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Application of conical 90-degree reflectors for solving the problem of mirror alignment in terahertz-range lasers

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***Abstract*. We report a study of the conical mirrors with an apex angle of 90° in the resonator of the gas-discharge HCN laser with the radiation wavelength of 337 μm (0.89 THz). Experimental results have shown that such mirrors do not require precise alignment. This makes it possible to improve the radiation stability, significantly simplify the construction of laser and reduce the complexity of its maintenance.**

Keywords: *terahertz-range laser, conical mirror, alignment of resonator mirrors.*

1. Introduction

The problem of alignment of the resonator mirrors is inherent in all lasers, but it is especially tangible for gas-discharge, submillimetre lasers that serve as the sources of radiation in the middle part of the terahertz frequency range (1 THz). In such lasers the mirror alignment should be conducted not only on the stage of assembling, but also periodically during the routine works on cleaning of the mirrors and discharge tube from the polymer coating. For long-term stability of radiation, it is necessary to ensure the stability of mirror alignment in the process of laser operation. This task is complicated by the fact that a large amount of heat is released in the gas discharge, which causes thermal expansion of the longitudinal rods forming a frame on which the mechanisms of mirror alignment are fasten (the length of rods usually exceeds 1 m). Equal elongation of rods can be compensated for by a mechanism of axial movement of the movable mirror. The terahertz-range laser resonators are usually equipped with such mechanisms because they need to be tuned to the resonance wavelength. However, with the appearance of differences in the lengths of the rods within a few tens of micrometres (due, for example, to uneven heating or a difference in the expansion coefficients of the rods) the alignment is violated and lasing power markedly decreases. To ensure the alignment stability, various system of thermostabilisation of fastening of the mirror elements are used, which considerably complicates and increases the cost of laser design. The development of the laser resonators with the mirrors that do not require precise alignment is an urgent problem, the solution of which would greatly facilitate the maintenance of a laser and would substantially simplify its entire design. The aim of this paper is to design a resonator for the terahertz-range laser, the radiation parameters of which are not sensitive to violation of the alignment of the mirrors.

2. Scenarios for solving the problem

As the resonator mirrors, triangular 90° corner reflectors can be used [1]. They do not virtually require alignment, but the problem with the output of radiation through the holes in such reflectors arises. Moreover, the corner reflectors are difficult in manufacturing and have elevated losses caused by three reflections from their facets. Of definite interest are the mirrors having a form of the inward-reflective, 90° conical surface [2]. These mirrors are relatively easy to manufacture, they introduce smaller losses into the resonator and possess the properties that allow them to be considered as an alternative to the corner reflectors. According to the laws of geometrical optics, the rays incident on such mirrors and lying in the planes containing the cone axis strictly return in the reverse direction after two reflections from the diametrically opposite generatrices, independently of the angle of inclination of the incident beam to the cone axis. The paths of the rays that do not lie in the axial plane are more complex, but the correction of the direction of the reflected beam towards the incident one is observed in this case as well. These studies have been conducted precisely to check the stability of energy characteristics of the terahertz-range lasers with respect to the misalignment of the conical 90-degree mirrors.

3. Experimental results

The experiments have been carried out using a gas-discharge HCN laser with a wavelength of 337 μm (0.89 THz). Such lasers are used for biomedical research [3]. First and foremost, the biomedical lasers should obey the requirements of reliability, long-term stability of the output power and ease of use. Therefore, the problem of mirror alignment and its stability is most urgent for these lasers. At the same time, these lasers are not subject to high demands concerning the power, polarisation and mode composition of radiation.

Two conical mirrors (Fig.1) were manufactured for the research. Both of them have an inward-reflective surface with the apex angle of 90°. The manufacture tolerances correspond to the downward angle to ensure that the mirror could compensate for the beam divergence. The output mirror (left in Fig.1) is made of aluminium alloy by turning. A circular opening located in the centre of the mirror serves for radiation outcoupling. The second mirror (right in Fig.1) is made

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Figure 1. Conical 90-degree mirrors.

of copper with the use of the building-up method on the conical model, which allowed one to obtain a high-quality vertex.

The output mirrors in the discharge terahertz-range lasers are most often subject to assembling followed by inevitable alignment. They have to be dismantled when cleaning the resonator, replaced when selecting an optimal feedback at the output in the case of changing the working substance and pump modes, as well as during transition to the lines of radiation with different gain. Consequently, the resonator having an output mirror that does not require precise alignment, in combination with a flat mirror, is of practical interest, and moreover, offers an opportunity to compare the influence of alignment violation for the flat and conical mirrors without their replacement. Therefore such a resonator was tested first (Fig. 2). It comprises the discharge tube (*1*) that serves as a waveguide, and the mirrors (*2*) and (*3*). The resonator length is 1500 mm; the discharge tube diameter is 50 mm. The output mirror (*3*) represents an inward-reflective lateral surface of the truncated right cone with an angle of 90° between the diametrically opposite generatrices (see photograph in Fig. 1, left). The flat metal mirror (*2*) has a device (*4*) to move along the cavity axis. It is used to tune the resonator to the resonance wavelength that represents an integer multiple of the half wavelengths of the radiation line of the active substance. The direction of radiation propagation in the resonator is shown by arrows. Under the pump action, an active substance is synthesised in the discharge tube (*1*), which leads to the generation and amplification of laser radiation as a consequence of its multiple reflections from the mirrors (*2*) and (*3*). Radiation that, due to diffraction, falls into the region of the central hole is coupled out of the resonator. The fact that the angle between the diametrically opposite generatrices of the conical mirror is somewhat smaller than 90° also contributes to the displacement of laser radiation to the cavity axis (the optimisation with respect to the angle was not performed).

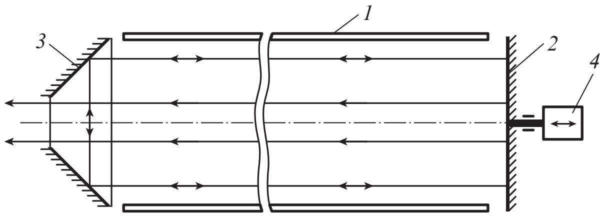

Figure 2. Scheme of the laser resonator with a flat highly reflecting and conical 90-degree output mirrors: (*1*) discharge tube; (*2*, *3*) mirrors; (*4*) device for moving the mirror (*2*).

Laser radiation at the wavelength of 337 μm with the output power of 3 mW was obtained in a gas-discharge HCN laser with the resonator under consideration. A comparison of the misalignment impact on the laser output power in the case of flat and conical mirrors was conducted. The corresponding dependences are presented in Fig. 3. Zero angle of inclination of the mirrors corresponds to perfect alignment, when the axes of the mirrors are parallel to the resonator axis. The inclination of each mirror was implemented alternately via a corresponding alignment mechanism, with consequent return to its original position. Each time when the angle of inclination was changed using the mirror displacement mechanism, the resonator length was corrected to be tuned to the maximal power. Figure 3 shows that the misalignment of the 90-degree conical mirror has a much less negative impact on the lasing power than the misalignment of the flat mirror.

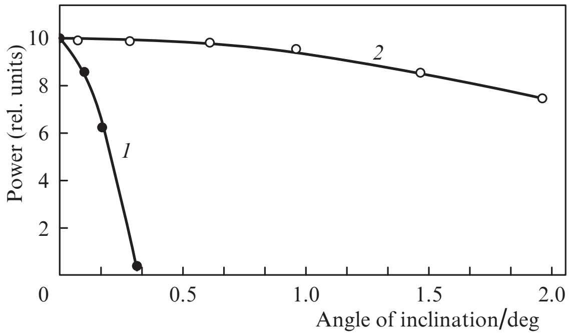

Figure 3. Experimental dependences of the output power of the HCN laser on the angles of inclination of the flat (*1*) and conical (*2*) resonator mirrors to its axis.

Then the second, 90-degree conical mirror, the photograph of which is shown in Fig. 1 (right), was installed into the resonator instead of the flat mirror. In this resonator (Fig. 4), radiation at the wavelength of 337 μm with the output power of 2 mW was generated. The laser operated without a thermostabilisation system. The misalignment of both conical 90-degree mirrors caused a rather weak negative impact on the radiation power – by about one to two orders smaller than the misalignment of the flat mirrors in similar resonators.

At this stage, we did not attempt to optimise the conical mirrors and gain the maximum power. The primarily task was to obtain lasing. In this connection, the resonator feedback was chosen deliberately weaker compared to the presumed optimal feedback. Diameter of the holes in the output

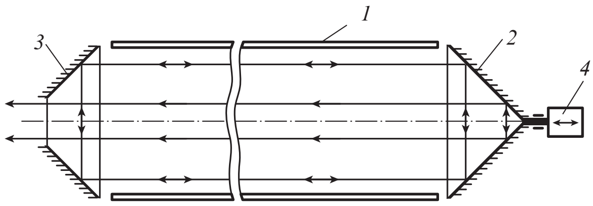

Figure 4. Scheme of the laser resonator with two conical 90-degree mirrors. The notations are the same as in Fig. 2.

mirror was 4 mm, though the optimal diameter of the hole in a plane mirror for this laser amounts to 13 mm. Therefore, the resulting radiation power was relatively low – several times less than in a similar laser with optimised flat mirrors. It should also be taken into account that the conical 90-degree mirrors, due to double reflection, introduce somewhat larger losses into the resonator than the flat mirrors. However, the reflection losses they have are still less than those of the 90-degree corner reflectors, where radiation undergoes three reflections. It should be noted that the resulting output power is more than sufficient for a variety of important biomedical research [3], which primarily require the reliability and stability of the laser, as well as the ease of its maintenance. In the future we plan to optimise the transmission coefficient of the output conical mirror, to study the impact of small deviations of the cone angle from 90° on the lasing power and also to investigate the polarisation and mode composition of laser radiation.

4. Conclusions

The experiments have shown that the conical 90-degree mirrors do not require precise alignment; therefore, the influence of thermal and mechanical impacts on the resonator alignment with such mirrors is small. This allows one to abandon the thermal stabilisation system of the resonator and eliminate from the construction of laser the complex mechanisms of the mirror alignment, together with a bulky frame of the longitudinal rods and transverse bulkheads, on which the mirrors are installed. Herewith, the mirrors can be mounted directly on the resonator waveguide. Thermal variation of the resonator length allows compensation for the displacement mechanism of the movable mirror.

The use of the conical 90-degree mirrors can significantly simplify the design of the terahertz-range lasers and facilitate their maintenance.

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