Simulation of radiation propagation in XeCl-laser system

A.G. Bessonov, V.F. Losev, and A.L. Magazinnikov

Institute for High-Current Electronics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

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The propagation of radiation is modeled through an amplifying laser system with the allowance made for the amplification saturation. The simulation is made for the case of an excimer laser system. The calculations have been performed in the quasi-optical approximation of stationary diffraction. The paper describes the influence of diffraction on the beam intensity distribution propagated through an amplifying medium and in vacuum.

Introduction

Excimer lasers are most effective and high-power sources of coherent radiation in the ultraviolet. Various applications of these lasers do require, as a rule, high quality of a laser beam. It is known that the minimum beam divergence is limited by the radiation diffraction. One of the ways of achieving high-quality radiation at a high power is its amplification.[1,2]

Theoretical investigations of the amplification conditions in laser systems always attract much interest. Numerical simulation makes it possible to perform the investigations under conditions when the experiment is difficult, expensive, or impossible. Sometimes such an experiment enables one to optimize the technical characteristics of systems in use, or to obtain supplementary information, which is difficult and sometimes impossible, to obtain in the experiment.

In this paper, using the means of computational mathematics the model has been developed of radiation propagation in a medium with the amplification saturation, and results calculated for XeCl-laser system are presented.

Calculated results

The process of optical radiation propagation through a nonlinear medium is described by the quasi-optical equation, which in a dimensionless form[3] is as follows:

$$\frac{\partial A}{\partial z} + i\Delta_{\perp}A + i\varepsilon A + \delta A = 0, \qquad (1)$$

where $A = f(x, y, z)$ is the complex amplitude of the radiation field; ε is the dielectric constant of the medium (dimensionless); $\delta = \alpha - g$, where α is the dimensionless absorption coefficient; g is the dimensionless gain factor of an active medium;

$$\Delta_{\perp}A \equiv \frac{\partial^2 A}{\partial r^2} + \frac{1}{r}\frac{\partial A}{\partial r}.$$

In our model the amplification saturation of an active medium is considered; i.e., the dependence of the medium gain factor on the radiation intensity:

$$g = \frac{g_0}{1 + I/I_{\text{s}}}, \qquad (2)$$

where g is the running gain factor; g_0 is the gain factor for a small signal; I is the radiation intensity; I_{s} is the saturation intensity.

The paper describes the process of radiation propagation in the active medium of a XeCl laser with the gain factor $g_0 = 0.05$ cm^{-1} and the unsaturated absorption coefficient $\alpha = 0.008$ cm^{-1}. The cross size of the active medium far exceeded the size of the input beam, which had homogeneous intensity distribution over its cross section. The intensity, exceeding by 100 times the input intensity I_0, was taken as the saturation intensity I_{s} for the amplifying medium considered in the calculations.

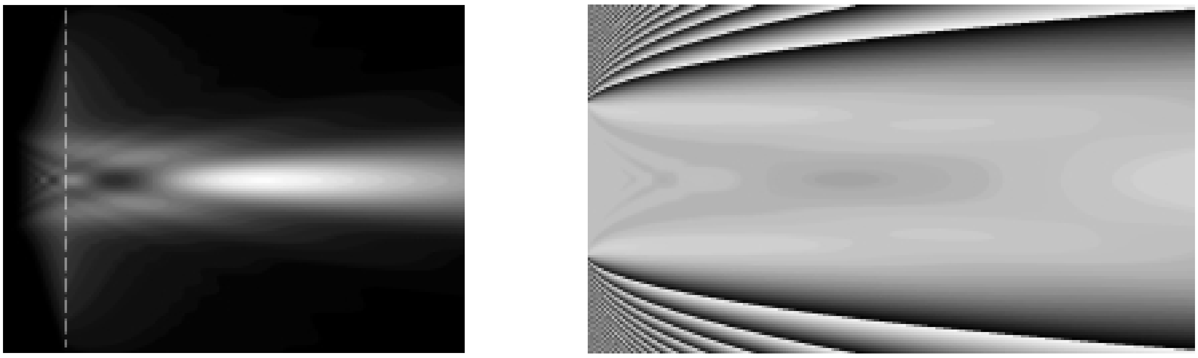

a *b*

Fig. 1. The variation of the distribution of the intensity (*a*) and the phase (*b*) in the beam cross section of radius $r = 0.1$ cm along the beam propagation axis in the amplifier–vacuum system of 7.5-m length (the amplifier length is 1 m, the vacuum length is 6.5 m). The amplifying medium boundary is denoted by dashed line. The scales of the figures along the beam propagation are identical.

Figure 1 shows the variation of distribution of the intensity (*a*) and phase (*b*) over the beam cross section of radius $r = 0.1$ cm along the axis of its propagation in the amplifier–vacuum system. The boundary of the amplifying medium is designated by dashed line. In the amplification zone, a gradual intensity increase was observed. In the figure this corresponds to the brightness. For the phase distribution Fig. 1, *b* shows the uneven variation of radiation phase in the beam periphery.

Figure 2 shows the diagrams of axial beam intensity of radius $r_1 = 0.1$ cm and $r_2 = 0.2$ cm depending on the distance. The length of the amplifying medium in both cases was 1 m. In the case of a beam of smaller radius, the competition was noticed in the zone of amplifying medium between the amplification process and diffraction. For this reason the intensity increase of a beam of smaller radius is lower than that for a beam with a larger radius.

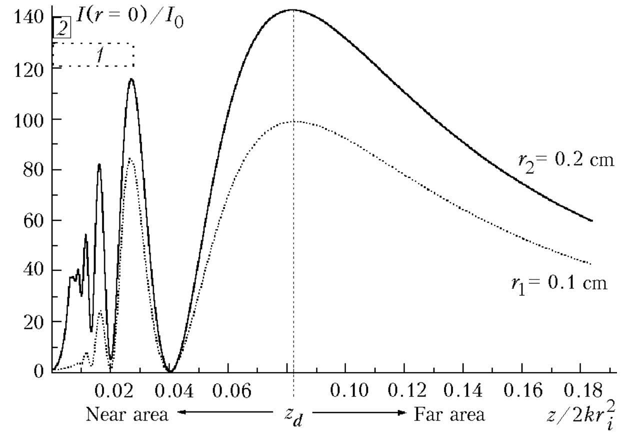


Fig. 2. The dependence of the radiation intensity along the optical axis on the distance covered. The positions of the amplifying medium for beams of radii r_1 and r_2 are shown by rectangulars *1* and *2*, respectively; z is the distance, in cm, measured along the optical axis, z_d is the diffraction length, k is the wave number, r_i is the beam radius (i = 1, 2).

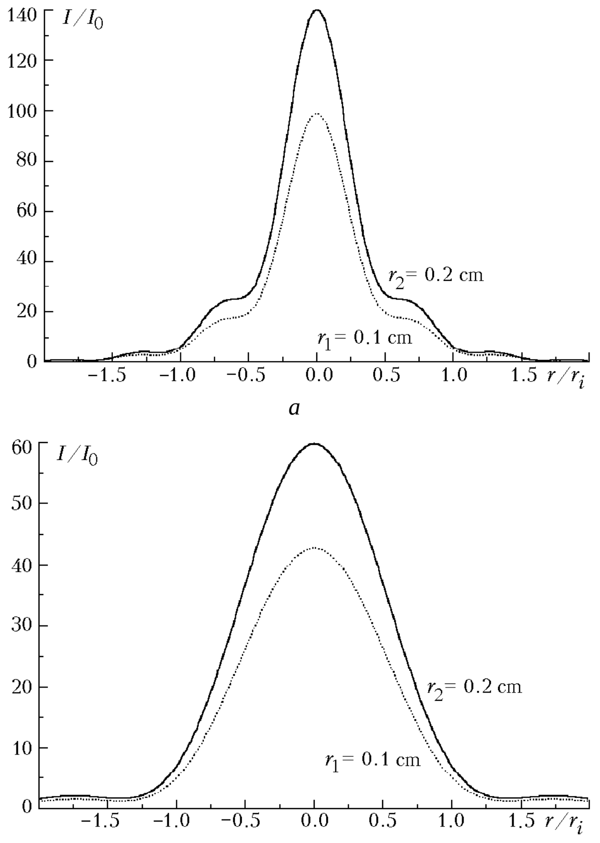
The position of the intensity maximum on the Airy disk is in a good agreement with the experimental data from Ref. 1.

Figure 3 shows the diagrams of the radiation intensity distribution in the cross section for beams of the same radii at a distance, which equals the diffraction length (3.25 m and 13 m, respectively) and at a distance, which is twice as large as the diffraction length. In the latter case the beam spreading due to the diffraction is observed.

Conclusion

This paper describes the model of radiation propagation through amplifying systems. The numerical simulation is performed of the radiation propagation for the case of XeCl laser as an amplifying medium. The behavior of radiation intensity and phase for beams of different diameter was investigated.

The results obtained have made it possible to conclude that the decrease of the beam radius results in an increase of the diffraction effects and may be a reason of a slower growth of the intensity of amplified and further propagated radiation. The calculated results demonstrate a good agreement with the experimental data obtained in different papers.



a

b

Fig. 3. The radiation intensity distribution in the cross section for different beam radii: (*a*) at the distance being equal to the beam diffraction length; (*b*) at the distance, being twice as large as the diffraction length.

References

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