Self-focusing of wave beams with a plateau-shaped intensity distribution

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It is shown by means of a numerical investigation method on a computer that only one focus can be formed during the self-focusing of axially symmetrical wave beams with a plateau-shaped intensity distribution. In this situation the total power flowing into the focus can be considerably greater than the critical value.

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A large number of both experimental and theoretical papers have been devoted to studying the propagation of high-power wave beams in nonlinear media.[1] Up to now many important properties of this phenomenon have been determined. Efforts involving numerical modeling of this phenomenon on a computer have been contributed a great deal to the study of the wave beam propagation process. Most of the attention has been focused on beams having a Gaussian transverse intensity distribution. It has been shown in Refs. 2 and 3 that in the propagation process of such a beam a multiple-focus structure is formed, with the number of foci being approximately equal to P/P_{cr}, where P is the total beam power, P_{cr} is the critical power. In this case a power approximately equal to P_{cr} enters each focus.

However, for a full understanding of the entire propagation picture for high-power wave beams in nonlinear media it is necessary to investigate beams with an initial distribution that is fairly arbitrary in nature.

This paper reports on the results of a numerical investigation, done on a BESM-6 computer, of the propagation of wave beams with an initial intensity distribution of the form

$$I = I_0 e^{-(r/a)^N}, \tag{1}$$

where a is the initial beam radius, $N \geqslant 2$. The wavefront was planar upon entry into the nonlinear medium.

A beam of this type is more acceptable in high-power lasers since it permits a better filling of the aperture of amplifiers for large values of the parameter N.

The stationary-with-time differential equation for a nonlinear Kerr type medium with three-photon absorption was considered

$$\Delta_{\perp} E + 2ik \frac{\partial E}{\partial z} + \frac{k^2 n_2}{n_0} |E|^2 E + ik^2 m_4 |E|^4 E = 0. \tag{2}$$

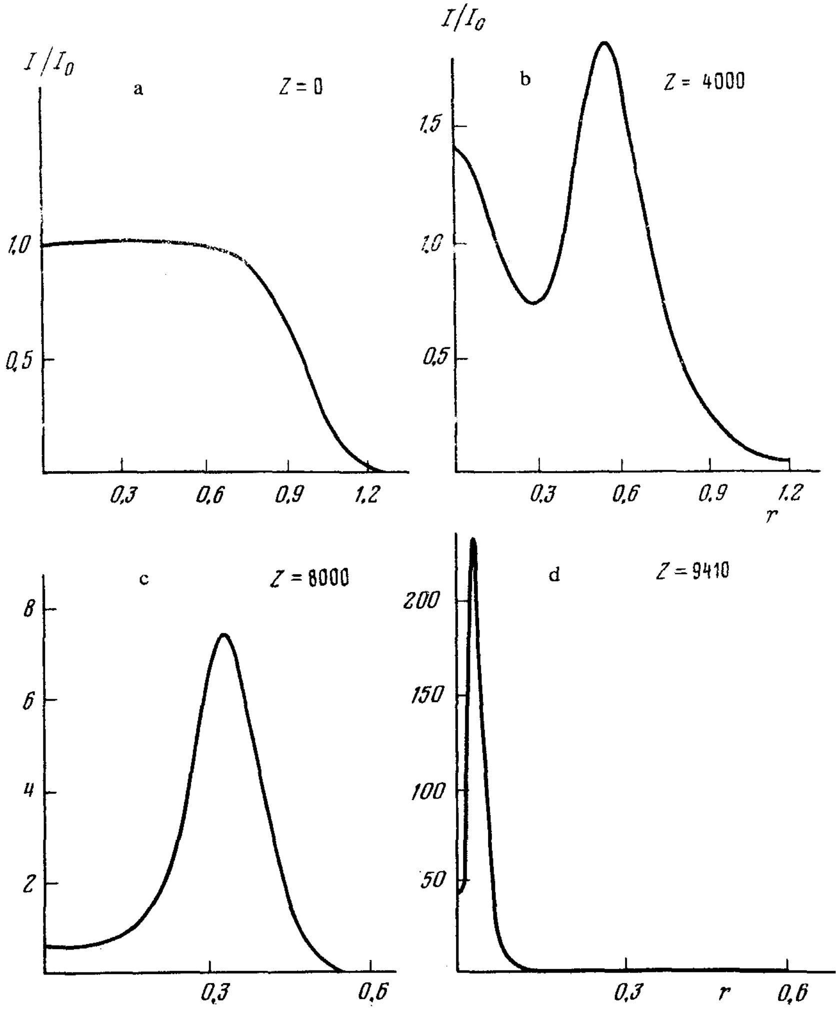

FIG. 1.

Here $k = (\omega/c)\, n_0$, n_0, n_2 are the linear and nonlinear refractive indices, m_4 is the three-photon absorption coefficient. The following parameter values were used in the calculations: $k = 6\times 10^4$ cm^{-1}, $n_2/n_0 = 10^{-20}$ CGS units, $m_4 = 3\times 10^{-12}$ CGS units, $a = 1$ cm. The parameter N was varied from 2 to 32, the initial beam power P was within the limits $10P_{cr} \leqslant P \leqslant 50\, P_{cr}$. The calculation procedure has been described in Ref. 4.

The calculation results for $N = 2$ were found to agree well with the results obtained in Refs. 2 and 3. For values $N > 2$ the character of the beam propagation is drastically altered. As an example, Fig. 1 shows the transverse intensity distributions for $P = 10P_{cr}$ and $N = 8$ for different distances from the point of entry into the nonlinear medium. As seen from the figures, a radially symmetrical ring is formed in the transverse distribution which gradually contracts toward the axis and forms the focus.

Figure 2 shows the dependence of the total power in the beam and the intensity

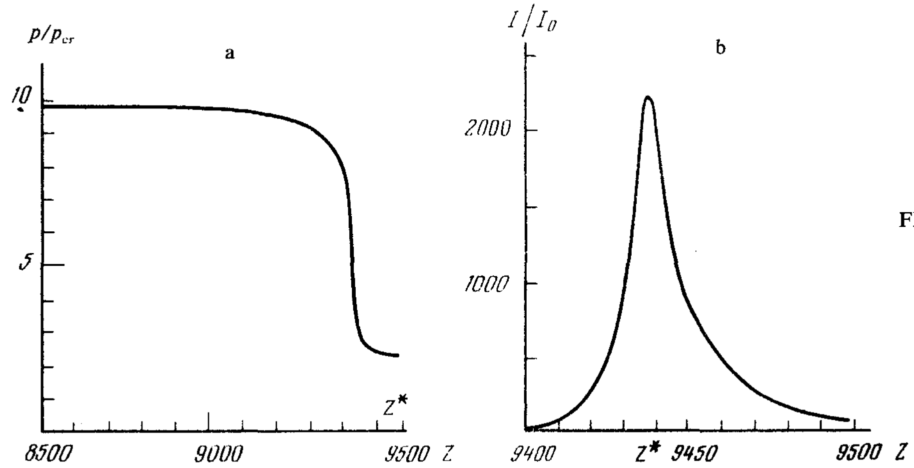

FIG. 2.

on the axis on the distance Z. These curves are drawn for Z in the vicinity of a focus. For $Z = 8000$ cm a power equal to $9P_{cr}$ is concentrated in the ring; in this case the total beam power is $9.9P_{cr}$. For $Z = 9410$ cm a power of $5.8P_{cr}$ is concentrated in the ring for a total beam power of $7.7P_{cr}$. The maximum intensity on the axis at the focus is reached at $Z = 9440$ cm. The total beam power after passage through the focus is equal to $2.4P_{cr}$.

Similar results were obtained also for other N and P. For large N several radially symmetrical rings are formed at first, which gradually contract toward the axis as the beam propagates. In this case the rings merge with one another and the total number of rings decreases. If a power greater than the critical is formed into a ring, then foci appear on the axis. Thus, for $N = 16$ and $P = 30\ P_{cr}$ the appearance of two foci was recorded, with a power considerably in excess of the critical value entering into each of them. Although the numerical calculations were performed for an input beam radius of $a = 1$ cm and a wave vector of $k = 6 \times 10^4$ cm^{-1}, the position of the focus can easily be recalculated for arbitrary a and k by using the relationship $ka^2/Z = \text{const}$.

As follows from the calculation results, the propagation picture for wave beams with $N \geqslant 2$ is significantly different from the multiple-focus structure realized for $N = 2$. In our opinion the primary reason for this difference lies in the fact that for $N > 2$ the linear diffraction at the very outset leads to a considerable transformation of the transverse distribution profile. The diffraction rings formed in this case then exert a decisive influence on the self-focusing process. Beams with a Gaussian transverse intensity distribution, however, as is well known, propagate in a linear medium with no change in the transverse profile. (Let us note that the analytical solution of the self-focusing problem for wave beams with $N > 2$, undertaken in Ref. 5, was unsuccessful in arriving at a complete description of the entire self-focusing picture).

Of considerable interest, in particular, is the result obtained by us that a power can enter the focus that is appreciably greater than P_{cr} and amounts to an appreciable fraction of the entire initial beam power.

In conclusion let us note that even if the transverse intensity profile is initially

Gaussian, then it may be distorted as the wave beam propagates in the medium, not only because of the refractive index nonlinearity, but also because of other reasons, such as stimulated Mandel'shtam-Brillouin scattering, the threshold of which can be below the threshold of self-focusing. Such a transformation of the profile can lead to a considerable deviation of the self-focusing picture from the multiple-focus structure even for beams initially having a Gaussian profile.

[1)]A fairly detailed bibliography dealing with this problem is contained in Ref. 1.

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