Influence of cavity parameters on the formation of mode structure of the coaxial lasers in lidar systems

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The cavity design of a coaxial laser with aspherical mirror is studied as a factor influencing formation of the radiant fluxes. The effect of plane mirror deformations on the principal parameters of the cavity and characteristics of the output emission is estimated. The results obtained allow some design parameters of a laser cavity to be chosen properly.

When developing lasers of the coaxial design, one of the main problems is to match the field of an optical cavity with the working volume of an active medium. The findings presented in Ref. 1 evidence that the field structure of such lasers results from superposition of the so-called multipass modes (M-modes) that cannot be focused by spherical optics into a continuous spot, but are focused only in a ring whose diameter depends on the tilt of radiant fluxes of a mode relative to the cavity axis.

Coaxial lasers employ cavities of different design. In particular, in Ref. 2 we consider the laser named Yupiter. This laser employs the cavity formed by an aspherical mirror *1* and a plane mirror *2* as shown in Fig. 1.

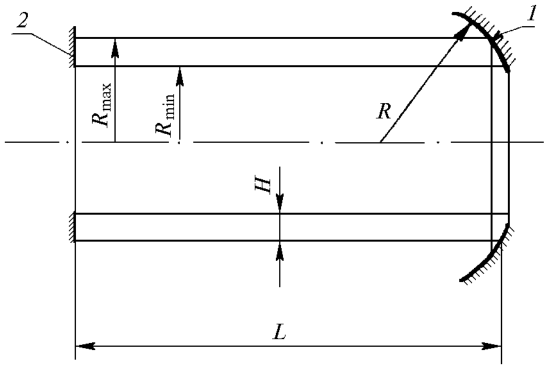


Fig. 1.

The aspherical mirror is an axisymmetric conoid whose envelope is an arc with the radius of curvature R; L is the cavity length; H is the gap formed by the walls of a discharge chamber. These walls limit the radius or the ring area illuminated on the aspherical mirror to R_{max} from outside and the radius of the ring area illuminated on the plane mirror to R_{min} from inside.

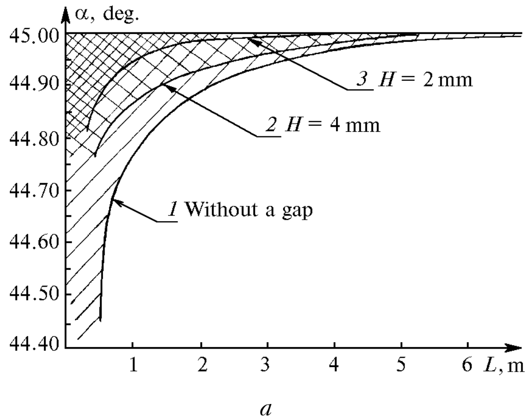
The aim of this paper is to estimate the influence of the cavity design parameters on the domains of existence of M-modes and the conditions of formation of their radiant fluxes in the cavity of a Yupiter laser.

The active medium in this laser is excited within the gap between the coaxial cylinders of the discharge chamber. The size of this gap has a significant effect on the formation of electromagnetic field in the cavity. In Ref. 3 it was found that in the plane model of the cavity the domain of existence of radiant fluxes depends only on the size of caustics. However, the generating multipass modes actually occupy other space in the gap of the discharge chamber.

In Ref. 4 we proposed a technique enabling one to determine the domain of existence of M-modes and design parameters of the laser cavity for such modes within the framework of a 3D model. This technique is used to demonstrate that the multipass modes can exist only in the cavities, which have the angle at the vertex of the equivalent cone equal to 90° or less. The minimum value of this angle depends on specific design parameters of the cavity. In this case, the above-mentioned domains are determined from the condition of self-reproduction of M-modes in the cavity with the aspherical mirror in the case when the walls of the discharge chamber do not restrict the mode travel path.

This technique has allowed us to derive the dependence of the permissible angles at the cone vertex α of the aspherical mirror on the cavity length L at the constant radius of illumination ring on the aspherical mirror R_{max} and different values of the working gap H. The results are shown in Fig. 2*a*.

If neglecting vignetting, the boundary of the domain of existence of multipass modes at the angle varying as shown in Fig. 2*a* is shown by the curve *1*. As the working gap H decreases, starting from some moment in time, the chamber walls start to affect the process of radiant flux formation (curves *2* and *3* in Fig. 2*a*). As this takes place, the domain of existence of multipass modes decreases. The gap affects the characteristics of the output radiation, in particular, the tilt angles of output rays. The tilt angles of the output rays ψ as functions of the illumination ring radius on the exit mirror R_{min} are shown in Fig. 2*b* for different values of the working gap H. One can see from this figure that as H decreases, the range of possible tilt angles of the output rays decreases too.



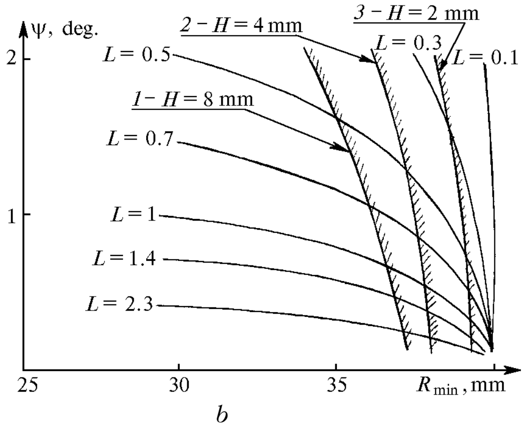


Fig. 2.

Using the technique from Ref. 4, we have determined the range of possible values of R providing for the existence of multipass modes in the entire volume of the discharge chamber. The calculated scheme of the cavity is shown in Fig. 3, where α_1 and α_2 are the angles between the cavity axis and the tangents to the envelope of aspherics at the boundary points. Other designations are the same as in Fig. 1. The limiting values of the angles α_1 and α_2 were determined from the plot (Ref. 4, Fig. 3*a*) for the boundaries of the domain of existence of the multipass modes. It is easy to see that the curvature radii can be found by the following equation:

$$R = \frac{H}{2\sin\,[(\alpha_2 - \alpha_1)/2]\,\cos\,[(\alpha_1 + \alpha_2)/2]}\,.$$

The radius R ensures overlapping of the range of the cone angles from α_1 to α_2 in the working gap equal to H. The actual values of the angle α_1 vary depending on the value of the chosen gap H. The dependence of R on α for different values of the gap H is shown in Fig. 4. The obtained dependences indicate that small values of H correspond to α close to 45°; the radiant fluxes in this case propagate only in the near-axis zone.

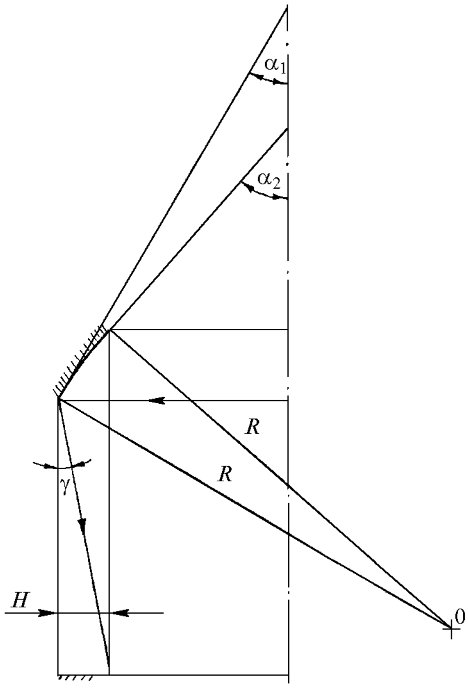


Fig. 3.

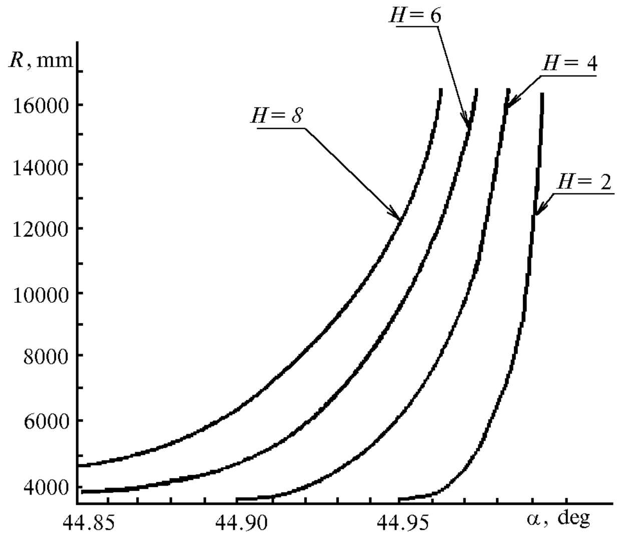


Fig. 4.

Under actual conditions of operation, the plane mirror is subjected to various effects of the environment (thermal and mechanical deformations, deformations due to atmospheric pressure if the mirror is the exit mirror of a laser, and others). Deformations are simulated by a change in the shape of the plane mirror making it cone-shaped. Figure 5*a* shows the path of rays in the 3D model of the cavity, in which the plane mirror M_2 is replaced with a cone-shaped mirror M_3 with the angle at the vertex close to 180°. The lower circle (Fig. 5*a*) is the locus, where optical rays reflect from the cone mirror M_3. The plane M_2 is now the base of the cone mirror and coincides with the plane mirror from the cavity described in Ref. 4. Figure 5*b* shows the section $O'N'BO$, in which B_2B is the envelope of the low conical mirror; OB is the radius of the base of the lower cone-shaped mirror, that coincides with the radius of the plane mirror R_{pl} from Ref. 4 (Fig. 2); B_2N' is the normal to the surface of the lower cone-shaped mirror; ε is the tilt angle of the envelope of the lower cone-shaped mirror to the cone base. We consider mirrors being both positive and negative cones. In spite of the slightly conic shape, hereinafter we refer to the mirror M_3 as to the plane mirror.

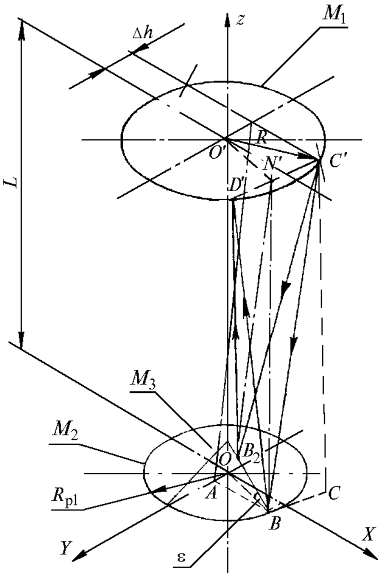


Fig. 5.

In the geometric optics approximation as applied to rays in the cavity and following the technique from Ref. 4, we have determined the coordinates of the point of reflection of optical rays from the conical surface of the mirror M_3:

$$X_{B2} = \left(\sqrt{X_B^2 + Y_B^2} - L \cos\varepsilon \cos\lambda\right) / (1 + \tan^2\beta);$$

$$Y_{B2} = X_{B2} \tan \beta,$$

where

$$\beta = \arctan (Y_B / X_B); \;\; Z_{B2} = L \cos \lambda \cos \varepsilon.$$

Numerical simulation of the cavity has allowed us to reveal that deformation of the plane mirror (formation of a slightly conical shape) affects practically all parameters of the optical cavity. Let us consider the most important effects.

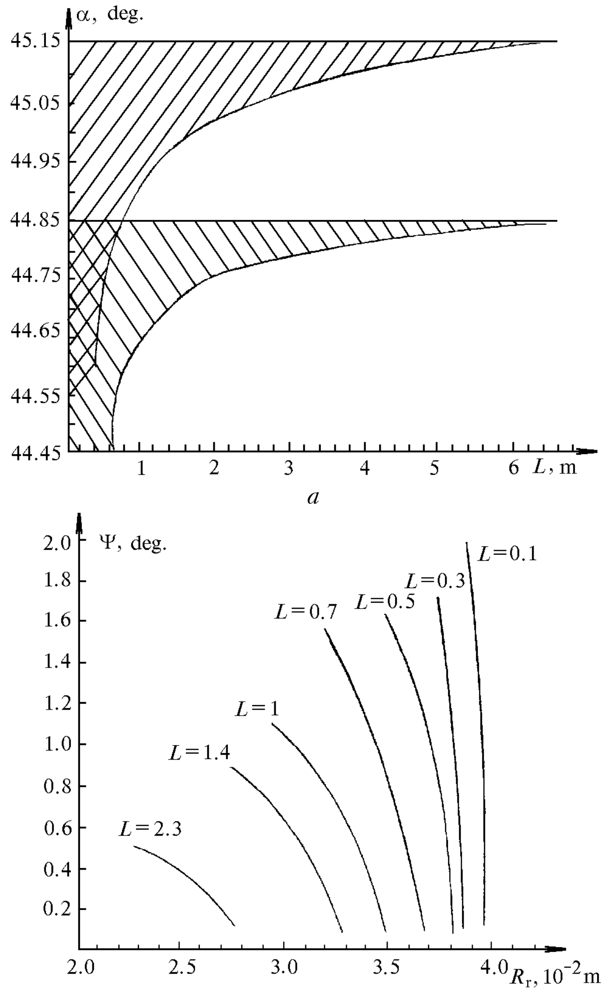
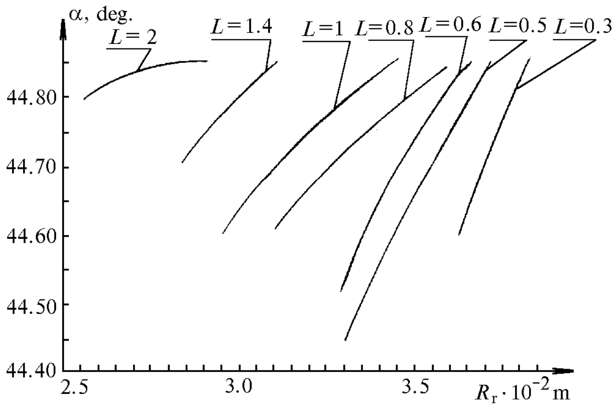


Fig. 6.

Figure 6*a* shows the dependence of possible angles at the cone vertex of an aspherical mirror α on the cavity length L for different values of ε. The shaded region in Fig. 6*a* indicates the range of permissible values of the angle α, at which the existence of multipass modes is possible. It follows from the plot that the range of possible values of the angle α at the cone vertex of the aspherical mirror shifts toward larger values in the case of negative conical shape of the mirror M_3. In contrast, at a positive ε the domain of existence of M-modes shifts toward smaller values of α. The upper boundary of the domain of existence of multipass modes can be derived from the equation $\alpha = \varepsilon/2$. Obviously, even a small deformation (only slightly conical shape) of the plane mirror strongly affects the tilt angle of the output rays. Figure 6*b* shows the dependence of the tilt angle ψ on the radius of illuminated ring, R_r, on the plane mirror at different cavity lengths in the case of deformation of the plane mirror by the angle ε = 0.3. The dependences shown in Fig. 6*b* indicate also that deformation of the plane mirror may significantly change the diameter of the ring of the output radiation beam. This fact should be taken into account in choosing parameters of the discharge chamber. The angle α at the cone vertex of the aspherical mirror as a function of the radius R_r of the illuminated ring on the plane mirror at different values of L can be determined from the plots in Fig. 7*a* for positive ε values. Vignetting of radiant fluxes inside the cavity by the walls of the discharge chamber has a strong effect on the domain of existence of slant multipass modes. Figure 7*b* shows how the boundaries of domains of existence of M-modes change at different gaps H. It follows from Fig. 7*b* that the vignetting effect of the walls of the discharge chamber sharply decreases the domain of existence of the multipass modes. This is a particularly pronounced at a large tilt angle of the output rays ψ.



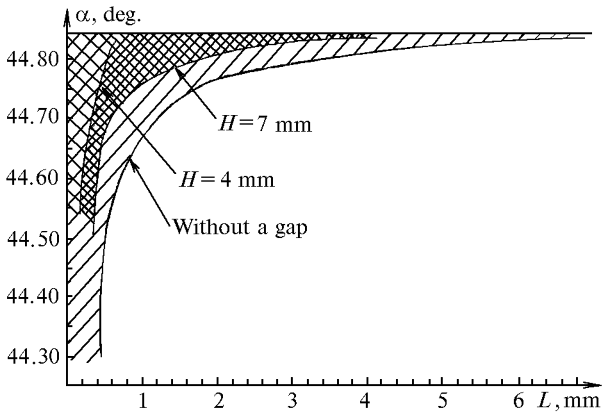


Fig. 7.

The results of this work allow the following conclusions to be drawn:

1. The size of the gap of a discharge chamber of a coaxial laser produces a significant effect on the character of free oscillations.

2. The maximum filling of the working gap of the discharge chamber can be achieved with the proper radii of curvature of the aspherical mirror. This also allows one to evaluate the technological imperfections in the aspherical mirrors of a coaxial laser.

3. The technological imperfections in the mirrors and deformations of the mirror shape (formation of a slightly conical shape) can strongly effect the characteristics of output radiation beam. Choosing proper design parameters of the cavity can form oscillations of a certain preset type.

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