Letters to the Editor

THE PHASE STRUCTURE OF THE OUTPUT BEAM OF A RUBY LASER

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EXPERIMENTS on the interference of waves from separate sections from a ruby laser beam [1] indicate a high degree of spatial coherence between these waves but do not give information about the structure of the phase front of the beam as a whole. This paper describes an experimental method for obtaining a lucid representation of the phase structure of the beam of any optical maser source of coherent radiation; we also present some preliminary results of an investigation of the phase front of a ruby laser having a large separation between its external mirrors (269 cm).

It is well known that the phase diagrams of radiant sources are determined by comparing the phases of the signal and reference beams. In optics a reference signal is most easily obtained by partial scattering of laser light by transparent, dielectric nonuniformities whose dimensions are small compared to the width of the light beam but large compared to a wavelength λ. The latter condition is necessary in order to obtain a sharp scattering indicatrix with its maximum in the primary beam direction. At distances $d \gg a^2/\lambda$ from the nonuniformity (of size a) the scattered radiation has the form of a spherical wave with a phase center approximately at the position of the nonuniformity. Superposition of the scattered and primary radiation forms an interference pattern whose character allows one to establish a structure of the phase front of the primary beam.

In Fig. 1 we show examples of the interference patterns observed at various separations d from one of the external mirrors of the ruby laser ($\lambda = 0.694\,\mu$). The dimensions of the laser were as follows; the separation between mirrors was 269 cm, the length of the ruby crystal was 7.2 cm, its diameter was 0.6 cm, and it was placed at a distance $l = 245$ cm from the external mirror beyond which the beam was photographed. The scatterer was a nonuniformity on the multi-layer dielectric coating on the reflector.

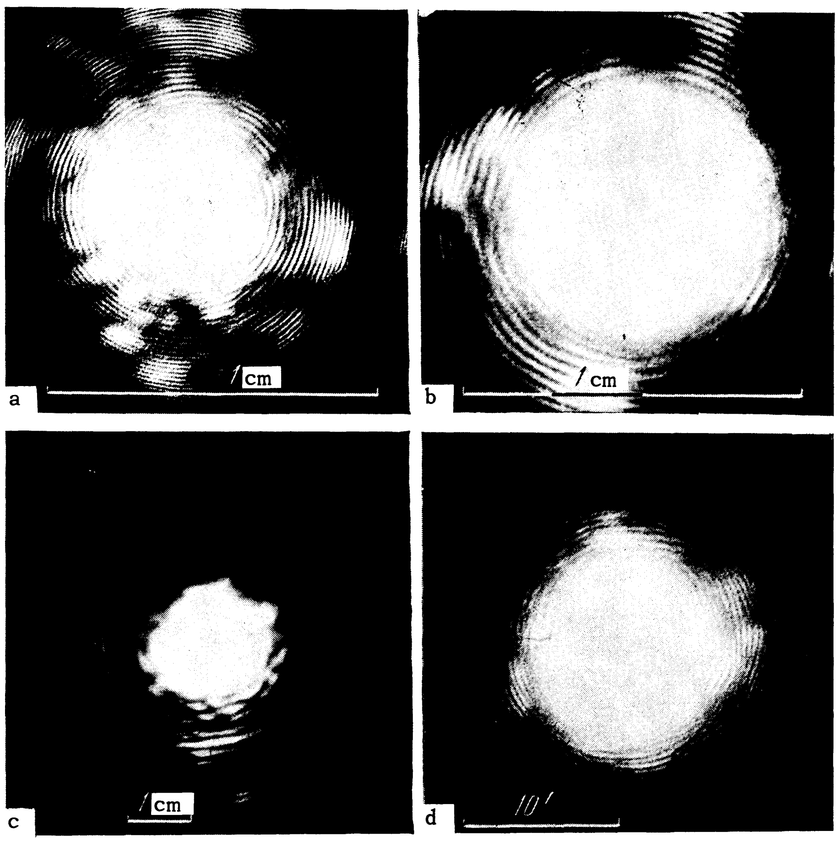

FIG. 1. Interference pictures observed at various separations d from the laser: a—75 cm, b—155 cm, c—900 cm, d—∞ (far field pattern).

The circular nature of the interference patterns (Fig. 1) indicates that the wave front of the laser beam is spherical. The position of the phase center of this front may be determined easily by treating the resulting field as a superposition of the radiation fields of two sources located at the phase centers of the primary beam and the scatterer, with the phase of the second source, the scatterer, being determined by the field of the primary source and equal to kD ($k = 2\pi/\lambda$, and D is the separation between the phase centers of the primary beam and the scattering nonuniformity). This assumption leads to the following expression for the radii of the interference maxima:

$$r_m^2 = (2m\lambda/D)\, d(d + D), \qquad (1)$$

where m is the order of interference. According to (1) the interference rings lying close to the axis of the system are first order maxima (m = 0, 1, 2, ...), which explains both the weak dependence of the radii on the frequency and also the experimentally observed high contrast of the interference pictures for large separations D between the phase centers.[1)]

For experimental determination of the parameter D it is more convenient to rewrite (1) in the form

$$p \equiv \bar{r}_m \Delta r_m/\lambda d = 1 + d/D;$$

$$\bar{r}_m = (r_m + r_{m+1})/2, \qquad \Delta r_m = r_{m+1} - r_m. \qquad (2)$$

Figure 2 gives the dependence of the parameter p on d for the laser described above. Within the limits of experimental accuracy, the experimental points lie on the straight line (2), corresponding to a value D = 288 cm, in agreement with the value D = 279 cm determined from the interference pattern at infinity. The position of the phase center of the radiation at infinity was also measured for several values of the separation l between the ruby crystal and the external mirror having the scattering nonuniformity; the values of l used were 65, 132, and 245 cm. The corresponding values of D obtained were 76, 140, 279 cm, and indicate a connection between the position of the ruby in the cavity and the position of the phase center of the output light beam.

These experimental results do not follow from the well known conception of the modes of an open Fabry-Perot resonator, and illustrate the fruitfulness of applying the present method of phase measurement in obtaining a more detailed understanding of the operating properties of lasers.

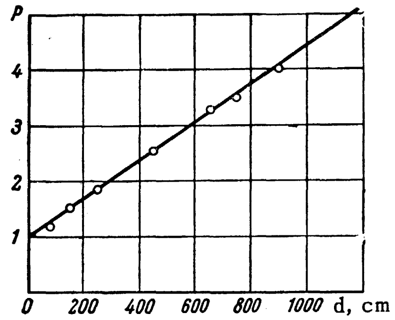

FIG. 2

In conclusion we note that the pattern of interference rings sometimes observed in the near field of ruby[2-3] or gas lasers arises from the interference of the primary beam with radiation scattered by randomly distributed nonuniformities on the reflecting surface of the external mirrors.[2)] In view of the present work the above explanation seems to be more probable and convincing than the explanation proposed by Stoicheff and Szabo[2] who assumed the laser cavity behaves as a Fabry-Perot interferometer.

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1)This is the principal difference between these patterns and Fabry-Perot interference pattern, although in both cases the dependence of the radii of the rings on their number is the same: $r_m \sim \sqrt{m}$.

2)Pictures such as these, photographed in the beam of a helium-neon laser at 1.153μ, were first demonstrated to one of the authors of the present paper by A. I. Mash. They are easily observed visually by placing a semi-transparent mirror with nonuniformities in the beam of a gas laser at 0.6326μ; this may be used both to study the laser itself and as a preliminary source of scattering centers for the investigation of the beams of pulsed lasers.

[1] V. V. Korobkin and A. M. Leontovich, JETP **44**, 1847 (1963), Soviet Phys. JETP **17**, 1242 (1963).

[2] B. P. Stoicheff and A. Szabo, Appl. Optics 2, 811 (1963).

[3] I. D. Abella and C. H. Townes, Nature **192**, 957 (1961).

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