LASERS

COAXIAL LASER RESONATOR WITH SMOOTH ADJUSTMENT OF RADIATION OUTPUT

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A new design of a laser resonator with smooth adjustment of radiation output is presented. Adjustment can be performed over a wide range and directly during laser operation. This provides optimal feedback under various laser operating conditions. The active element has an annular sectional shape. The pumping and cooling elements can be placed on the outer and inner sides of the active element. This ensures a uniform distribution of pump energy and good heat dissipation from the active substance. Gaseous, liquid and solid substances can be used as an active medium. The possibility of obtaining optimal feedback and homogeneity of the active substance make it possible to increase the efficiency of laser generation. Coaxially arranged conical mirrors provide a rational change in the radiation path in the cavity. The radiation makes a complete passage through the cavity in four different ways. This allows to minimize the effect of inhomogeneities of the active substance on the radiation, which improves the spatial-angular and energy characteristics of the output laser radiation. Conical 90° mirrors that are used in the laser cavity do not require careful alignment and provide increased laser stability. Such a resonator scheme is suitable for use in a wide frequency range, including the terahertz range.

KEY WORDS: *laser, coaxial laser resonator, feedback adjustment, conical mirrors, active medium, diffraction*

1. INTRODUCTION

The homogeneity of the active medium of the laser and the optimal feedback coefficient are important conditions for the high efficiency of laser generation. The maximum efficiency of a laser, like any generator, is achieved only with optimal feedback. With an increase in the fraction of laser radiation emerging from the cavity, the fraction of stimulated radiation decreases, and the fraction of spontaneous emission increases even to such an extent that laser generation may not occur at all. A decrease in the fraction of the emitted radiation can lead to saturation of the active substance and to an increase in losses in the cavity.

The optimum of feedback depends primarily on the gain and losses in the cavity and on its sizes. In most schemes of laser resonator, feedback is provided by selecting the transmission coefficient of the output mirror. If the output mirror has constant parameters, then the choice of coupling can be made by replacing the mirrors. In this case, the alignment of the resonator may be disturbed, and it becomes necessary to carry out additional alignment after each replacement. In addition, due to the discreteness of the parameters of the mirrors, it is difficult to precisely select the optimum. But even a carefully selected mirror cannot be optimal in all operating regimes, since the gain and losses in the cavity can change during the operation of the laser. Based on this, the advantage of continuous feedback change becomes obvious, which allows for maximum generation efficiency on all laser operation regimes.

Smooth adjustment of feedback in the laser can be carried out using an additional movable mirror [1,2]. However, it is important that the elements of the mirror moving mechanism do not introduce losses into the resonator, and the direction of the output radiation beam does not change during adjustment. For this, the structural elements of the moving mirror moving mechanism should not overlap the radiation path, and the angle of incidence of radiation on the output mirror should not change.

Resonators with an active element of an annular cross section have great prospects [3-5]. In such resonators, it is possible to perform pumping and heat sink from the outer and inner sides of the active element. At the same time, it is possible to significantly increase the homogeneity of the active substance, which increases the efficiency of the generation process and positively affects the spatial-angular characteristics of laser radiation. However, it is practically impossible to completely eliminate all heterogeneities of the active substance, since various factors are their cause. Such factors may include temperature gradients in the active substance and the heterogeneity of its chemical composition or crystal lattice. Inhomogeneities can cause turbulence when moving liquid or gas in lasers with pumping the active substance, and inhomogeneities of gas discharge are added to gas-discharge lasers. However, the negative impact of all kinds of inhomogeneities can be significantly reduced if resonators are used in which the radiation passes in different way at oncoming passages through the active substance [6,7].

Adjusting the radiation power in resonators with an annular cross-sectional shape of the active element can be achieved using a coaxial system of conical mirrors with a movable inner cone [8]. The direction of the output laser beam does not change during adjustment. However, this can increase the radiation losses on the inner surface of the active element. In addition, such a resonator requires careful adjustment. To simplify the adjustment, it is advisable that all the mirrors of the resonator have the form of 90° conical surfaces. Resonators with such mirrors practically do not require adjustment and have high stability [9-14].

The aim of this work is to develop and analyze a new laser resonator construction scheme with smooth adjustment of radiation output, which has increased stability and minimal losses.

2. LASER CAVITY DESIGN

The active element 1 of the annular cross section was used in the proposed new scheme of laser resonator [15,16] (Fig. 1). Annular conical mirrors 2, 3 are located on one end of the active element 1. Mirrors 2 and 3 are made in the form of conjugate lateral surfaces of truncated cones with angles at the vertices of 90° ± Δ, where Δ is the correction for adjustment the divergence of radiation. In fact, the conjugation of the conical mirrors 2 and 3 is an annular recess with a profile of 90° ± Δ. An annular 90° conical mirror 4 is located on the opposite end of the active element 1. The output conical 90° mirror 5 is located in the center of the mirror 4, equipped with a mechanism 6 for continuous movement along the axis of the resonator.

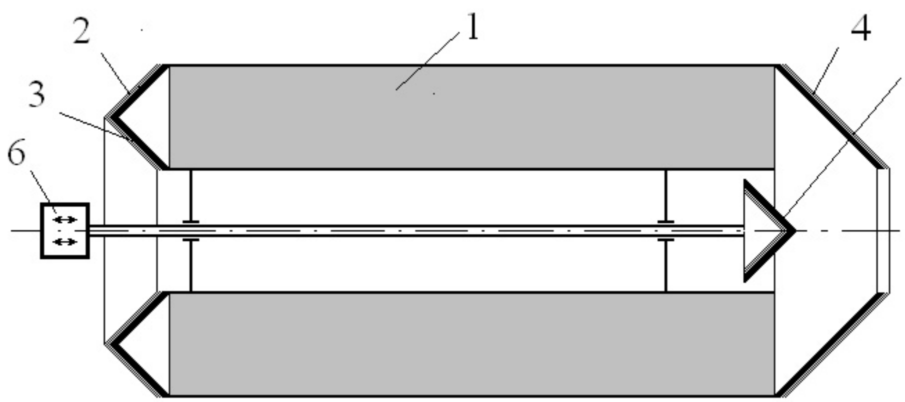

FIG. 1: Scheme of laser resonator

The active element 1 has an annular cross-sectional shape, which allows to place the elements for pumping and cooling from the inside and outside (Fig. 2(a)). The annular cross-sectional shape allows to obtain different areas of the lateral surface of the active element with the same cross-sectional area (Fig. 2(b)). Thus, for active media having a high absorption of pump energy, the shape of the active element having a small layer thickness can be selected. In this case a large lateral surface area provides intensive heat removal from the active element. In addition, the annular cross-sectional shape of the active element in gas-discharge lasers allows the use of highly efficient coaxial electrodes located on its inner and outer sides. All this allows to obtain high uniformity of the active element. The ring shape of the cross section is acceptable for the active substance of any state of aggregation. A cuvette of the appropriate form is required when using liquid and gaseous active media.

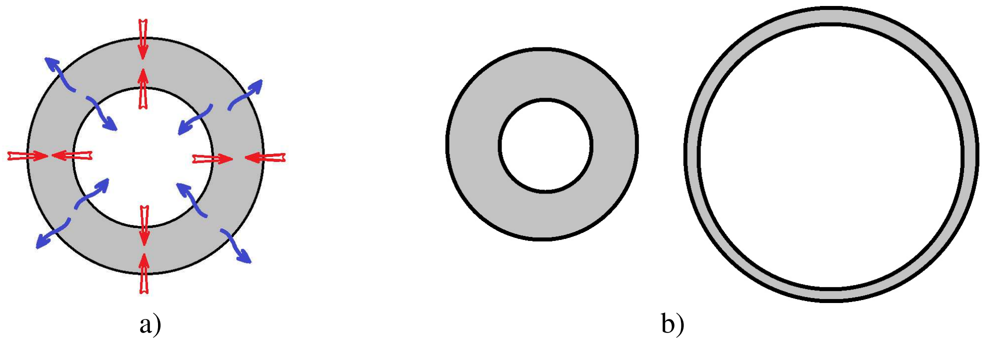

FIG. 2: The advantages of the annular cross-section of the active element: the possibility of pumping and heat removal together with the outer and inner sides (a) and the possibility of obtaining different areas of the lateral surface of the active element with the same cross-sectional area (b)

The ring conical 90° mirrors used in the laser do not require careful alignment, since they have the ability to reflect radiation in the opposite direction even with some inclination (Fig. 3). Consequently, deformations of the laser design, causing misalignment of the mirrors, have little effect on the direction of propagation of radiation in the cavity. This makes the resonator more resistant to thermal and mechanical influences and simplifies its adjustment.

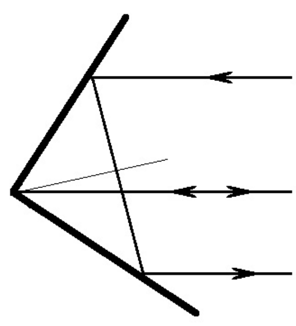

FIG. 3: Reflection from a conical 90˚ mirror when it is tilted

The path of the rays in the cavity and the adjustment process are shown in Fig. 4. The resonator forms coherent radiation, the direction of propagation of which is parallel to the axis of the resonator. The radiation is transferred to the opposite side relative to the contact surface of these mirrors when reflected from the mirrors 2, 3. The radiation is transferred to the diametrically opposite location of the annular active element 1 when reflected from the mirror 4. Radiation passes through the active substance 1 in four different ways due to this resonator geometry. This allows one to minimize the effect of inhomogeneities of the active substance on radiation [6,7]. Laser radiation is shifted to the outer and inner edges of the active substance 1 upon repeated reflection from the mirrors. This is due to diffraction and the presence of a correction for the taper of mirrors 2, 3. Then the radiation falls on the conical mirror 5 and it is removed from the resonator.

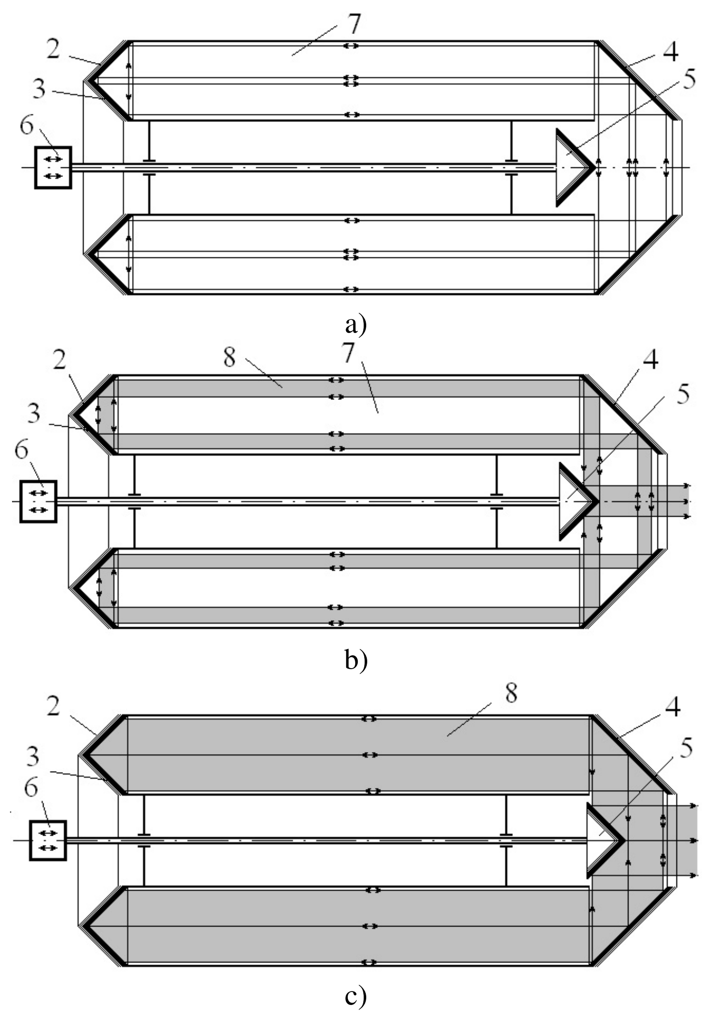

FIG. 4: The path of the rays in the cavity in the process of adjustment; limits of adjustment (a,b) and the average position of the adjustment mirror (c)

Adjustment of the radiation output is carried out by shifting the conical output mirror 5 along the axis of the resonator using the movement mechanism 6. Mirror 5 divides the volume of the active element into two zones – generation zone 7 and amplification zone 8 (Fig. 4). In zone 7, radiation is repeatedly reflected from mirrors 2, 3, 4, and from zone 8 it is removed from the resonator. The radiation falls from zone 7 to zone 8 due to diffraction and correction Δ to the taper of mirrors 2, 3. The movement of the conical mirror 5 along the axis of the resonator changes the ratio of the volumes of zones 7 and 8, and, consequently, changes the fraction of radiation output from the resonator. In one extreme position (Fig. 4(a)), radiation from the resonator is not removed at all, in the other extreme position (Fig. 4(c)) all radiation is removed. The optimal connection is achieved at a certain average position (Fig. 4(b)). Maximum laser efficiency achieved in regime of optimum feedback.

A change in feedback is required when the regime of laser work changes (for example, a change in the pump power or gain of the active substance). This can be done by moving the mirror 5 directly during laser operation. The system of conical mirrors 4 and 5 can be considered an output mirror with a variable transmission coefficient. The transmittance of such an output mirror is proportional to the ratio of the volumes occupied in the active substance by the generation zone 7 and the amplification zone 8. Approximately the transmittance of the output mirror K_{out} can be estimated as:

$$K_{out} = 100\% \, V_{gain} / V_{act},$$

where V_{act} is the total volume of active medium, V_{gain} is the volume of the "gain zone", i.e., part of the volume of the active substance from which radiation is directly removed from the resonator. However, this is an estimated formula, and it does not take into account the effect of the correction Δ on the taper of mirrors 2, 3, which can significantly change the feedback value.

Correction Δ to the taper of mirrors 2, 3 allows to expand the range of use of such a laser resonator scheme and adapt it to different conditions of use, various active substances and frequency ranges. The correction Δ is introduced with the sign "+" or "–" to the taper of mirrors 2, 3 during their manufacture, so that the angle between the reflecting surfaces of mirrors 2, 3 becomes equal to $90^\circ - 2\Delta$ or $90^\circ + 2\Delta$ (Fig. 5). This can either partially compensate for the diffraction divergence of radiation in the active medium or contribute to even greater divergence.

An angle of less than 90° between the reflecting surfaces of mirrors 2 and 3 is used when it is necessary to partially compensate for the diffraction divergence of radiation in the active substance. This may be necessary when a number of factors are combined, for example, when (for certain ratios between the wavelength of radiation and the width of the annular cross section of the active medium) the diffraction divergence of radiation in the resonator is high, and the gain in the active substance is not high enough. As a result, the optimum of feedback is either not achieved at all, or it is achieved when the movable output mirror is in a position close to the limit of the minimum radiation output (Fig. 4(a)). In this case, the output radiation beam will have a small diameter, which may not always be acceptable. In addition, this can lead to unacceptably high divergence of the laser beam at certain ratios with the wavelength. In such cases, the angle between mirrors 2 and 3 is less than 90° should be used to achieve optimum coupling or increase the diameter of the laser beam.

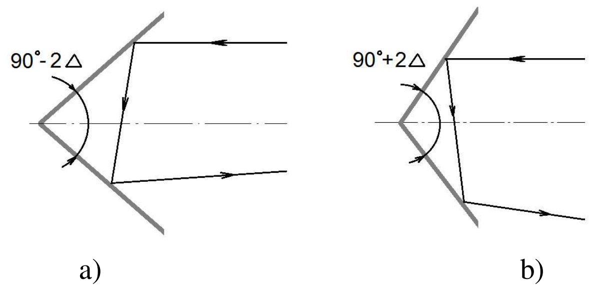

FIG. 5: Correction of the divergence of radiation in the active substance, a decrease in divergence (a) and an increase in divergence (b)

An angle greater than 90° between the reflecting surfaces of mirrors 2 and 3 is used in the case when it is necessary to increase the divergence of radiation in the active medium. This is required for a more intense output of radiation from generation zone 7 to amplification zone 8 (Fig. 3). For example, this may be required when using active media with high amplification factors and wide annular cross sections.

The specific value of the correction Δ to the angle between the ring mirrors is selected based on a number of factors − gain in the active substance, the radiation wavelength, the geometric dimensions of the resonator and the active element, the required cross section of the laser beam and the permissible divergence.

3. CONCLUSIONS

A new design of a laser cavity with smooth adjustment of the radiation output is considered in this work. It is possible to apply the proposed resonator scheme for lasers of any ranges. Such resonator uses only reflective optics, both to create feedback and to output radiation from the resonator. Therefore, metal mirrors can be used, which is especially important for high-power IR lasers. A wide adjustment limit allows to choose almost any feedback in the laser. The ability to change feedback during the operation of the laser is an essential advantage, especially in lasers with a variable gain of the active medium. Such a resonator is highly resistant to thermal and mechanical influences and it is easy to configure due to the use of conical 90° mirrors that do not require careful alignment.

An annular cross section of the active substance provides uniform pumping and intensive heat removal from the active substance. This improves the efficiency of laser generation and the stability of laser radiation. Radiation performs a complete round trip of the resonator in four different ways. As a result of this, the negative effect of possible heterogeneities of the active substance on the spatial-angular characteristics of the output laser beam is reduced.

The proposed new laser resonator scheme is subject to further investigation and modeling of the laser generation process. The promising use of such a resonator is indicated by the use in it of a number of physical and technical solutions that have been successfully tested previously.

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