NONLINEAR OPTICAL PHENOMENA

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Phasing of multichannel laser radiation upon stimulated Brillouin scattering

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Abstract. **We investigated the phasing of pulsed two- and four-channel laser beams due to phase conjugation upon transient stimulated Brillouin scattering (SBS) in a double-pass amplification scheme. A high quality of beam phasing was experimentally demonstrated with the use of a microlens raster and an angular selector in the SBS-mirror scheme. The data obtained in the numerical simulation of transient SBS are in good agreement with experimental ones.**

Keywords: *phasing of laser radiation, phase conjugation, stimulated Brillouin scattering.*

1. Introduction

Among the topical and promising ways of raising the power and brightness of laser radiation is the development of multichannel laser systems with mutual phasing of radiation in parallel channels [1]. In the present work we consider the phasing of a multichannel laser beam in a double-pass amplification scheme with the help of phase conjugation (PC) upon stimulated Brillouin scattering (SBS) [2], when the multichannel radiation is focused into a volume cell with an SBS medium and is scattered from the common hypersonic grating. Therefore, the phasing reduces to the PC in the special case of a laser pump beam with a nonuniformly fragmented spatial structure, and the phasing quality should be determined by the PC quality. Andreev et al. [3] considered the phasing scheme of coaxial laser beams in the four-wave mixing with several SBS cells. In our work we realised the scheme of phasing due to the PC in the focusing of spatially separated pump beams into a common SBS cell and reversed-wave formation from spontaneous Stokes noise.

When a lens focuses a one-channel laser beam into an SBS cell, the PC quality decreases with increasing pump wavefront distortions and with SBS saturation weakening (for low SBS mirror reflectivities) [4], under the self-action of the pump beam [5], under nonstationarity of the process [6], etc. It is possible to obviate several problems and obtain a high PC quality by employing a system for pump radiation focusing into the SBS cell with an ordered microlens raster and an angular selector [7–10]. The objective of our work is to demonstrate the phasing of a multichannel laser beam with the use of an SBS mirror with a microlens raster. This is done under transient conditions, when the duration of the pump pulse is comparable to the hypersound relaxation time.

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2. Experimental setup

Our experimental setup is schematically represented in Fig. 1. A radiation beam (wavelength λ = 1.053 μm, pulse duration τ_p = 30 ns, energy E = 30 mJ) with a near diffraction-limited divergence $\theta = 1.3 \times 10^{-3}$ rad is formed at the output of the master oscillator (a neodymium glass laser) (*1*). A telescope (*2*) increases the beam diameter to illuminate a mask (*4*) located in front of an amplifier (*5*). The mask is an opaque screen with two or four openings 3 mm in diameter spaced at 4.5 mm, which permits forming a two- or four-channel laser beam. Upon amplifying the laser pulse to an energy E = 150–300 mJ in the amplifier (*5*), the multichannel beam is directed onto the SBS mirror, which consists of an angular selector (*7*), a Fresnel microlens raster (*8*), a focusing lens (*9*), and an SBS cell (*10*). The angular selector is completely transparent to the pump and affords rejection of the non-reversed component of the Stokes radiation. To decouple the SBS mirror from the master oscillator, advantage is taken of an optical isolator (*3*), which comprises a Faraday cell and a polariser.

The spatial characteristics of the laser and amplified Stokes radiations are recorded with CCD cameras (*11*) and (*12*), respectively. The PC quality can be judged by the degree of similarity of the intensity distributions obtained in the near- and far-field zones. The pump and Stokes radiation

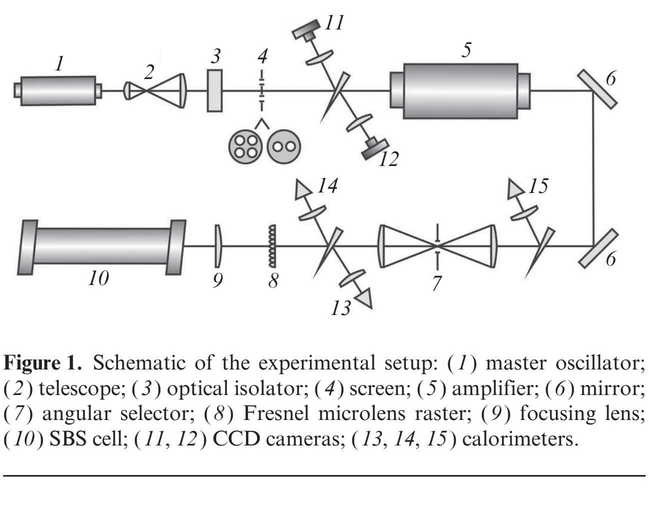

Figure 1. Schematic of the experimental setup: (*1*) master oscillator; (*2*) telescope; (*3*) optical isolator; (*4*) screen; (*5*) amplifier; (*6*) mirror; (*7*) angular selector; (*8*) Fresnel microlens raster; (*9*) focusing lens; (*10*) SBS cell; (*11*, *12*) CCD cameras; (*13*, *14*, *15*) calorimeters.

energies prior to and after the passage through the angular selector are measured with calorimeters (*13*), (*14*), and (*15*). The ratios of these calorimeter readings define the reflectivity R of laser radiation from the SBS mirror and the selection coefficient (the radiation energy fraction transmitted through the selector) k for the Stokes radiation.

An SF_6 and Xe gas mixture at a pressure of ~50 atm serves as the active medium of the SBS mirror. In this medium the gain for the Stokes radiation is g = 72 cm GW^{-1}. The hypersound relaxation time τ for λ = 1.053 μm is equal to ~36 ns, and therefore $\tau_p/\tau \sim 1$, i.e., a transient SBS excitation regime is realised. The authors of [8–10] showed that a high PC quality upon SBS of laser radiation is achieved for a specific configuration of the SBS mirror with a raster of identical microlenses [7]. For a focusing with a lens, a close-to-ideal reversal coefficient may be obtained only for a deep SBS saturation, when the reflection coefficient is higher than 80%–90%. By contrast, when advantage is taken of an SBS mirror with a microlens raster, a high PC quality is achieved for any power, beginning with the threshold one. In our experiments, use was made of an eight-level Fresnel lens raster with a focal length f = 5 cm and a microlens diameter d = 0.5 mm. The scheme of laser radiation focusing into the SBS cell is shown in Fig. 2. The raster is positioned in such a way that both characteristic regions with enhanced laser radiation intensity, which exert the greatest effect on the SBS dynamics, are located for a specific geometry and in specific sequence inside the SBS cell: the focal plane of the focusing lens (zone I) and the image plane for the foci of individual microlenses of the raster (zone II). In this focusing configuration, the SBS excitation threshold energy is equal to ~100 mJ.

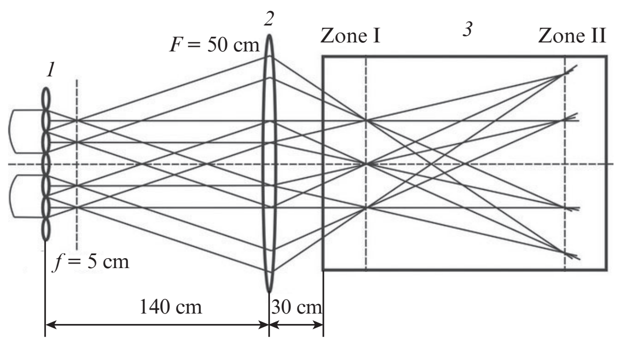

Figure 2. Schematic of laser radiation focusing into the SBS cell: (*1*) raster; (*2*) focusing lens; (*3*) SBS cell.

3. Phase summation of laser radiation

Let us consider the results of our experiment involving the phasing of a two-channel laser beam. Initially we estimated the distortions introduced into the wavefront of the master oscillator beam in the propagation of the radiation and its amplification in the forward and backward passages through the optical path. For this purpose the SBS cell was replaced with an ordinary plane mirror. Figure 3 shows the far-field intensity distributions for the radiation at the input to the amplifier and for the output radiation (i.e., for the radiation amplified, reflected from the mirror, and amplified again in its backward passage). One can see that the amplifier and the elements of the optical path introduce significant distortions into the reference radiation wavefront. This is also confirmed by the measurements of the energy fraction in the central spot of the recorded intensity distributions. It is equal to 65% for the input radiation and to 33% for the output one.

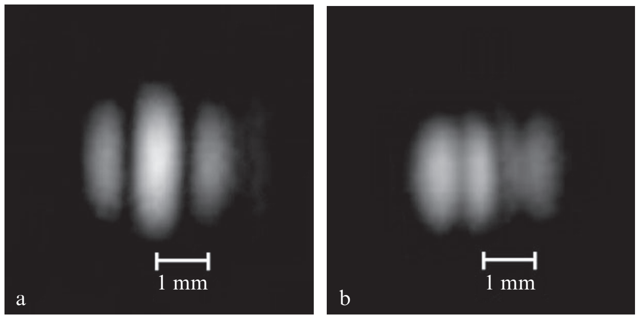

Figure 3. Far-field intensity distributions for the radiation at the input to the amplifier (a) and for the output radiation (b) in the case of a two-channel beam in the scheme with a plane mirror.

To compensate for the accumulated phase distortions, an SBS mirror was used. Figure 4 shows the near- and far-field intensity distributions for the laser radiation at the input to the amplifier and for the output Stokes radiation (the radiation reflected from the SBS mirror and amplified in its backward passage). One can see that the PC quality is rather high. Two separate beams (Fig. 4b) were recorded in the near-field zone; the far-field intensity distributions of the laser and Stokes beams were hardly different (Fig. 4d). The energy fraction in the central spot in the far-field zone of the amplified Stokes radiation amounts to 78% (we are reminded that it is equal to 65% for the input radiation). Furthermore, measurements of the selection coefficient for the Stokes radiation showed that a substantial fraction of reflected radiation passed through the angular selector (k = 76% ± 9% for R = 24% ± 5%), i.e., the energy fraction contained in the non-reversed Stokes component is small.

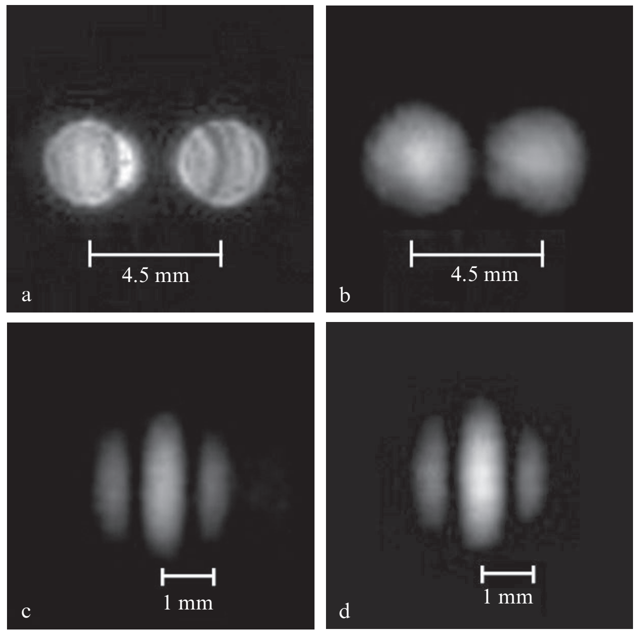

Figure 4. Near- (a, b) and far-field (c, d) intensity distributions for the two-channel laser beam at the input to the amplifier (a, c) and for the amplified Stokes radiation (b, d) in the scheme with the SBS mirror.

Numerical simulation of the phase summation of laser radiation was carried out using a computational model and a programme describing transient SBS [9]. The simulations were performed assuming a two-dimensional medium, which permitted us to describe the main physical effects attending the SBS (diffraction, SBS saturation, transient processes related to the hypersonic wave damping) and at the same time drastically shortened the computation time. Furthermore, in these simulations the amplification of laser and Stokes radiations was not considered, i.e., the quality of the beam phasing was determined primarily by the operation of the SBS mirror. In other respects the simulation parameters corresponded to our experimental conditions.

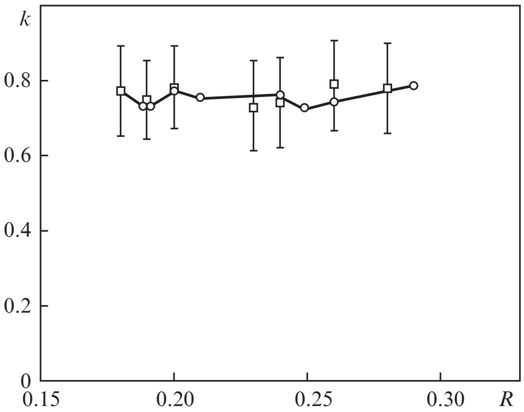

Figure 5. Calculated (○) and experimental (□) dependences of the selection coefficient k on the laser radiation reflection coefficient R for a two-channel laser beam in the scheme with the SBS mirror.

Figure 5 shows the values of the selection coefficient obtained in the simulations and experiments for different values laser radiation reflectivity. In the simulations and in the experiment the average value of the selection coefficient $\langle k \rangle$ is equal to $\sim 75\%$. Figures 6a and b show the calculated profiles of the intensity I of laser radiation at the input to the angular selector and of the Stokes radiation at the output from the selector. For ease of comparison, the values of laser and Stokes radiation intensities are normalised to their corresponding maximum values. One can see that the simulated intensity profiles of the laser and Stokes radiations are in rather close agreement both in the near-field (Fig. 6a) and far-field (Fig. 6b) zones, i.e., the PC quality is high. Figures 6c and d show the intensity profiles of amplified Stokes radiation recorded experimentally. Like in our simulations, we observed a good agreement between the laser and Stokes radiation intensity profiles.

Therefore, the use of the microlens raster in the scheme of two-channel laser beam focusing in the SBS cell makes it possible to obtain a high PC quality for moderate reflection coefficients and to realise the phasing of two laser beams.

Let us discuss the results of the experiment on the phasing of a four-channel laser beam. Figure 7 shows the far-field intensity distribution for the radiation at the input to the

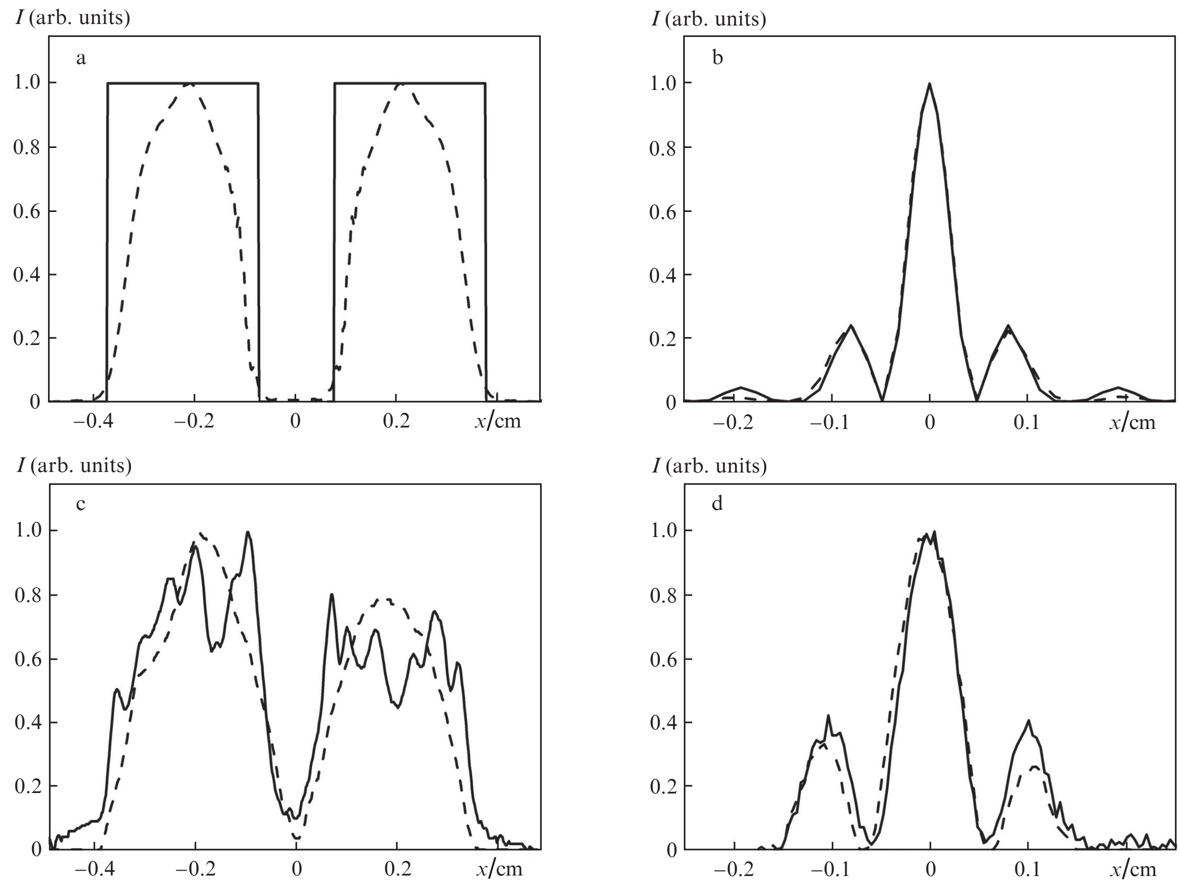

Figure 6. Simulated (a, b) and experimental (c, d) intensity profiles of the laser (solid curves) and Stokes (dashed curves) radiation in the near-field (a, c) and far-field (b, d) zones for a two-channel laser beam in the scheme with the SBS mirror.

amplifier and the output amplified radiation in the scheme with an ordinary plane mirror. One can see that the wavefront of the reference radiation is significantly distorted upon its propagation and amplification in the forward and backward passages through the optical path. As in the case of a two-channel beam, the energy fraction in the far-field central spot for the input radiation (55 %) is much higher than for the output one (14 %).

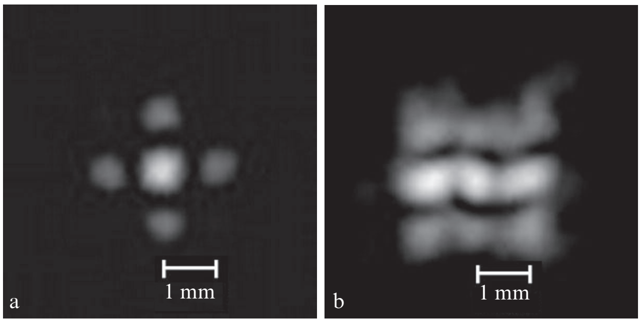

Figure 7. Far-field intensity distributions for the radiation at the input to the amplifier (a) and the output radiation (b) for a four-channel laser beam in the scheme with the SBS mirror.

Figure 8 shows the far- and near-field intensity distributions for the laser radiation at the input to the amplifier and for the amplified Stokes radiation at the output in the case of the SBS mirror with the microlens raster. Like in the previous case, the PC quality of the laser beam is high. The selection coefficient amounts to 74 % ± 9 % for $R = 24\% \pm 5\%$, i.e., the bulk of amplified Stokes radiation passes through the selector. The energy fraction in the far-field central spot is equal to 65 % for the amplified Stokes radiation (for the input radiation it is equal to 55 %).

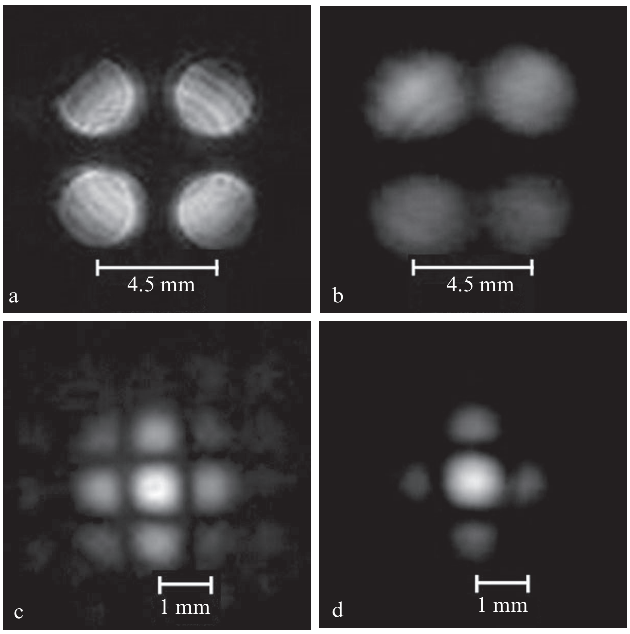

Figure 8. Near- (a, b) and far-field (c, d) intensity distributions for the four-channel laser beam at the input to the amplifier (a, c) and for the amplified Stokes radiation (b, d) in the scheme with the SBS mirror.

Therefore, our simulations and experimental data demonstrate the feasibility of phasing a multichannel pulsed laser beam with the use of the PC in the SBS of focused beams when the reversed Stokes radiation arises from spontaneous noise.

4. Conclusions

In this work we studied the phasing of multichannel laser radiation due to the PC effect upon transient SBS of focused beams. The phasing of two- and four-channel beams was experimentally investigated using a pulsed neodymium laser in a double-pass amplification scheme. A comparison of the far- and near-field intensity distributions of the multichannel laser and Stokes radiations suggests that a high PC quality is reached when a microlens raster and an angular selector are employed in the scheme of radiation focusing into the SBS cell. In the case of a two-channel (four-channel) beam, the energy fraction in the far-field central spot for the amplified Stokes radiation amounts to 78 % (65 %), which is even higher than for the input laser radiation – 65 % (55 %). In this case, the SBS reflection coefficient for the laser radiation was equal to 24 % and the transmittance of the angular selector was equal to 75 %. Numerical simulations were made of the phasing of two laser radiation channels with the use of a two-dimensional numerical model of transient SBS. The resultant calculated values of the laser radiation selection coefficient and the far-field radiation intensities are in good agreement with experimental data.

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