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# Diffraction of a Gaussian beam on a gradient lens with a fractional degree of dependence on the radius

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**Abstract**

The diffraction of a Gaussian beam with circular polarization on a gradient microlens with layers of subwave thickness was considered in this paper. Numerically, using the method of finite differences in the time domain (FDTD), I estimated the parameters of the focal lengths by the depth of the focus and the transverse dimension.



*Keywords:* diffraction optics; laser beams; subwave structures; gradient lens; FDTD; circular polarization

## 1. Introduction

The connection between the fibers (when transmitting information over optical fibers) is more convenient when using gradient elements [1,2], which are the subject of study of gradient optics [3]. Usually such elements are some extent an analog of the lens, which forms a short focus. As a rule, two gradient elements are used: one at the output, which dissipates the laser beam and one at the input that collects the laser beam [4]. However, they need to be quite accurately reconciled [5,6]. Nevertheless, gradient lenses have a several advantages, due to flat surfaces, which make

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them useful, including when used for light collimation from fiber [4]. Thus, the propagation of light rays along a curve makes it possible to use gradient elements for a better focus [7-10].

One of the advantages of using axicon is the formation of an extended focus [11,12], including, with a subwave transverse dimension [13,14]. In [15], a new diffractive optical element (a fracxicon) was proposed: the axicon whose phase function is representable in the form of a power function of the radius. It was any positive real number, including fractional. The conical axicon and the parabolic lens are particular cases of the fracxicon [16,17].

The calculation of the diffraction of a Gaussian beam on a layered lens, a conical axicon and a diffraction axicon consistent with each other showed that a layered lens with a linear change in the refractive index has the advantage over a diffraction axicon with the same numerical aperture, because allows the formation of narrower focal segments [18,19]. In this paper, I consider the focusing of a Gaussian beam on a gradient lens with a fractional degree of dependence on the radius. To numerically simulate the diffraction of the laser beams in question, the finite time-difference method (FDTD) with using high-performance computations [20]. In contrast to the integral calculation of field propagation in a parabolic medium [21,22], the FDTD method allows one to take into account the layered character of the gradient lens in question.

## 2. Diffraction of a Gaussian beam on a gradient lens

Modelling parameters: wavelength λ = 1.55 μm., size of the computational domain x, y, z ∈ [–4.5λ; 4.5λ]. The step of discretization in space is λ/21, the step of time sampling is λ/(42c), where c is the speed of light. The thickness of the absorbing layer of PML is 0.65λ. A fundamental Gaussian mode with circular polarization is used as the input laser radiation. To compare the diffraction of the input beam on a gradient lens, the diffraction of a Gaussian beam on a diffraction axicon is also considered. The refractive index for the lens changed from the maximum value at the center (n = 3.47) to the minimum value (n = 1.5) at the edge, according to the following law:

$$N(r) = n_0(1 - \alpha r^{\beta}), \tag{1}$$

where $n_0$ = 3.47 – value of the central layer (maximum), $r$ – radius of the structure, $\alpha, \beta$ – variable parameters.

Let the width of the lens along the propagation axis of the laser beam be denoted by L (fix the size, $L$ = 1.55λ). The phase difference between the central ray and the ray passing at a distance from the center for the diffraction axicon is:

$$\Delta\varphi_{диф} = -k \cdot NA \cdot R, \tag{2}$$

where NA is the numerical aperture of the axicon, $R$ is the radius of the axicon. The numerical aperture of the axicon is:

$$NA = n_0 L \alpha . \tag{3}$$

To estimate the parameters of the focal lengths being formed, the half-width of the half-depth of the intensity (FWHM) and the depth of focus (DOF) are considered. Numerical simulation results (intensity) for a gradient lens and a diffractive axicon matched to it are presented in Figures 1 and 2.

For a gradient lens at β = 0.5, an increase in α leads to a decrease in the size of the focal spot as the length of the light needle decreases, at β = 1.5, an increase in α also decreases the length of the light needle, but the FWHM focal spot size remains unchanged.

It should be noted that the most compact focal spot was obtained for a gradient lens at α = 0.12 and β = 0.5. Commit these parameters and we will vary the width L of the gradient lens. The results of numerical simulation are given in Table 2. The decrease in the width of the lens by 1.55 times caused an increase in the length of the light segment by a factor of 12.