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Pulse shape control using a main Brillouin amplifier and a reshaping Brillouin amplifier

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In order to finely control the Stokes pulse shape from stimulated Brillouin scattering generator, a novel Brillouin amplifier system including a main Brillouin amplifier and a reshaping Brillouin amplifier is put forward. In this two- Brillouin-amplifier scheme, the main amplifier can control the general pulse shape by changing the delay time between the pump and the Stokes seed, while the reshaping amplifier can finely control the pulse shape, especially the rising edge of the pulse by changing the distance between the two amplifiers. Theoretical and experimental researches show that distance between the two amplifiers is the most important parameter to finely control pulse shapes. And results prove that this scheme is a simple and efficient way to control the pulse shape.

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Keywords: Pulse shape control, Stimulated Brillouin scattering, Brillouin amplifiers

1. Introduction

Though Brillouin amplifier has been widely applied to achieve compressed pulse with high power and high quality, seldom is it applied to control pulse shape[1,2]. However, some potential applications of stimulated Brillouin scattering (SBS) in high power systems require that the reflected pulse shape from the SBS phase conjugate mirror (PCM) is identical with the incident pulse, or the PCM has the ability to control the pulse shape[3,4].

Stokes pulses reflected from traditional SBS PCM are compressed with steep leading edge because of the feature of pulse compression [5, 6]. According to [7], in the scheme of main oscillator—power amplifier (MOPA), the interaction process of pump and Stokes seed in the amplifier can be adjusted by changing the delay time between the pump and the Stokes seed entering the amplifier, and thus the output Stokes pulse shape is controlled. However, in this scheme, the ability of the single Brillouin amplifier to control Stokes pulse shape is limited. Based on [7], in this letter, we put forward a new configuration of two Brillouin amplifiers including a main amplifier and a reshaping amplifier, which can control output Stokes pulse shape better. In the main amplifier, the pulse shape is coarsely controlled by adjusting the delay between the pump pulse and the Stokes seed pulse entering it. While the reshaping amplifier is used to finely control the pulse shape by controlling the distance between the two amplifiers. The ability of this new scheme of two Brillouin amplifiers to control Stokes pulse shape is theoretically and experimentally researched, and results prove that this scheme is a simple and efficient way to precisely control the Stokes pulse shape.

2. Theoretical research and discussion

The physical model of this two-Brillouin-amplifier scheme is shown in Fig.1. In front of the main amplifier A_1 with a length of l_1, the reshaping amplifier A_2 with a length of l_2 is placed. A_1 and A_2 are filled with same SBS medium. Stokes seed, which is generated by the Brillouin generator with the same SBS medium, and the pump wave are counterpropagating. Compared with the Stokes seed, the pump pulse is delayed when entering the system, so the tailing edge of the Stokes seed is amplified by the pump in A_1. While in A_2, the leading edge of the Stokes seed meets pulse peak of the pump, and is weakly amplified because of the short length of A_2. Regulating the distance between the two amplifiers L and the delay time between the Stokes seed and the pump, the output pulse shape can be finely controlled.

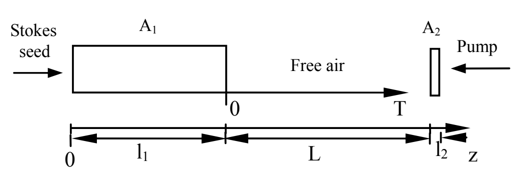


Fig.1. physical model of the scheme of two Brillouin amplifiers.

In the two amplifiers, the pump wave and Stokes wave follow the Maxwell coupled wave equations, and the phonon wave in the SBS medium is described by the Navier-Stokes equation [8,9]. According to [10], omitting the transverse variation of waves and applying the usual slowly-varying-amplitude approximation, the equations can be written as:

$$\left[\frac{\partial}{\partial z}-\frac{n}{c}\frac{\partial}{\partial t}\right]A_L=-ig_1QA_S+\frac{\alpha}{2}A_L \quad (1a)$$

$$\left[\frac{\partial}{\partial z}+\frac{n}{c}\frac{\partial}{\partial t}\right]A_S=ig_1Q^*A_L-\frac{\alpha}{2}A_S \quad (1b)$$

$$\left[\frac{\partial}{\partial t}+\Gamma\right]Q=ig_2A_LA_S^* \quad (1c)$$

Here A_L, A_S and Q are complex amplitudes of the pump, Stokes and acoustic phonon, respectively. Γ is associated with the phone lifetime in the SBS medium. $g_{1,2}$ denote SBS coupling coefficients, and α represents the absorption coefficient of the medium. $|A_L|^2$ and $|A_S|^2$ are intensity of the pump wave and Stokes wave with boundary conditions:

$$A_S(z=0,t)=A_S(t)\ A_L(z=l_1+L+l_2,t)=A_L(t)$$

.

In the free air between the two amplifiers, the pump wave and Stokes wave obey the equations as follows:

$$\frac{\partial A_L}{\partial z}-\frac{1}{c}\frac{\partial A_L}{\partial t}=0 \quad (2a)$$

$$\frac{\partial A_S}{\partial z}+\frac{1}{c}\frac{\partial A_S}{\partial t}=0 \quad (2b)$$

In the amplifiers, the numerical method for partial differential equations of (1) is applied as [7], the results are:

$$G_{Sj}A_{Lj}^{m+1}+G_jA_{Sj}^{m+1}-A_{Lj+1}^{m+1}=r_BA_{Lj}^m \quad (3a)$$

$$-G_{Lj}A_{Sj}^{m+1}-G_jA_{Lj}^{m+1}+A_{Sj+1}^{m+1}=r_BA_{Sj}^m \quad (3b)$$

Here, $r_B=\frac{n\Delta z}{c\Delta t}$, $G_j^{'}=\frac{g\Gamma\Delta t\Delta z}{4}$,

$G_j=G_j^{'}P_j^m$, $G_{Lj}=1-r_B+G_j^{'}\left|A_{Lj}^m\right|^2-\frac{1}{2}\alpha\Delta z$,

$$G_{Sj}=1+r_B+G_j^{'}\left|A_{Sj}^m\right|^2+\frac{1}{2}\alpha\Delta z,$$

$P_j^m=(P_j^{m-1}+2A_{Lj}^mA_{Sj}^m)e^{(-\Gamma\Delta t)}$ and $P_j^0=A_L^0A_S^0e^{(-\Gamma\Delta t)}$.

In the free air between the two amplifiers, Eqs.(2a) and (2b) are discretized as:

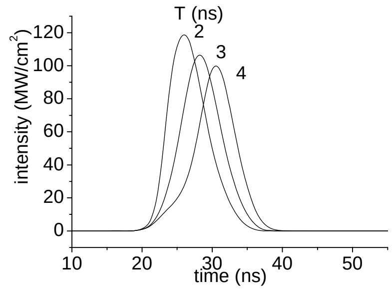
$$A_{Lj+1}^{m+1}-(1+r)A_{Lj}^{m+1}+rA_{Lj}^m=0 \quad (3c)$$

$$(1+r)A_{Sj+1}^{m+1}-A_{Sj}^{m+1}-rA_{Sj+1}^m=0 \quad (3d)$$

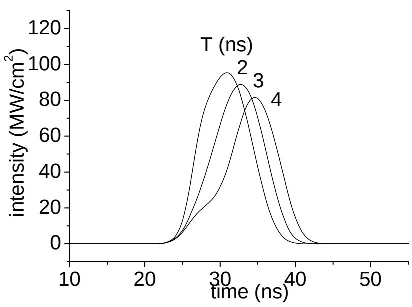
Eqs.(3a-d) combined with boundary conditions is the complete mathematical model.

The following parameters are applied in numerical simulations: the pump is Gaussian-shaped pulse with the wavelength of 1.06μm and the full width at half maximum (FWHM) of 8ns. For the Stokes seed with a steep leading edge, it is simulated as a Gaussian-shaped pulse, whose FWHMs at the leading edge and tailing edge are 4ns and 8ns respectively. The refractive index of the SBS medium in the two amplifiers is 1.5, the SBS coupling coefficients is 6cm/GW, phonon lifetime is 0.5ns, and the absorption coefficient is zero. The length of A_1 and A_2 are l_1=40cm and l_2=1cm, respectively. An encounter time T is defined as a time corresponding to the distance between the end face of A_1 and the encounter position where the peaks of the pump and the Stokes seed meet. When the encounter position is just at the right face of A_1, seen in Fig.1, T=0.

Theoretical researches prove that the distance between the two amplifiers L is the most important and convenient parameter to finely control the leading edge of the Stokes pulse. Fig.2 shows the dependence of output pulse shapes on encounter time with different L. It can be seen that the encounter time T coarsely determines the shape of the output pulse: when the T is smaller, the pulse duration is shorter and the leading edge is steeper, with the increasing of the T, the pulse duration is broadening. Also it shows that the distance between the two amplifiers can finely control the pulse shapes, especially the leading edge of the pulse. It can be seen clearly in Fig.3 and Fig.4, which respectively present the rule of leading edge and pulse width vs. L at different T. We can see that the rising edge is becoming shorter with the increasing of L at first, after a minimum, it is becoming broader and boarder. It can be explained as: because the pump enters A_1 later than the seed, only the tailing edge of the Stokes seed can be effectively amplified by the pump in A_1. As a result, the peak of the Stokes pulse moves backward and its leading edge becomes broader. And the longer the T is, the longer the pulse duration is. When A_2 is placed in front of A_1 and is close to A_1, which means L is shorter, this scheme of two amplifiers is similar to that of single amplifier, and the effect of A_2 is a longer amplifier. So the leading edge of output pulse is shorter with the increasing of L. Only if L is long enough, the function of A_2 is really to finely adjust the leading edge. In this case, the seed is amplified earlier and earlier with the increasing of L, so its rising edge is becoming broader and broader, and reaches its maximum until its root of leading edge meets the pump peak in A_2. After that, the rising edge will become shorter with the increasing of L.



a) L=50cm



b) L=150cm

Fig.2. Dependence of output pulse shapes on the encounter time T with different L.

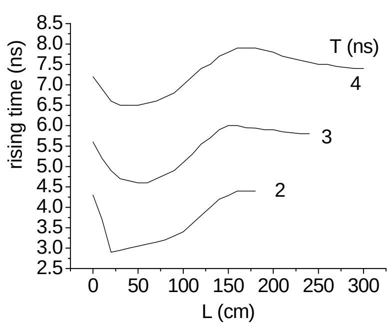


Fig.3 Rising time vs. L with different T.

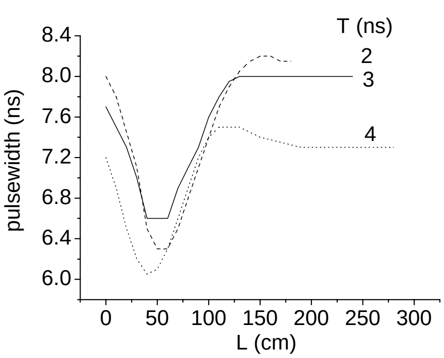


Fig. 4. Pulsewidth vs. L with different T

3. Experimental research and discussion

The scheme of our experimental setup is shown in Fig. 5. A Q-switched Nd:YAG laser produces single longitudinal quasi-Gaussian pulses with wavelength 1.06μm and linear polarization at 1Hz repetition rates. A large part of the output beam from YAG laser is used as the pump and enters the system of two amplifiers through the polarizer P_1. While the reflected beam from P_1 enters a SBS oscillator and generates the Stokes seed pulse. The Stokes seed goes through the delay line of M_3 and M_4, and then enters the system. All SBS cells are filled with CCl_4. Pulse shapes are detected by a PIN photoelectric tube and recorded by digital oscilloscope TDS684A. Typical pulse shapes of the pump and the Stokes seed pulse are shown in Fig.6. The pulse duration and rising time of the pump are 6.2ns and 4.0ns, respectively. Those of the Stokes seed are 5.1ns and 1.6ns. Energy of the pump and the Stokes seed are about 52.2mJ and 4.3mJ, respectively. It is obvious that the leading edge of the Stokes is steeper than the pump for the effect of pulse compression in the SBS generator.

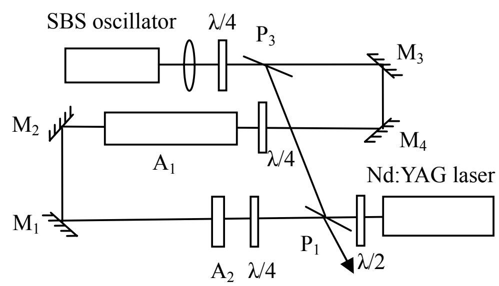
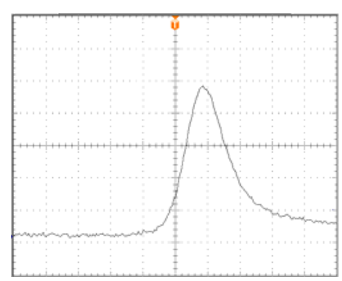
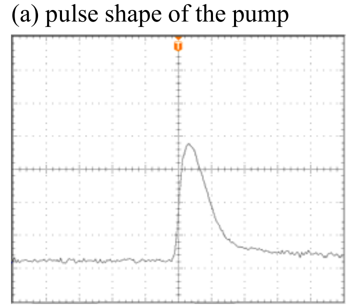


Fig.5 Schematic diagram of the experiment setup



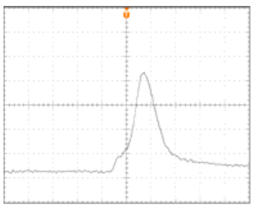
(a) pulse shape of the pump



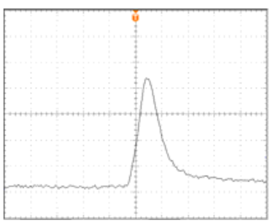
(b) pulse shape of the Stokes seed

Fig.6. Typical pulse shapes of the pump and the Stokes seed pulse.

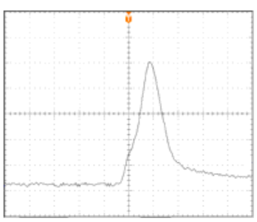
The dependence of pulse shapes on the distance between the two amplifiers L is presented in Fig.7 when the encounter time T is 2ns. And the rising time and pulse duration as a function of L are shown as dots in Fig.8, the theoretically calculated results are also presented as solid trace. We can see, as expected, that when L is short (less than 20cm) the leading edge is becoming shorter with the increasing of L, and when L is long enough, the leading edge is becoming longer and longer with the increasing of L. Theoretical curves match well with the experimental results.



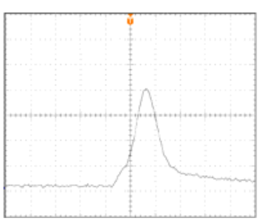
(a)



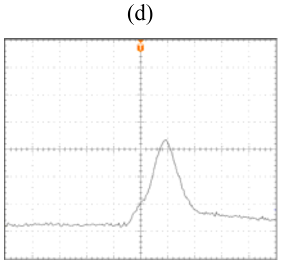
(b)



(c)

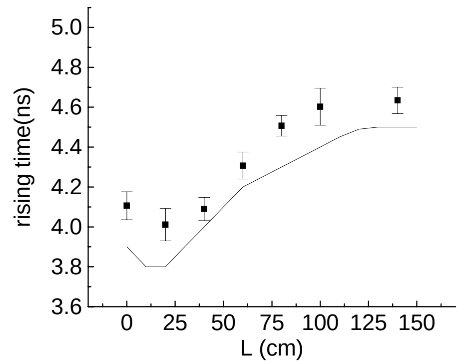


(d)

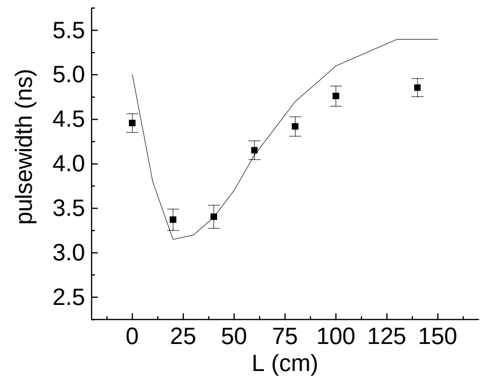


(e)

Fig.7. Dependence of pulse shapes on L. (a) L=0cm (b) L=20cm (c) L=40cm (d) L=80cm (e) L=100cm



(a)



(b)

Fig .8. a rising time vs. L (b) pulsewidth vs. L

4. Conclusion

In conclusion, a system of two Brillouin amplifiers is put forward to control Stokes pulse shapes. In this system, a main amplifier is used to coarsely control the pulse shape, and a reshaping amplifier is applied to finely control the pulse shape. Theoretical and experimental results show that the encounter time T coarsely determines the pulse shape, while the distance between the two amplifiers L is the most important parameter to finely control the pulse shape. Researches prove that this scheme of two Brillouin amplifiers is a simple way to finely control Stokes pulse shape, especially the leading edge of it.

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