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Investigation on the effect of beam divergence angle upon output waveform based on stimulated Brillouin scattering optical limiting*

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This paper investigates the effect of beam divergence angle on output waveform based on stimulated Brillouin scattering optical limiting. Output waveforms in the case of different pump divergence angles are numerically simulated, and validated in a Nd:YAG seed-injected laser system. The results indicate that a small pump divergence angle can lead to good interaction between pump and Stokes, and a platform can be easily realized in the transmitted waveform. In contrast, a peak followed by the platform appears when the divergence angle becomes large.

Keywords: stimulated Brillouin scattering, optical limiting, waveform, beam divergence angle

PACC: 4265C, 4225B

1. Introduction

During the past several decades, stimulated Brillouin scattering (SBS) has been a focus of theoretical and experimental investigations in the field of nonlinear optical phase conjugation. However, most of them are concentrated on backward Stokes scattering light rather than transmitted light.[1−10] When the pump power density exceeds the SBS threshold, a strong SBS process takes place, during which a quick energy transfer from pump to Stokes occurs. Therefore, the transmitted pulse of SBS optical limiting is characterized by a flat top.[11−13] In Refs.[14]–[17], several proposals, including double SBS optical limiting, one-time SBS optical limiting adopting short pump wavelength or short phonon-lifetime medium, and inserting a dye plate after SBS optical limiting, have been presented to realize flat-top waveforms. All these themes facilitate the application of a flat-top waveform in the time domain. Besides phonon lifetime, pump divergence angle also affects the transmitted waveform greatly. A flat-top waveform can be obtained by choosing a medium with short phonon lifetime in the case of a small pump divergence angle. When the pump divergence angle is large, it is difficult to generate a flat-top waveform even if a medium with a much shorter phonon lifetime is chosen.

This paper investigates the effect of pump divergence angle on the transmitted waveform in the time domain based on SBS optical limiting. The output waveforms in case of different pump divergence angles are numerically simulated, and validated in the Nd:YAG seed-injected laser system. The results indicate that small pump divergence angle can lead to good interaction between pump and Stokes, and a platform can be easily realized in the transmitted waveform. In contrast, a peak followed by the platform appears when the divergence angle becomes large.

2. Theoretical predictions

According to the theoretical model of SBS optical limiting in Ref.[18], the output waveforms shown

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in Fig.1 for different pump divergence angles are numerically simulated. In simulation, the incident light wavelength is 1064 nm, with a repetition rate of 1 Hz and pulse width of 8 ns. The cell length and focal length of the lens are 40 cm and 10 cm, respectively. The SBS medium is HT-270 with gain coefficient of 2.3 cm/GW, absorption coefficient of 10^{-3} cm^{-1} and phonon lifetime of 0.1 ns.

From Fig.1, it can be seen that when the pump divergence angle is 0.4 mrad, the output waveform is almost a platform. However, small peaks appear in the front edge when the pump divergence angle is increased to 0.8 mrad and 1.2 mrad. Therefore, a perfect flat-top waveform in time domain can be generated by SBS optical limiting only when the divergence angle is small.

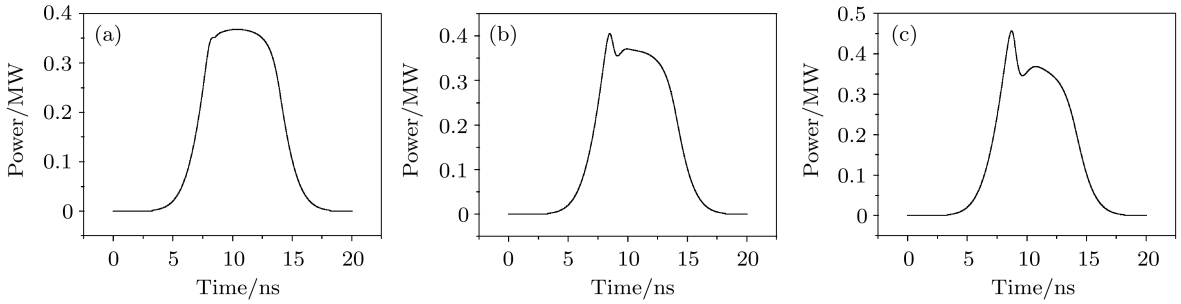


Fig.1. Simulation of output waveforms based on SBS optical limiting in the case of different pump divergence angles: (a) 0.4 mrad; (b) 0.8 mrad; (c) 1.2 mrad.

3. Experimental investigations

The experimental setup is shown in Fig.2. The continuum's Nd:YAG seed-injected laser outputs s-polarized light, which becomes p-polarized after passing a 1/2 wave plate and then circularly polarized after passing a 1/4 wave plate. The SBS system comprises a generator cell and a focus lens L. The pump light is focused into the generator cell to produce Stokes light. Polarizer P together with the 1/4 wave plate forms a light isolator, preventing the backward SBS light from entering the YAG oscillator. The Stokes light becomes s-polarized after passing the 1/4 wave plate, and is reflected by polarizer P. The pump energy can be adjusted by the 1/2 wave plate. The energies of pump pulse, output pulse, and Stokes pulse are measured with energy meter OPHIR. The pulse shapes are detected with PIN photodiode and recorded with digital oscilloscope TDS684A. The pump divergence angle shown in Fig.2(b)[19] is changed by beam-expanding and collimation, and measured with the wavefront analysis system CLAS^{TM}-2D.

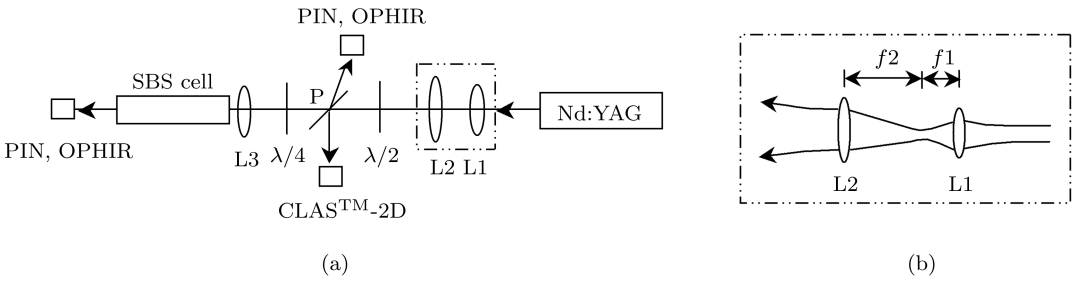


Fig.2. Experimental setup: (a) whole system; (b) divergence angle adjusting part.

The experimental parameters are identical to those in the simulation. The output waveforms are shown in Fig.3, and agree well with the simulation. It can be seen that when the pump divergence angle is small, the output waveform is almost a platform. However, a peak appears in the front edge when the pump divergence becomes large.

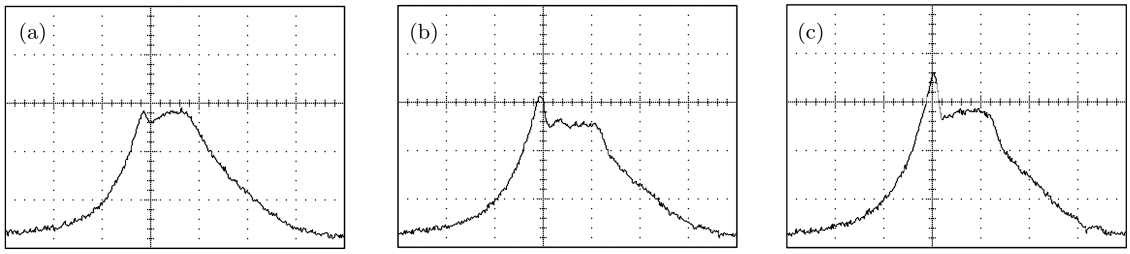


Fig.3. Experimental result of output waveform based on SBS optical limiting with different divergence angles: (a) 0.4 mrad; (b) 0.8 mrad; (c) 1.2 mrad.

4. Analysis and discussions

Since the divergence angle of the pump beam is larger than that of Stokes, the former plays a key role in the interaction between the pump and Stokes beam,[20] and thus affects the output waveform in the time domain based on SBS optical limiting. As to the Gaussian beam, the dependence of the waist radius at the focus on beam divergence angle can be denoted by

$$\omega = \frac{1}{2} f\theta, \tag{1}$$

where ω is the waist radius of the Gaussian beam, θ is the pump divergence angle and f is the focal length. The waist radius is proportional to the divergence angle. A small waist radius corresponding to a small divergence angle can lead to good interaction between pump and Stokes, and even energy at the rim of the beam is also completely transferred. Therefore, the transmitted pulse is almost a flat-top waveform. However, a peak will appear in the front edge due to the incomplete energy transfer at the beam rim when the divergence angle is large.

In order to validate the influence of divergence angle on the interaction between pump and Stokes, transmitted energy as a function of divergence angle shown in Fig.4 is numerically simulated with 21 mJ pump energy. It can be seen that the output energy increases with increasing pump divergence angle. This is because the interaction at the beam rim becomes weak as the pump divergence angle increases. As a result, the output energy of SBS optical limiting increases. In the experiment, when the pump energy is 21 mJ, the output energies are 9.5 mJ, 10.6 mJ and 11.5 mJ corresponding to pump divergence angles of 0.4 mrad, 0.8 mrad and 1.2 mrad, respectively.

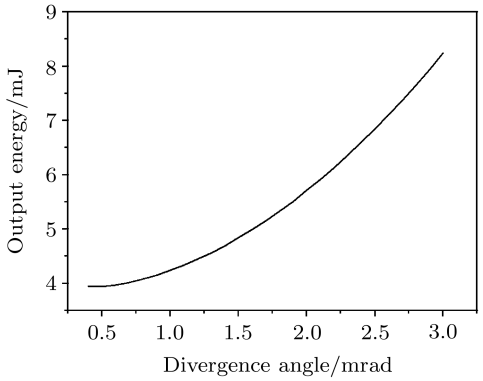


Fig.4. Simulation of output energy through SBS optical limiter as a function of divergence angle.

5. Conclusions

When the pump energy exceeds the SBS threshold, a strong SBS process takes place and the energy is quickly transferred from pump to Stokes. As a result, the output waveform in the time domain based on SBS optical limiting is a plateau. Besides the phonon lifetime, the pump divergence angle also affects the SBS optical limiting waveform greatly. Small pump divergence angle can result in good interaction between pump and Stokes and thus complete energy transfer. As a result, the output waveform is almost a platform. However, large pump divergence angle will result in the appearance of a peak due to the incomplete energy transfer at the beam rim. The generation of a flat-top waveform in the time domain may facilitate some novel applications.

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