

Stimulated Brillouin scattering phase conjugation of light beams carrying orbit angular momentum

(Invited Paper)

Xudong Chen (陈旭东), Chengcheng Chang (昌成成), and Jixiong Pu (蒲继雄)*

Fujian Key Laboratory of Light Propagation and Transformation, College of Information Science and Engineering, Huaqiao University, Xiamen 361021, China

*Corresponding author: jixiong@hqu.edu.cn

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We investigate the stimulated Brillouin scattering (SBS) properties of light beams carrying orbit angular momentum (OAM). The phase conjugation of light beams carrying OAM is experimentally achieved in an SBS mirror with a random phase plate. The spectrum and the pulse width compression of SBS light are measured. It is shown that the phenomena of pulse compression is observed and OAM conservation is confirmed in the SBS process. The OAM transfer from photons to phonons may find potential applications in photon-phonon conversion-based signal-processing schemes by using OAM multiplexing.

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In recent years, vortex beams have gained considerable attention. Vortex beams possess unique phase distribution and orbit angular momentum (OAM)^[1]. Therefore, vortex beams have a lot of potential applications in different fields such as optical trapping and manipulation of particles^[2], laser processing^[3–5], optical telecommunication^[6,7], and so on.

On the other hand, stimulated Brillouin scattering (SBS) is a significant topic in nonlinear optics^[8]. Its specific properties have been widely studied and have been applied in many applications, such as phase conjugation^[9,10], pulse duration compression^[11,12], and line width compression^[13], even in the research for slow light^[14]. Recently, the stimulated Brillouin amplification for vortex beams has been reported^[15,16]. The controllable OAM transfer between photons and phonons was realized and the potential of using OAM multiplexing to extend the capacity of a photon-phonon conversion-based signal-processing scheme was demonstrated.

However, in Refs. [15,16] the SBS signal was pumped by a Gaussian beam, but not a vortex beam, and converted to a vortex beam with a spiral phase plate (SPP). As the theoretical forecasts and experimental demonstration^[17], the Stokes beam generated by a directly focused vortex laser beam represents a random combination of different modes, as they have the same amplification coefficient. Therefore, it is impossible to achieve the SBS phase conjugation of a directly focused vortex beam. In order to conjugate the optical vortex, it is necessary to destroy the spatial structure of vortex beam in the SBS cell. It has been proposed that it is possible to use a transparent random phase plate for phase conjugation of a vortex beam due to the initiation of a high-fidelity phase-conjugation in the SBS cell^[18]. However, until now, few detailed experimental results have been reported. In this Letter, we will experimentally investigate

the SBS of a vortex beam generated in a SBS phase-conjugating mirror (PCM) with a random phase plate.

The experimental setup is shown schematically in Fig. 1. The laser used is an injection seeded pulsed Nd:YAG laser running at 532 nm (Spectra Physics, Quanta-Ray Pro 230), with a repetition rate of 10 Hz, pulse width of 10 ns, and a linewidth of 90 MHz. We use an SPP made of fused silica to shape the laser beam to an optical vortex with topological charge (TC) $l = 2$. The polarization of the laser output is vertical and is converted to be horizontal by a half-wave plate (HWP) in order to penetrate the polarizing beam splitter (PBS). The linearly polarized vortex beam passes through the PBS and a quarter-wave plate (QWP), then becomes a circularly polarized vortex beam. In what follows, the incident vortex beam is referred to as the pump beam. This pump beam passes through a light-shaping diffuser (LSD, RPC Photonics) and forms a laser speckle beam whose divergence angle is measured to be about 1° . Therefore, it could not be well focused with a single convex lens. A telescope system, formed by two lenses of focal length 300 and 150 mm, respectively, is used to focus the laser speckle beam into an SBS cell (water) to excite SBS. The backward SBS light becomes vertically

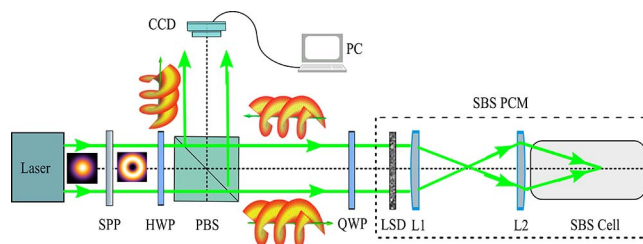


Fig. 1. Experimental setup of SBS pumped by a vortex beam. D, diffuser; L1, L2, lenses.

polarized after passing through the QWP again, then is reflected by the PBS to the detectors.

The intensity profile of the incident pump beam after the PBS is recorded by a CCD-based beam profiler (Ophir, SP620U). The pump beam has an annular spatial profile due to a phase singularity, as shown in Fig. 2(a). Figure 2(b) presents the intensity profile of the SBS signal reflected by the PBS. One can find that the SBS signal keeps an annular spatial profile. The TCs of the incident pump beam and that of the reflected SBS signal are examined using a tilted spherical biconvex lens^[19]. As shown in Figs. 3(a) and 3(b), the three bright and stable stripes and their orientation indicated that the TC of the input pump beam and that of the reflected SBS signal are +2 and -2, respectively. It should be noted that the TC of the backward SBS signal is reversed when reflected by the PBS, while the OAM does not change. Therefore, we may conclude that the TC of the SBS signal reflected from the SBS PCM maintained the same TC with that of the incident vortex beam; the wavefront of the pump beam is exactly reversed and the OAM changed by $4\hbar$ ^[20].

In order to compare the reflection by SBS PCM with the reflection by a conventional mirror, a conventional mirror is placed after the PBS. The incident pump beam is reflected by the mirror and the PBS, and also examined by using a tilted lens. As shown in Fig. 3(c), the similar pattern to that of Fig. 3(a) indicates that the TC remains unchanged after twice conventional reflection and the OAM remains unchanged.

To check the spectral component of the signal we received, we employ a Fabry-Perot (F-P) etalon to form a spectrum. The F-P etalon used is a solid etalon made of quartz with a free spectral range (FSR) of 20.1 GHz. Figure 4 shows one of the measured spectra of the SBS

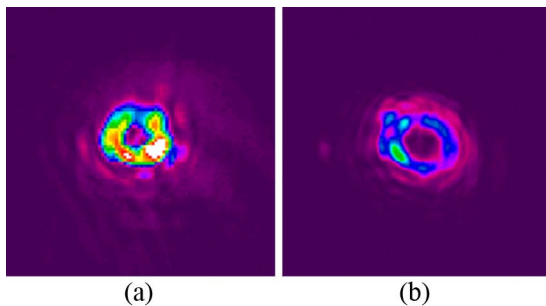


Fig. 2. Intensity profile of (a) the pump beam and (b) the SBS signal.

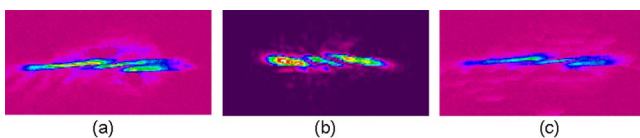


Fig. 3. Experimental intensity distributions of (a) the pump beam, (b) the received SBS signal, and (c) the mirror reflection beam formed after the tilted lens, respectively.

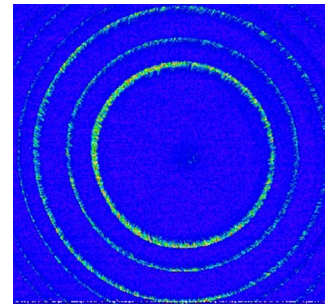


Fig. 4. Measured spectrum of Brillouin scattering in water.

signal generated in water recorded by a CCD. It can be clearly found that the spectrum includes two rings, where the outer one represents Rayleigh scattering, and the inner and stronger one represents the Stokes component of Brillouin scattering^[21].

Figure 5 gives the measured pulse durations of the pump beam and SBS. The oscilloscope used was the Agilent model DSO 7104A with the bandwidth of 1 GHz. The detector used was an Electro-Optics Technology model ET 2000 with a rising time of 200 ps. It is clearly seen from Fig. 5 that the pulse duration was effectively compressed from 10.6 to 4.5 ns during SBS in water.

To check the important role that the LSD played in the SBS process, we removed the LSD from the optical path and then recorded the SBS signal again. Figure 6(a) presents the speckle pattern formed after the LSD. As shown in Fig. 6(b), the SBS signal did not maintain the annular profile any more, that is the phase conjugation did not occur due to the failure of selection of the conjugated mode^[27]. During the SBS process, each elementary optical vortex belonging to the speckle pattern emits an acoustical vortex wave with doubled TC. Hence, the OAM conservation is achieved in the SBS PCM.

In conclusion, we experimentally investigate the SBS properties of a vortex beam. We obtain the SBS phase conjugation of a vortex beam with the help of an LSD and confirmed OAM conservation in the SBS PCM. The

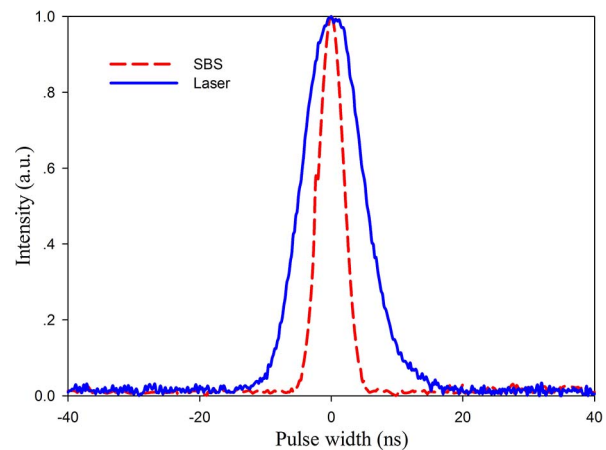


Fig. 5. Measured pulse width of the laser beam and that of Brillouin scattering in water.

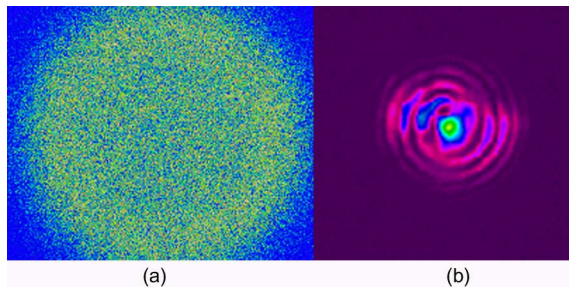


Fig. 6. (a) Speckle pattern recorded after the LSD; (b) the intensity profile of SBS generated in the SBS cell without the LSD.

physical mechanism can be ascribed to the high phase-conjugating fidelity SBS and the acoustical vortex wave with a doubled TC generated by the speckle field in the SBS medium^[18]. Hence, although only the SBS phase conjugation of the vortex with a TC of 2 is investigated, similar results can be obtained for a vortex beam with other TC. We also measure the spectrum and pulse width of the SBS signal. The results show that the pulse width of the vortex beam is efficiently compressed during SBS in water. The OAM transfer from photons to phonons may find potential applications in extending the capacity of a photon-phonon conversion-based signal-processing scheme by using OAM multiplexing.

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