SPATIAL STRUCTURE OF THE RADIATION OF A “TRAVELING-MEDIUM” LASER

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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

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PHYSICS

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SPATIAL STRUCTURE OF THE RADIATION OF A "TRAVELING-MEDIUM" LASER

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In the present work, the spatial distribution of the intensity of the electromagnetic field of the stimulated radiation of a ruby "traveling-medium" laser with a small circular diaphragm inside a plane-parallel resonator was studied experimentally.

In the case of an ideally homogeneous laser, the spatial structure of the radiation field on the resonator mirrors is determined by the transverse structure of the mode, or group of modes, participating in oscillation. Such field distributions, characteristic of particular transverse modes, are readily observed in gas lasers (1-3). The transverse modal structure of solid-state lasers can be observed only in rare cases (4–6).

The spatial structure and the number of modes present in oscillation determine the divergence of the radiation. In real solid-state lasers the divergence of the radiation exceeds by several times the limiting value given by the theory of a homogeneous laser (7).

This indicates the presence of substantial inhomogeneities in solid-state lasers. In works (8, 9), on the basis of an analysis of the spatial structure of the radiation, these inhomogeneities were investigated. The result of these works was the assertion of a "stepwise" character of the inhomogeneities occurring in solid-state active media.

In works of our laboratory (10–13) it was shown that if a sufficiently small diaphragm is introduced inside the plane-parallel resonator of a "traveling-medium" laser, this leads to nonspiking radiation.

Fig. 1

Figure 2

Figure 2: Figure 2

Figure 3

Figure 3: Figure 3

In the present work, the field distributions of the radiation of a ruby "traveling-medium" laser were investigated in detail: 1) in the plane of the resonator mirror (near zone) and 2) in the principal focal plane of an objective placed behind the resonator (far zone). The diameter of the diaphragm inside the plane-parallel resonator was varied from 0.2 to 1 mm.

There are two papers in the literature ([14], [15]) in which the spatial structure of the field was studied in the presence of a diaphragm in the form of a slit inside the resonator. These works were carried out on a stationary laser.

The scheme of our setup is shown in Fig. 1. Z_1 and Z_2 are the resonator mirrors with reflection coefficients of 99.5 and 84%, respectively. The length of the crystal became 7.5 cm, with a diameter of 8 mm, for a resonator length $L = 60$ cm. The diaphragm D was located near the output mirror Z_2. The velocity of motion of the active medium was $v \sim 80$ cm/sec.

Fig. 2

Fig. 3

Figure 2a shows one of the photographs depicting the distribution of the radiation on the resonator mirror at one instant of time. The sweep was performed with an SFR-2M in the time-magnifier mode with a frame exposure of $\tau = 1.6$ μsec. Figure 2a corresponds to motion at a velocity $v \sim 80$ cm/sec; the diaphragm had a diameter of 1 mm and was located at a distance of 2 cm from the output mirror Z_2. A diaphragm of 1 mm diameter in the resonator does not increase the generation threshold in comparison with the threshold without a diaphragm. It is not difficult to see that the radiation field on the external mirror consists of rings reminiscent of Fresnel diffraction. In addition, there are bands, marked by arrows, crossing the diffraction rings. The appearance of these bands was at first unclear. Investigation showed that the position of the indicated bands does not change when the active rod is rotated about the resonator axis. However, after rotation of mirror Z_2 about the resonator axis by an angle of 90°, these bands also rotated by the same amount. Thus it became clear that the bands crossing the diffraction pattern are produced by the mirrors. Indeed, the substrate of mirror Z_2 had a wedge $\sim 3'$. Calculation shows that such a wedge-shaped plate should produce equal-thickness interference fringes with a period $\Delta l = 0.26$ mm, which is indeed observed experimentally.

The experiment was repeated for a laser with a diaphragm diameter of 0.7 mm.

The result was the same. But in the case of a stationary active medium the bands marked by arrows in Fig. 2a change their position chaotically from frame to frame. As is known, in a stationary active medium (in an ordinary laser) the generation frequency jumps chaotically from spike to spike, which leads to jumps of the interference fringes. In the case of a "traveling medium," however, the pattern obtained is the same as in Fig. 2a.

It should be noted that the pattern of the field distribution in the transverse section of the radiation beam, when there is a diaphragm D inside the resonator, depends on the distance of the plane of this section from mirror Z_2.

The distribution of the electromagnetic field by directions is shown in Fig. 2b. The appearance of the pattern resembles Fraunhofer diffraction. It is not difficult to see that the ideal Fraunhofer pattern is disturbed by an additional spur (indicated by an arrow). Its origin is associated with the wedge shape of the substrate of mirror Z_2. The result of microphotometry of this pattern is given in Fig. 2c.

The divergence of the radiation of the "traveling-medium"laser is almost equal to the diffraction divergence, i.e. $\theta \sim 1.2\lambda/D$, where D is the diaphragm diameter.

If the field distribution is photographed in the plane of the diaphragm, then the pattern has the form shown in Fig. 2e (diaphragm diameter 1 mm). In this case, as is known, the spike regime is still observed. The individual systems of concentric circles visible in this figure are evidently associated with the presence of generation channels (16). Such patterns are not observed with a diaphragm of diameter 0.7 mm, when the generation intensity has a non-spiking character.

It is interesting to note the fact of the spontaneous formation of generation channels, which is observed in the active medium $CaWO_4 : Nd^{3+}$. Experimentally, multichannel generation of a laser on $CaWO_4 : Nd^{3+}$ was found (see Fig. 3a, b). The dimensions of these channels are $\sim$ 1-1.5 mm. When the $CaWO_4 : Nd^{3+}$ rod moves, one channel gives spike generation, and another non-spiking generation (Fig. 3b).

Careful examination of the near zone shows that the channel with spike generation has a complex structure that changes with time. In this case the generation region has a greater spatial extent than in the channel of non-spiking generation. Introducing a diaphragm of diameter 1 mm into the resonator in the path of the channel with spike genera-

leads to the disappearance of the spikes and the generation becomes spikeless, while the near zone retains its form in time (see Fig. 3e).

Thus, this is a direct observation of how inhomogeneity of the active medium in the transverse direction affects the temporal regime of generation.

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Note: Figure translations are in progress. See original paper for figures.