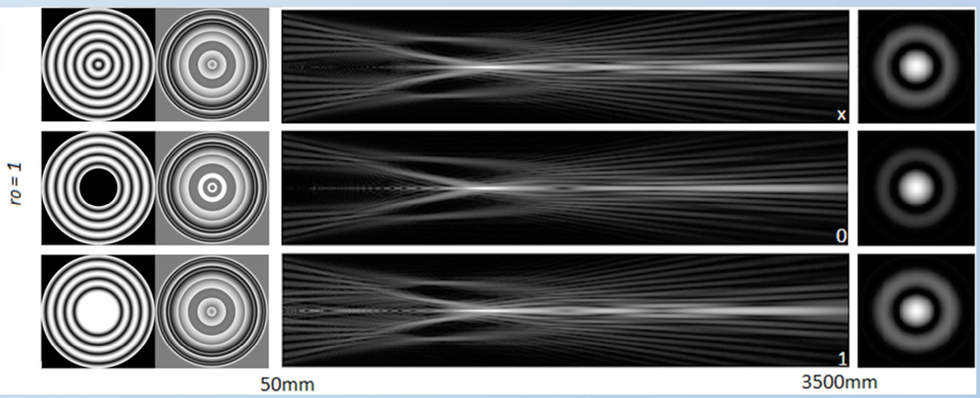

Fig. 2. Longitudinal intensity pattern for $n = 2$. (x) - the amplitude of the function does not change; (0) $- r < r_0$, and the amplitude in this region becomes equal to 0; (1) $- r < r_0$, and the amplitude in this region becomes equal to 1.

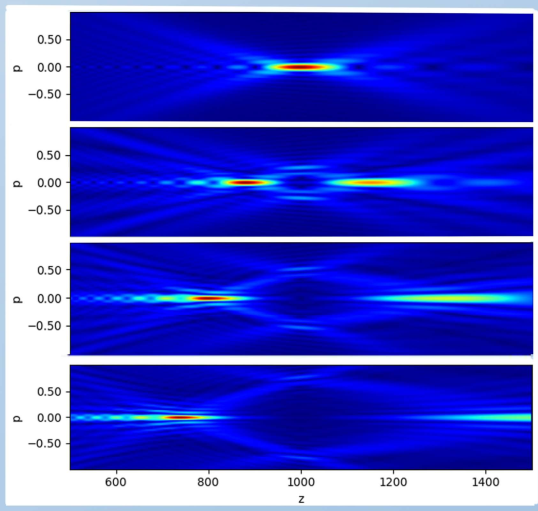

Fig. 6. Longitudinal intensity pattern for $n = 2, r_0 = 0$. Parameters α_2 from top to bottom: 0, π, 2π, 3π.

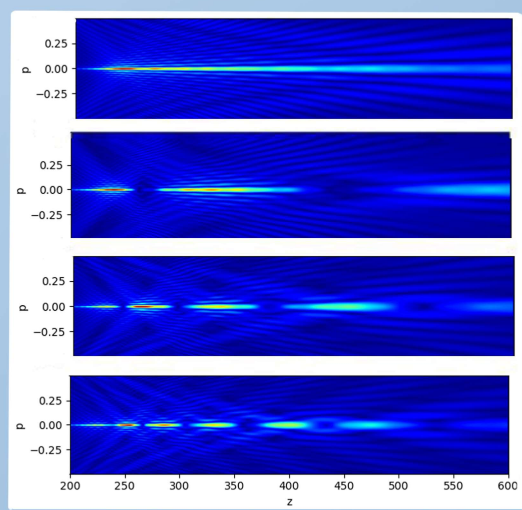

Fig. 7. Longitudinal intensity pattern for $n = 3, r_0 = 0$. Parameters α_2 from top to bottom: 0, π, 2π, 3π.

Conclusion

The properties of lenses with quadratic and cubic dependencies on the radius with different apertures in the central part are illustrated. Using a binary axicon, optical traps of various sizes and lengths were built. It is shown that the power of the function also makes it possible to control the structure of optical traps.

References

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