On a new method of obtaining highly collimated light beams using the wavefront reversal phenomenon

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The possibility of obtaining, in the absence of a reference wave, radiation with a divergence that is close to diffraction-limited is suggested and demonstrated experimentally. The method consists of adding the frequencies of two light waves with complex-conjugate phase multipliers.

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All currently known methods of transforming multimode optical radiation into single-mode in one way or another assume the presence of a reference wave with a plane front, through the use of which as a reference point one can obtain a considerably higher power light beam with close to diffraction-limited divergence. Here we are referring to methods based on static or dynamic holography,[1-3] induced scattering,[4,5] double passage of the reference wave through an optical amplifier with a mirror to reverse the wavefront,[6,7] etc. However, because of the difficulties involved in creating a reference wave with an adequately large aperture these methods lose their effectiveness in many cases.

A method is suggested below for obtaining radiation with a plane wavefront without a reference wave that uses the addition in a nonlinear medium of the frequencies of two multimode light beams with complex-conjugate phase multipliers. In order to obtain, in the absence of a reference wave, a light beam with a phase opposite in sign to the original beam, wavefront reversal (WFR) by means of Mandel'shtam-Brillouin induced scattering (MBIS) can be used.[8] Here, only that part of the phase which depends on the spatial coordinates changes sign. At the same time, the phase, characterizing the time dependence of the complex amplitude of the light wave, remains unchanged (see Ref. 9).1) By adding the frequencies of two light beams, one of which is reflected from a conventional mirror and the other from an MBIS mirror, one can compensate the spatial distortions of the wavefront present in the original beam without, however, compensating the time variations of the phase. As a result the radiation at the summed frequency will have a wavefront identical in shape to that of the mirror surface, in particular, for a plane mirror the wavefront will also be plane.

Let us stress that the summing procedure is done, generally speaking, for radiation with an arbitrary aperture, i.e., light beams of large cross section with a high degree of collimation can be obtained at the summed frequency. The closeness of the wavefront to plane depends on the surface quality of the mirror reflecting one of these beams, on the quality of the WFR by means of MBIS, on the accuracy of the superposition of the fields of both beams at the entrance to the frequency-summing element, the length of this element and amount of relative deflection of the waves interacting in

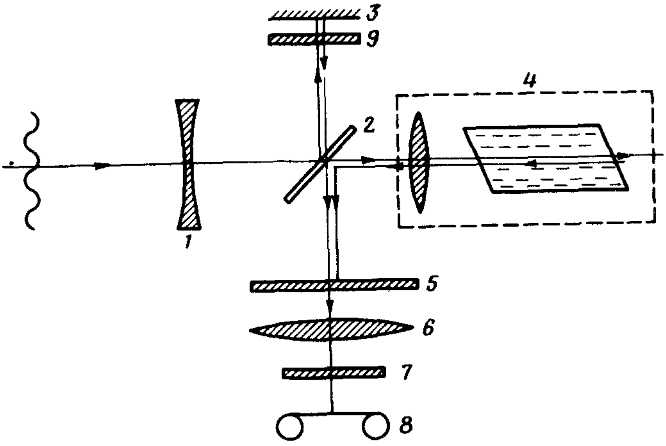

FIG. 1.

it, and the specific nature of summing process (for practical frequency summing it is convenient to use a doubling element, designed to combine the ordinary and extraordinary waves through a scalar interaction or two ordinary waves through a vector interaction).

The following experiment was performed to demonstrate the possibilities of the technique (Fig. 1). The multimode beam of a neodymium laser ($\lambda = 1.06\ \mu$m) with a divergence $\theta = 6\times 10^{-4}$ rad and a diameter $d = 0.6$ cm passed through the diffusing lens 1 ($F = -1$ m), increasing its divergence to $\theta = 6\times 10^{-3}$ rad, and the beamsplitter plate 2 with reflection coefficient $R = 10\%$. The reflected portion of the beam struck the plane mirror 3, while the transmitted portion was incident on the MBIS mirror 4, consisting of a lens ($F = 15$ cm) and an acetone cell. After reflection the beams returned to the plate 2 and then struck the doubling crystal ($LiIO_3$, 1.35 mm long), on the surface 5 of which they were superimposed and matched in power by means of the filters 9.

Doubling of each of the beams separately was first observed in the experiment. The angular spectrum of the second harmonic of both beams was approximately the same and had the form shown in Fig. 2a (the photographs were made using a mirror wedge with a ten-fold attenuation factor). With combined doubling of the beams the angular spectrum of the second harmonic was qualitatively altered (Fig. 2b). The presence of the bright spot in the spectrum (indicated by arrows in Fig. 2b) means that during the doubling compensation of the phase nonuniformities occurs for some of the radiation. Densitometer measurements of the films showed that the intensity of this

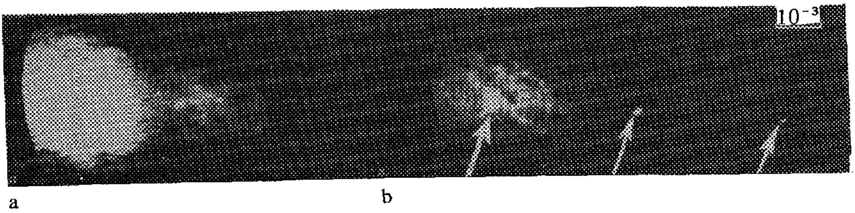

FIG. 2.

spot is more than 300 times greater than the intensity of the surrounding background, corresponding to the second harmonic radiation of each beam separately. The bright spot is asymmetrical; the amount of divergence along different directions is 2×10^{-4} and 0.8×10^{-4} rad and is quite close to the diffraction-limited value. The difference in the divergences may be due to amplitude modulation of the original first harmonic wave, to some misalignment of the mirror 3, or to imprecise WFR of the focused beams by the MBIS.[10]

This was not the optimum scheme. In particular, the *ooe* scalar interaction was used here, permitting the doubling of each beam separately. This was the cause of the observed background around the bright point. In addition, the fields of both beams, as is not hard to show, were not strictly conjugate at the surface 5. However, because the "dephasing" length of the beams, equal to twice the distance between the mirror 3 and crystal 5 (in our case this distance amounted to 10 cm), was considerably less than the length over which phase modulation changes into amplitude, the inaccuracy in the conjugation of the fields played no significant role.

Thus, through the summing of the frequencies of two beams with complex-conjugation fields it is possible to reduce radiation divergence significantly and to increase the spectral radiance compared to the case of independent doubling of each beam. This, of course, does not contradict the second law of thermodynamics, since upon reflection of any fraction of the radiation from the MBIS mirror the total entropy in the system is not reduced but is only redistributed in such a manner that some of it is now due to the hypersonic wave with a highly nonuniform phase profile excited in the medium, reflection from which gives WFR.

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[1)] A sign change of this portion of the phase during any transformation of the light wave in a stationary medium in the absence of a highly stable frequency reference point is impossible since this would contradict the condition of time-invariance of the physical processes.

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