# *STIMULATED EMISSION IN COMPLEX MODES*

M. P. VANYUKOV, V. I. ISAENKO, and V. A. SEREBRYAKOV

S. I. Vavilov Optical Institute

Submitted to JETP editor January 16, 1964

J. Exptl. Theoret. Phys. (U.S.S.R.) **47**, 2019-2021 (December, 1964)

It is demonstrated experimentally that stimulated emission occurs in complex modes in lasers with plane polished walls. These modes can be explained by the presence within the sample of closed ray paths caused by multiple reflections from the side and end walls.

## INTRODUCTION

It was shown earlier [1-4] that polished side walls of lasers are responsible for the occurrence of off-axis modes giving emission at discrete angles to the sample axis. The case where the off-axis modes arise because of closed ray paths in the sample formed by multiple specular reflections from a single pair of parallel side walls has been closely studied [1,4].

In the present paper we consider the formation of more complex modes whose angular distribution of radiation is considerably different from the angular distribution of emission in the cases previously studied.

## EXPERIMENTAL RESULTS

The experiments were carried out with apparatus described earlier [1]. The output of a neodymium glass laser was photographed with an image converter in both the near and far fields.

In Figs. 1 and 2 we show photographs of the radiation distribution in the far and near fields of glass lasers of square and rectangular cross-sections whose end walls had dielectric coatings. The system of points in Figs. 1a, c, and e and Fig. 2a reflects a discrete angular distribution of radiation (far field pattern); the remaining photographs show the distribution of radiation over the end face (near field).

Figures 1a and b, which pertain to the laser with the square crosssection, indicate that, in addition to the simplest off-axis modes characterized by sets of points arranged along two mutually perpendicular directions, there is additional radiation which appears in the photograph as sets of point pairs lying to one side of the primary directions. These points are arranged symmetrically with respect to the on-axis direction, in which in the present case there is no emission.

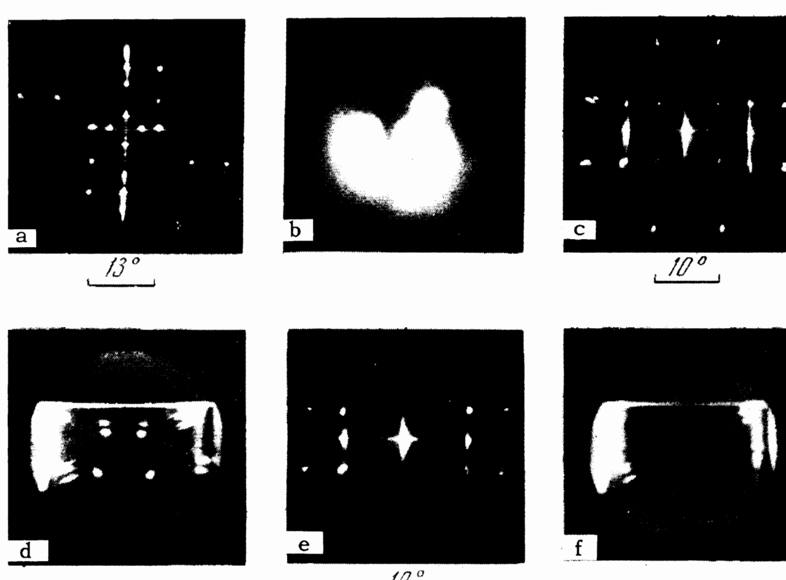


FIG. 1. The angular distribution of emission (a, c, d) and the corresponding end wall emission (b, d, f) for a neodymium glass laser with a square cross section (a, b) and rectangular cross section (c, d, e, f).

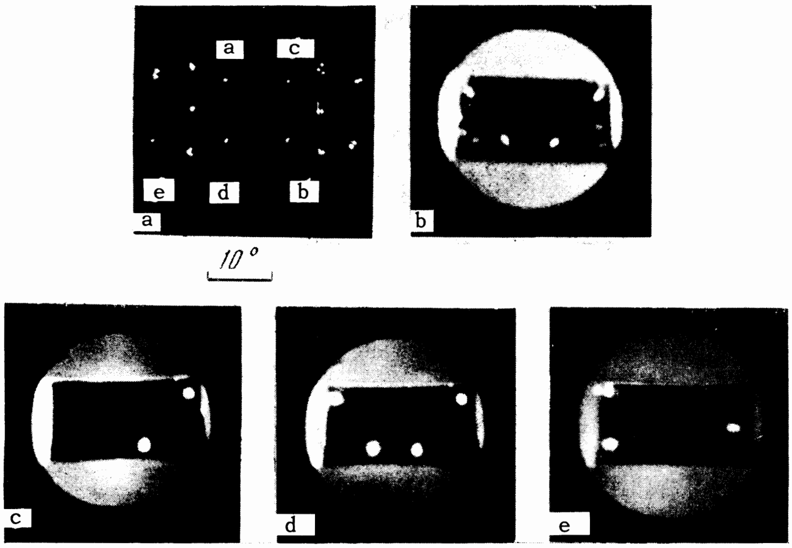


FIG. 2. The far field pattern (a) and the corresponding near field pattern (b) for a sample of rectangular cross section. The near field pattern was photographed in the emission from particular modes: c – for the rays corresponding to the points a and b in Fig. 2a; d – for the rays a-d in Fig. 2a; e – for the remaining rays.

Figures 1c and d illustrate another case of laser action in complex off-axis modes. The emission occurs partially in the axial direction but also in eighteen other isolated directions which exhibit symmetry about the axial direction. It should be pointed out that in the present case the fraction of the emission going into the simple off-axis modes is small in comparison to the fraction going into the complex modes.

Comparison of Figs. 1c and d and Figs. 1e and f, which show emission from the same sample under several different excitations, shows that emission from six localized regions (Fig. 1d) must be responsible for the eight discrete directions which disappear as one changes from the lasing behavior characterized by Fig. 1c to that characterized by Fig. 1e.

Close comparison of the near and far field emission patterns was carried out for the laser that showed a readily reproducible lasing pattern (Figs. 2a and b). Figure 2c is a photograph of the end face of the laser taken in radiation corresponding to the direction labeled by point a (cf. Fig. 2a). The radiation in direction b (Fig. 2a), which was symmetric with respect to a, has the same near field pattern as the radiation in direction a. If we photograph the end of the laser in the light of rays a, b, c, and d, we obtain the pattern shown in Fig. 2d, whereas if we use the light in direction e we get the pattern shown in Fig. 2e.

## DISCUSSION OF RESULTS

The complicated modes which we have observed must be ascribed to rays within the laser having closed paths due to multiple reflections not only from a single pair of parallel surfaces but from several pairs which make angles with respect to one another. Figure 3 shows the construction of a ray path corresponding to emission of radiation from four points on the end face of the laser (cf. Fig. 2d). Radiation should be emitted in two directions from each of the spots on the end face. The directions of these beams lie in a single plane which is perpendicular to the end face of the sample. The emission of two rays from a single point

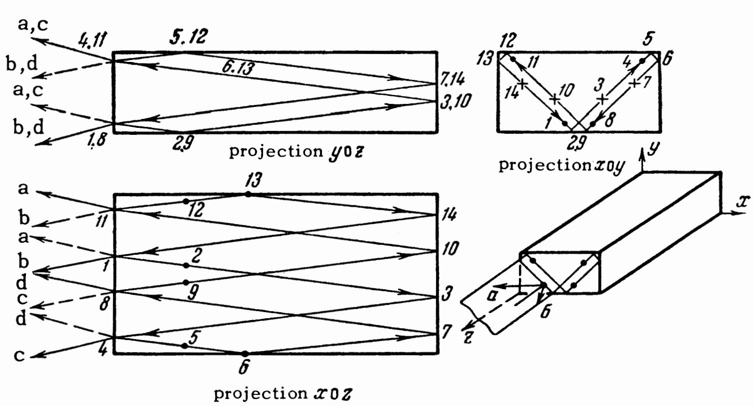


FIG. 3. Construction of the ray paths for the laser action shown in Fig. 2d. A given number always represents the same exit point of a ray from the surface of the sample.

on the end face corresponds to rays inside the sample travelling in opposite directions; this is analogous in the theory of resonators to the existence of not less than two directions for each mode. As may be seen in Fig. 3 the emissions from regions 4, 8, 11, and 1 coincide in direction.

The question arises why only a relatively small number of paths within the sample occur, rather than the infinitely large number which might be expected. Evidently this is connected with the imperfections of the resonator. Actually, only the end walls of the samples were finished with interferometric accuracy. The side surfaces are parallel only within 1—3′. Because of this the conditions for closed paths are fulfilled only for certain contours and hence laser action occurs in only a fraction of the volume of the sample in the form of separate light pipes whose axes correspond with the directions of the light rays. These pipes form distinct "simple" interferometers which give rise to the observed laser action.

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Translated by J. Armstrong
293