SPATIAL DISTRIBUTION OF THE ELECTRIC FIELD PRODUCED BY FOCUSING THE OUTPUT OF A RUBY LASER

T. M. BARKHUDAROVA, G. S. VORONOV, V. M. GORBUNKOV, and N. B. DELONE

P. N. Lebedev Physics, Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor February 24, 1965

J. Exptl. Theoret. Phys. (U.S.S.R.) 49, 386-388 (September, 1965)

The spatial distribution of the focused radiation from a ruby laser is investigated experimentally. It is shown that the minimum spot size of the focused radiation corresponds to the size of the diffraction distribution of the light from the spots in the non-focused beam entering the objective. As a result of interference caused by superposition of the various diffraction distributions, a fine structure is produced in the distribution of the focused radiation. Various possibilities for improving the focusing and obtaining high electric field strengths are considered.

THE spatial distribution of the electric field created by focusing the output of a ruby laser is of interest in many experiments in physics [1]. In the present work we describe an investigation of the field created by a Q-switched ruby laser. The laser consisted of a standard crystal 120 mm long and 10 mm in diameter, a spiral flash lamp IFK-15000 and a Kerr cell for switching the cavity Q. Investigations were carried out using laser output powers of from several megawatts per pulse to several tens of megawatts per pulse.

Lenses of 45 and 120 mm focal length, corrected for spherical aberration at 6943 Å, were used for focussing the output. The spatial distribution of the electric field was studied by means of photographic brightness measurements. A microscope objective formed a magnified image on film of the minimum cross-section of the focused radiation. The angular aperture of the microscope objective was greater than the aperture of the focused beam. Neutral density attenuators were used for the photometric measurements.

A typical photograph of the laser radiation distribution just before the focusing lens is shown in Fig. 1. The local non-uniformities in brightness are several hundred microns in size. The overall nature of the distribution is determined by the particular ruby crystal used and the orientation of its optic axis. The operating conditions of the laser (tuning of the cavity, pumping level, crystal temperature, instant of Q-switching) effect only the distribution and brightness of the local non-uniformities. This type of spatial distribution of the emission is typical for a laser operating with standard crystals [2]. The non-uniform brightness is due to the superposition of a number of high order modes [2,3]. The angular divergence of the various high order modes is essentially the same [2] and is of the same order of magnitude as the total divergence of the laser output.

The diameter of the output beam for a single mode is $D_m = D_m^0 + \alpha_m L$ where D_m^0 is the diameter of the lasing region on the end face of the crystal, α_m is the angular divergence of the mode, L is the distance between the end of the crystal to the beam cross-section in question, and m is the angular index of the mode (the number of zeroes in the intensity distribution in a given direction). The field configuration of an individual mode is determined by the resonant properties of the cavity, consisting of external mirrors with a non-uniform crystal between them. The dimensions of the individual emitting regions (filaments) are of the order $d_m \approx D_m/m$.

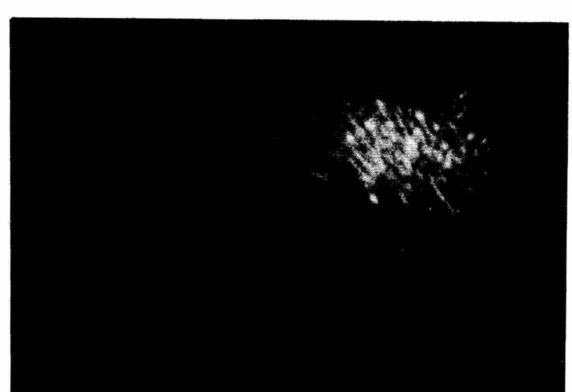

FIG. 1. A photograph of the laser emission distribution at the input of the focusing lens.

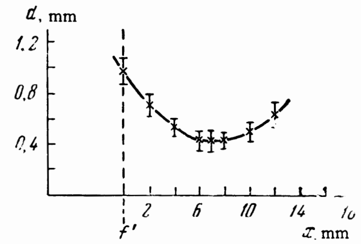

FIG. 2. Dependence of the average spot size (square root of the area) of the focused laser emission on the separation between the focal plane of the lens (located at the left) and the given cross-section. The lens, of f′ = 120 mm, was placed 1 m from the laser.

The average spot size of the focused radiation as a function of separation from the focal plane of the lens is given in Fig. 2. The minimum spot size does not occur in the focal plane but somewhat beyond. This means that the wave front of the radiation incident on the lens has a finite radius of curvature R. The experimental results correspond to an R of the order of 2 meters. This is in agreement with data obtained in [2].

The minimum spot size is of the order of several hundred microns. Typical photographs of the radiation distribution in the minimum-diameter spot are shown in Fig. 2. The local brightness nonuniformities have dimensions of the order of several microns.

The observed spatial distribution of the focused radiation may be explained as follows. In focusing a single mode (which gives rise to a spot with a diameter $d_m \sim D_m/m$ at the input to the lens) each filament will form a diffraction distribution whose radius (Airy radius) in the focal plane is

$$r \sim \lambda f' / d_m.$$

Since the wavefronts of the individual modes at the output of the lens are nearly spherical, the diffraction distributions for the various spots superpose. The resulting interference gives rise to the fine structure of characteristic size $\sim \lambda f'/D_m$. The diffraction depth of focus is

$$\Delta \approx 8\lambda (f' / D_m)^2$$

and is determined by the path difference of the axial and peripheral rays.

Since the laser output consists of many modes, the distribution of the focussed radiation is the result of the superposition of the distributions of the various modes. The experimentally observed minimum spot size (Fig. 2) and the size of the local non-uniformities (Fig. 3a) correspond to the values $d_m \approx 0.25$ mm and $D_m \approx 6$ mm, which are in agreement with the appearance (Fig. 1) of the radiation distribution at the input to the lens.

Decreasing the focal length of the lens used caused a linear decrease in the minimum spot diameter. When the lens was moved farther away from the laser the minimum spot size decreased, as did the diameter of the local non-uniformities; these changes are due to the increases in d_m and D_m caused by the divergence of the laser beam.

The extent of the brightness non-uniformity in the minimum diameter spot was investigated. For typical laser operating conditions, the brightness in isolated local non-uniformities was 30-50 times larger than the average brightness. Correspondingly the average electric field strength was 2×10^6 V/cm and the local field in the bright regions was of the order of 10^7 V/cm.

It should be noted that both of the possibilities for increasing the electric field strength in the focal spot of a laser which is operating under fixed conditions—viz., a) decreasing the focal length of the lens used, and b) moving the lens

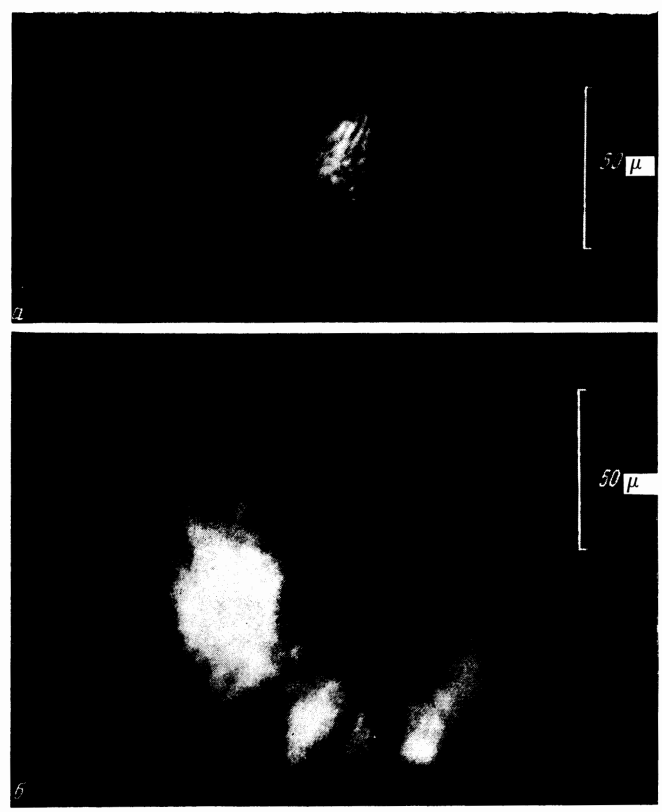

FIG. 3. Photograph of the cross-section of the focused radiation: a — in the plane of the minimum spot size, b — in a defocused plane displaced relative to the plane of minimum spot size by 300μ. This displacement corresponds to the position of the first minimum in the diffraction intensity along the axis of a beam of diameter d = 6 mm. The radiation was focused with a lens having f′ = 45 mm placed 4 m from the laser.

further from the laser—are limited by the relative aperture of the lens. A sizable increase in the electric field strength can be obtained only by exciting lower order modes.

The authors are grateful to V. S. Zuev, V. K. Korobkin and A. M. Leontovich for valuable discussions.

[1] L. V. Keldysh, JETP 47, 1945 (1964) Soviet Phys. JETP 20, 1307 (1965); Bunkin, Karapetyan, and Prokhorov, ibid. p. 216, transl. p. 145; Askaryan, Delone, and Rabinovich, ibid. 46, 814 (1964) transl. 19, 555 (1964); R. Meyerand and A. Haught, Phys. Rev. Lett. 11, 401 (1964); Ya. B. Zel'dovich and Yu. P. Raĭzer, JETP 47, 1150 (1964), Soviet Phys. JETP 20, 772 (1965); Mandel'shtam, Pashinin, Prokhindeev, Prokhorov, and Sukhordev, ibid. p. 2003, transl. p. 1344; Ya. B. Faĭnberg Sb. Fizika Plazmy i problemy termoyadernogo sinteza (Coll., Plasma Physics and Problems in Thermonuclear Fusion), 3, 300 (1963).

[2] A. M. Leontovich and A. P. Veduta, JETP 46, 71 (1964), Soviet Phys. JETP 19, 51 (1965).

[3] D. Bradley, Nature 199, 1281 (1963).

Translated by J. A. Armstrong
50