The difference between the experimentally obtained width (13.5 cm^{-1}) and the theoretical one is determined principally by the inhomogeneity along the crystal at our disposal. The presence in the crystal of several regions with different values of the refractive index was verified by the generation in it of the second harmonic of 1.15-μ He-Ne laser radiation [7].

Thus, when a $LiNbO_3$ crystal of good quality is used it is realistic at present to expect a resolution of $\sim$0.1 cm^{-1} in the near infrared.

In addition, the discussed method makes it possible to register photographically individual sections of the IR spectrum. This may be of interest if it is necessary to register the IR spectra of pulsed processes, when scanning is impossible.

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HOLOGRAPHIC METHOD OF AMPLITUDE-PHASE CORRECTION OF LASER BEAMS

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One of the main problems of quantum electronics is to obtain a maximal axial brightness of stimulated emission, for which purpose it is necessary to use a nearly-plane wave front and homogeneous amplitude distribution over the cross section of the beam. As is well-known, this requirement is approximately satisfied only by the lowest transverse mode TEM_{00}, but it occupies the minimum volume in the active medium. Modes with higher transverse indices have a much larger volume and make it possible to obtain a higher radiation power. The amplitude structure (mode spots) and the phase structure (jumps of the phase π between neighboring spots) of the beams become, however, more complicated. As a result, the axial brightness of the radiation even decreases compared with the TEM_{00} mode.

It is enticing and of unusually great practical importance to develop a method of converting radiation modes with arbitrary transverse indices (in the general case - beams with a complex irregular front) with minimum loss into a flat Gaussian beam[1]. This makes it possible to increase greatly the axial brightness of the radiation of real lasers, especially those operating with imperfect media.

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[1] Within the framework of ordinary optics it is possible in fact only to compensate for the spherical component of the phase front and to separate the corresponding regular part of the beam, a process that entails considerable losses.

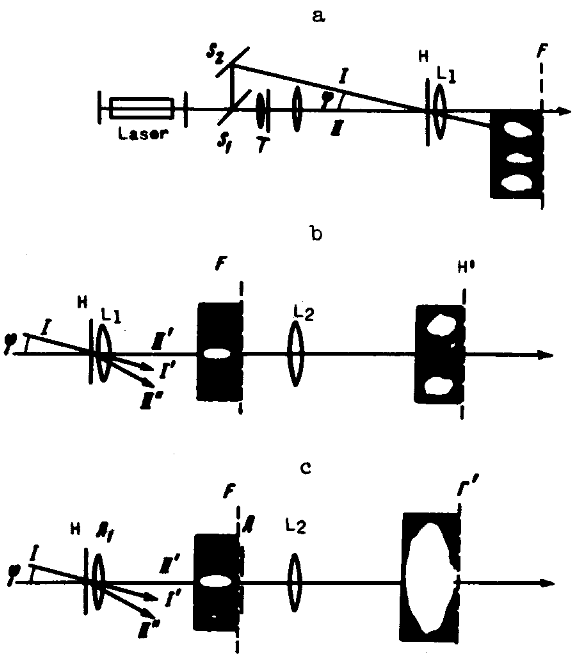

Fig. 1. Schematic optical diagrams of the recording (a), the phase correction (b), and the amplitude-phase correction (c) of laser beams: M_1 - semitransparent mirror, M_2 - mirror with $R \simeq 1$. The picture of the far zone is observed in the focal plane F of lens L_1, and that of the near zone in the plane H' which is made conjugate with the plane of the hologram by lenses L_1 and L_2. An example of the conversion of radiation of the TEM_{02} mode is shown.

The principal solution of the problem in question can be obtained with the aid of the holographic principles, which make it possible to realize amplitude-phase conversions with coherent beams of arbitrary complexity. By recording on the hologram the result of the interference of the laser radiation beam with a plane wave coherent with it, and using the initial beam for the illumination of the hologram during the reconstruction stage, we obtain in one of the diffraction orders a wave with a plane front [1]. In the present paper we propose a method of complete amplitude-phase conversion of laser beams into beams with plane fronts and with a Gaussian distribution of the amplitude. With the He-Ne laser as an example, such a correction has been realized with high efficiency and it is shown that it leads to an appreciable increase of the axial brightness of the radiation.

The optical schematic diagram of the method is shown in Fig. 1. The interference of the laser beam I with the distribution in the plane of the hologram $u_1(x) = A_1(x) \exp[i\theta(x)]$ and of beam II with plane wave front and homogeneous amplitude $u'_2(x) = A_2(x) \exp[ikx \sin \phi]$, formed of part of the laser radiation with the aid of telescope T with a diaphragm in the focal plane, is recorded on the photographic plate H (Fig. 1a) (for simplicity, the one-dimensional case is considered). During the reconstruction, the processed hologram is placed in the previous position, the splitting device is removed, and the entire radiation of the laser is directed on the hologram (Fig. 1b).

The amplitude-phase distribution in the principal diffraction beams II' and II" directly behind the hologram are respectively of the form

$$u_2'(x) = \alpha A_1^2(x) A_2(x) \exp[ikx \sin\phi], \tag{1}$$

$$u_2''(x) = \beta A_1^2(x) A_2(x) \exp[i(2\theta - kx \sin\phi)].$$

The coefficients α and β are determined by the properties of the recording medium, by the irradiation conditions, and by the subsequent treatment.

It follows from (1) that the beam II', which coincides in direction with the beam II, has a plane front, and all the phase inhomogeneities are doubled in the beam II", which makes an angle φ with the beam I'. The latter means that all the mode jumps of the phases become multiples of 2π, i.e., they vanish.

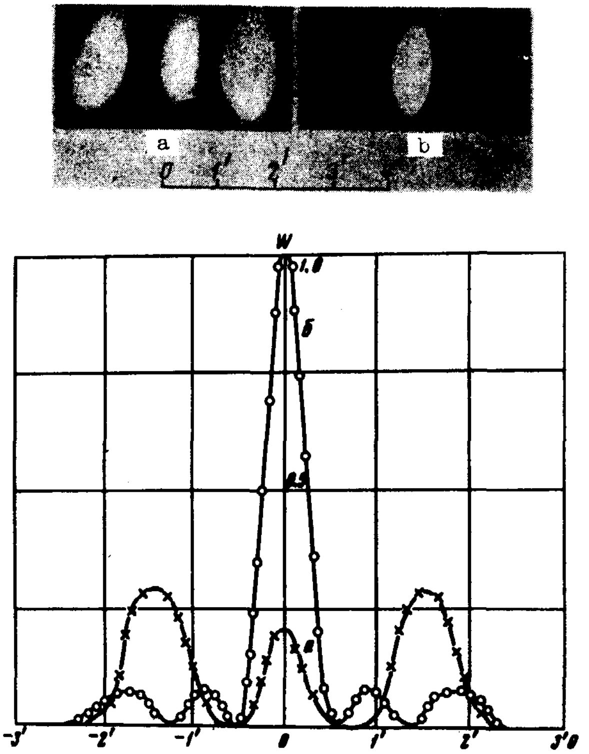

Fig. 2. Far zone of the TEM_{02} mode (a - prior to phase correction, b - after the correction) and the corresponding photometric curves normalized to equal energy.

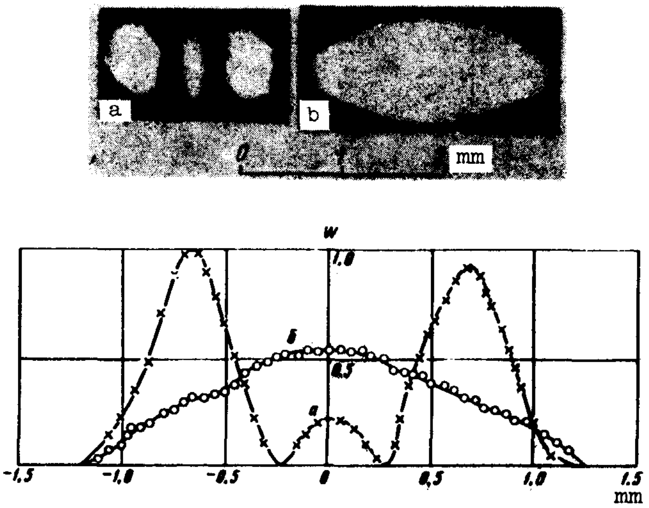

Fig. 3. Near zone of the TEM_{02} mode (a - prior to amplitude-phase correction, b - after the correction) and the corresponding photometric curves with allowance for the fact that the area under curve b amounts to ∿75% of the area under curve a.

All that remains is the total curvature of the wave front, which also is doubled. Eliminating it with the aid of a correcting lens, we obtain a flat wave front also in the case of beam II (obviously, the foregoing pertains also to all other odd orders).

According to (1), correction in accordance with the scheme of Fig. 1b is incomplete, since the amplitude structure of the reconstructed beams remains complicated. As is well-known, the far zone of such beams, together with the principal correlation peak corresponding to the Gaussian beam with the plane front, contains additional peaks of smaller brightness. The elimination of the latter with the aid, for example, of an optical system with a diaphragm D in the focal plane (Fig. 1c) corresponds to complete amplitude-phase conversion of the laser beam[2]).

The experimental realization of the correction was in accordance with the scheme of Fig. 1, which was assembled on the optical bench OSK-3. The radiation source was the LG-75 He-Ne laser. Stable generation on isolated transverse modes was attained with the aid of small misalignments of the resonator. The interference angle was $\phi = 2 - 5°$, making it possible to use the photographic materials with a resolution up to 300 lines/mm. The photographic plate was processed with the standard D-19 developer and an acid fixer. To increase the efficiency of the conversion, the hologram was bleached with a 1.5% solution of potassium ferricyanide. The restoration of the position of the hologram during the reconstruction stage was ensured by means of a special holder.

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[2]) The operation of amplitude correction can be realized also holographically, by using the far zones of the phase-converted beam and of beam II for recording the hologram.

Figure 2 shows the energy distribution in the far zone of the beam II' for the TEM_{02} mode before and after the phase correction. The principal maximum of the corrected beam contains ∿75% of the total energy and has a divergence smaller by a factor ∿4 than the initial beam. The amplitude correction in accordance with the scheme of Fig. 1c completed the conversion of the complicated beam into a Gaussian beam with a plane front (Fig. 3). Similar results were obtained for beam II" upon elimination of the spherical component of the corrected front.

The most direct indicator of the efficiency of the beam-correction method is the coefficient of increase of the axial brightness

$$\eta = \left(\frac{\Delta W}{W}\right)_{corr} \Big/ \left(\frac{\Delta W}{W}\right)_{init},$$

where $(\Delta W/W)_{corr}$ and $(\Delta W/W)_{init}$ are the fractions of the energy of the corrected and initial beams going into a specified solid angle. For the TEM_{02} mode, the amplitude-phase correction has led, within the limits of the principal maximum of the angular distribution, to an increase of the axial brightness by more than 4 times. η increases even more with increasing traverse indices, and for the two-dimensional modes it increases like the product of the corresponding one-dimensional coefficients. Therefore even at relatively low efficiency of the hologram (it amounts to ∿30% in the described experiments), the method is of practical interest.

In conclusion let us stop to discuss the possible energy coefficients of conversion and the prospects of the development of the method. The use of thick-layer phase holograms [2] or of holographic gratings with a specified line profile [3, 4] makes it possible to obtain 100% conversion of the laser beam in one diffraction order. For holography purposes, in particular, it is useful to develop gratings that transform the initial beam into two first-order beams, i.e., which play the role not only of a corrector but also of a beam splitter. In the case of pulsed lasers, the most promising is the development of dynamic correctors using nonlinear media. Finally, interesting results should be obtained by placing the hologram in the resonator [5], since in this case it will serve simultaneously as a phase corrector and as a dispersion element in generators with variable frequency.

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