Wavefront inversion in superradiance

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Wavefront inversion in superradiance was observed in experiment. To excite the superradiance the laser radiation was distorted by an inhomogeneous phase plate and was focused into a dye solution. Part of the backward superradiance recovered the initial divergence of the exciting radiation after passing back through the distorting plate.

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Observation of the reversal of the wavefront in SMBS and SRS, wherein the field of the backscattered radiation is the complex conjugate of the pump field, was reported previously.[1-3] This phenomenon is due to formation, in the nonlinear medium, of a three-dimensional amplifying dynamic structure (hologram), in which the predominant amplification is produced by scattered-field configurations that are correlated with the pump field. This effect, however, is not reducible merely to stimulated-scattering processes. It should manifest itself also in the recording of the amplified dynamic holograms in resonant media.[4] In this communication we present experimental results of the observation of the inversion of the superradiance wavefront.

The experimental setup is illustrated in Fig. 1. The dye was pumped with the second harmonic of an yttrium–aluminum garnet laser L with pulse duration ~20 nsec. A diaphragm D of 1.5 mm diameter cut out the central part of the beam with a divergence 0.8 mrad at half-width. The radiation intensity in the unfocused beam was

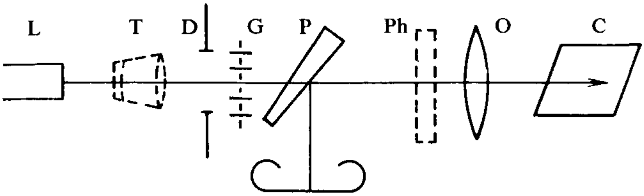

FIG. 1. Diagram of experimental setup.

$I_L \approx 1$ MW/cm^2. After passing through the elements of the optical system, the radiation was focused with an achromatic objective O ($F = 37$ mm, aperture 30 mm) into a cell C (length 50 mm) filled with a standard solution of rhodamine-6G. The pump wavelength $\lambda_L = 532$ nm coincided with the center of the absorption contour of the dye, and the coefficient of linear absorption at this wavelength was $g_L = 11$ cm^{-1}. The backward superradiance was diverted with a glass wedge P to the recording system.

When the undistorted laser beam was focused into the cell with the dye, the divergence angle of the backward superradiance was ~ 1 mrad. The superradiance occupied a rather wide spectral band in the region 545–565 nm, with a maximum at the center of the luminescence band. The close values of the divergences of the exciting radiation and of the backward superradiance are evidence of inversion of the wavefront. Within the limits of the experimental error (10–15%), all the backward superradiance had an inverted wavefront.

Introduction of a phase plate Ph (glass etched in hydrofluoric acid) the laser-beam front was distorted and the divergence increases by approximately 50 times (see Fig. 2b). The distances from the phase plate and from the cell to the principal planes of the objective were 185 and 40 mm, respectively. The photograph (Fig. 2c) shows the far zone of the backward superluminescence radiation after passing in succession through the objective and the phase plate. As seen from the photograph in the far zone, the superluminescence radiation consists of a central bright beam and a diffuse halo. The divergence of the central beam is 1.1 mrad. The propagation direction, divergence, and intensity of the central beam remained practically unchanged after transverse displacement and rotations of the phase plate. Despite the fact that the average density of the energy in the diffuse background is much lower than the energy density in the central spot, the total energy of the background (in an angle 5×10^{-2} rad) exceeded under the experimental conditions the energy of the central beam by approximately 5–10 times.

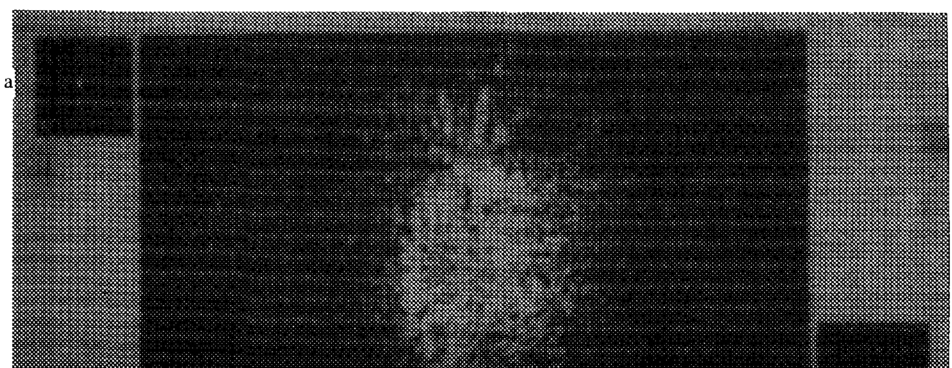

FIG. 2. Far zone of the radiation: a—of laser beam, b—of laser beam distorted by the phase plate, c—of the reconstructed superluminescence field.

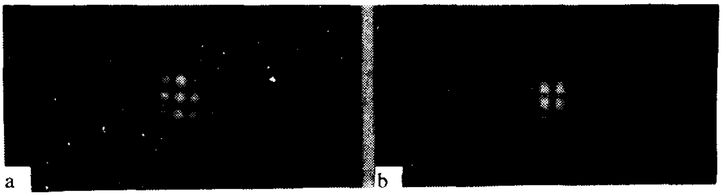

FIG. 3. Photographs of reconstructed images when the radiation was focused into the cell (a) and ahead of the cell (b).

The results indicate that in the backward superluminescence radiation, just as in SMBS and SRS, the predominant amplification takes place in the field configuration that is complex conjugate to the pump field. However, in contrast to the SMBS and SRS, when a phase plate is introduced the discrimination of the uncorrelated modes of the superluminescence field has a less pronounced character. This result agrees with theoretical estimates[5] showing that as a result of the strong nonlinear dependence on the pump energy density the gain of the inverted mode is 1.2–1.5 times larger than for the uncorrelated modes.

The considered effect makes it possible to reconstruct images carried by the pump radiation. To this end, the laser beam was broadened fivefold by a telescope T and passed through a diaphragm D of 5 mm diameter. Instead of the phase plate, a metallic grid G was placed in the beam (mesh 0.9 mm, wire diameter 0.25 mm). The image of the grid was reconstructed both when the radiation was focused into the cell (Fig. 3a) and when the focus of the objective was ahead of the cell (Fig. 3b). In both cases the transverse dimension of the reconstructed image remained unchanged. The localization of the image had a complicated dependence on the experimental setup.

If the focal construction is ahead of the cell, then as a result of the self-focusing the pump field in the medium breaks up into a number of nonintersecting channels. Superradiance develops in each of them independently and without mutual coherence. Therefore the depth of field of the reconstructed image is small (~ 1 cm) and its localization is close to that of the image of the front wall of the cell as constructed by the lens.

As the focus of the objective advances deeper into the cell, the distance from the principal plane of the objective to the reconstructed image increases and approaches the distance to the object. The reconstructed image has a large depth of field ~ 10 cm. The low measurement accuracy of the point of image localization did not make it possible to compare our results with results on the reconstruction of dynamic holograms by means of SMBS and SRS.[6,7]

The results of the present paper show that the effect of inversion of the wavefront can be observed in a large class of resonant media.

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