Conservation of spatial coherence of Stokes beams amplified in a multimode pumping field

A. A. Betin and G. A. Pasmanik

Radiophysics Research Institute
(Submitted April 14, 1976)
Pis'ma Zh. Eksp. Teor. Fiz. **23**, No. 10, 577–580 (20 May 1976)

Using A Mandel'shtam-Brillouin converter as an example, it is shown that effective pumping of multimode optical radiation into a single-mode Stokes wave is feasible in principle, and the conditions under which such a pumping can be realized are explained. A similar spatial-coherence conservation effect is observed also in the amplification of Stokes beams having a more complicated profile in a strongly inhomogeneous pumping field.

PACS numbers: 42.65.–k

1. It is now regarded as established that the spectral brightness of spatially inhomogeneous (multimode) optical radiation can be greatly increased by con-

verting it into a Stokes component via stimulated Raman scattering[1] or Mandel'shtam-Brillouin scattering[2] in an optical resonator. However, the use of Raman scattering in a resonator to increase appreciably the spectral brightness of the light beams and, in final analysis, to convert the radiation into single-mode, is greatly hindered by imposed requirements connected principally with reliable selection of the longitudinal and transverse modes of the Raman generator, and also by the greatly limited possibilities of producing sufficiently short Stokes pulses.[2,3]

At the same time, these difficulties can be easily overcome by using for the indicated purpose Raman amplifiers with multimode pumping, under the condition that the spatial coherence of the amplified waves be conserved. However, in such a formulation the question of amplifying a single-mode signal in both Raman and parametric amplifiers was not investigated experimentally. In this paper we demonstrate for the first time, using a Mandel'shtam-Brillouin amplifier as an example, the possibility of pumping over multimode (spatially incoherent) optical radiation into a coherent Stokes wave, and ascertain the conditions under which this pumping can be realized.

2. A theoretical analysis has shown[4] that conservation of the spatial coherence of the signal requires effective averaging, by means of the Stokes wave, of the inhomogeneities of the gain induced by the incoherent pumping; the parameters of the exciting radiation must satisfy the condition

$$\gamma = \int_0^L \Gamma^2 z_c \, dz \ll 1 , \qquad (1)$$

where $\Gamma = gI_L$ is the increment per unit length, I_L is the intensity of the pump on the beam axis, L is the interaction length, $z_c = k\rho_L^2$ is the longitudinal correlation length of the exciting radiation, and ρ_L is the characteristic scale of the transverse correlation of the pump field. At $\gamma \gtrsim 1$, the averaging regime is not realized and the spatial coherence of the amplified signal is not conserved.

3. An experimental investigation of the effect of conversion of incoherent radiation into a single-mode Mandel'shtam-Brillouin component (see Fig. 1)

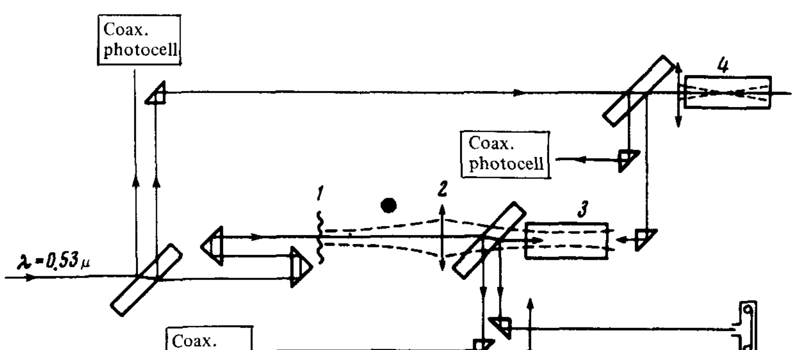

FIG. 1. Block diagram of setup.

was carried out in a cell with acetone 3 ($L = 30$ cm), in which a pulse of the second harmonic of a neodymium laser ($\lambda = 0.53\ \mu$, duration $t_L = 25$ nsec, beam dius $r_L = 0.1$ cm, energy up to 25 J) and a Stokes pulse ($t_s = 25$ nsec, $r_s = 0.1$ ı), attenuated by a factor of approximately 85 relative to the pump, were ap- ied simultaneously from opposite sides. The pump beam divergence $\theta_L \approx 1/k_L$ ıs varied by placing in the beam path glass plates 1 etched in fluoric acid. our experiments, the source of the spatially-coherent Stokes radiation, hav- ʒ a divergence close to the diffraction value ($\theta_s \approx 1.3 \times 10^{-4}$ rad), was SMBS cited in an additional cell 4 by a single-mode focused beam split off from the ain pump beam.

The averaging regime was investigated with a pump having a divergence $\approx 1.4 \times 10^{-2}$ rad, the image of which was transferred from the surface of the ate to the cell with the aid of a long-focus lens 2, the value of the parameter ıot exceeding 0.2 in this case. We registered the angular spectrum of the ıplified radiation, its total power, and a fraction of the power contained in small solid angle on the order of the diffraction angle (the power of the herent part of the signal). It follows from the results of photometry of the gular spectrum of the Stokes wave without amplification and with apprecia- e amplification, in the saturation regime, when the peak power of the Stokes mponent reached 75% of the peak power of the initial second-harmonic pulse ıe amplified pulse was in this case not more than 15% shorter than the mped pulse) that the width of the Stokes-signal spectrum (at the 0.5 level) practically unchanged in the course of amplification and is equal to $\theta_s \approx 1.5$ $.0^{-4}$ rad. To check whether the fraction of the energy of the amplified pulse contained in the angle $\sim \theta_s$, we registered in the far zone the power of a okes wave concentrated within an angle $\sim 3.3 \times 10^{-4}$ rad. It turned out that not ss than 80% of the total power of the Stokes wave is contained in this angle. mparing these data with the results of the photometry of the spatial spec- ım, we can state that in our experiments the peak power of the coherent part the wave reached 60% of the peak power of the pump (increase of spectral ightness $\sim 6 \times 10^3$).

In the investigation of the nonaveraging regime, the pump beam had a diver- ıce $\theta_L \approx 7 \times 10^4$ rad; the parameter γ amounted to 10—20. The measurements ve shown that in this case the coefficient of the conversion into the Stokes mponent can be also high, but the spatial coherence of the amplified signal not conserved and its divergence approximately coincides with the pump ergence.

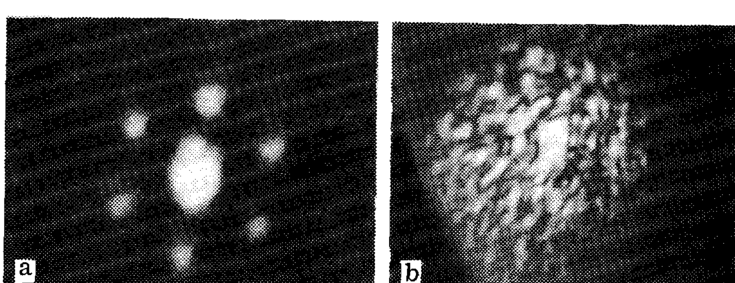

FIG. 2.

4. We note in conclusion that we have also investigated the amplification of beam carrying a definite image. In the case $\gamma \ll 1$ ($\theta_L \approx 1.4 \times 10^{-2}$ rad) the

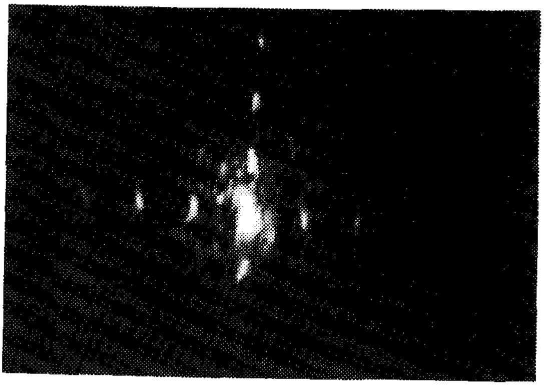

FIG. 3.

spectrum of the modulated Stokes beam was hardly distorted (see Fig. 2(a), which shows a photograph of the angular spectrum of the amplified beam, first modulated with a large-scale ($\rho_s \approx 0.15$ mm) hexagonal grid). To the contrary, at $\gamma > 1$ ($\theta_L \cong 7 \times 10^{-4}$ rad), the image of the grid in the beam spectrum is practically indistinguishable [Fig. 2(b)]. It is interesting to note that at the same pump divergence, with decreasing scale of the modulation of the primary beam the corresponding image in the spectrum of the amplified beam becomes distinguishable (see Fig. 3, which shows a photograph of the spectrum of the amplified wave, modulated by a rectangular grid with wire diameter $\rho_s \approx 25\ \mu$, much smaller than the correlation radius $\rho_L \approx 150\ \mu$). The cause of this effect is that for the spectral components propagating at angles $\theta > \theta_L$ the averaging conditions become less stringent (the correlation length z_c is replaced by ρ_L/θ).[4]

The authors thank V.I. Bespalov and V.I. Talanov for interest in the work and for a discussion of the results.

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