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Investigation on high-power load ability of stimulated Brillouin scattering phase conjugating mirror

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Abstract The factors that affect the performance of stimulated Brillouin scattering phase conjugating mirror (SBS-PCM) in high-power condition are demonstrated. In high-power condition, the reflectivity is limited by both the SBS medium and the PCM configuration. FC-72 is found to be the best SBS liquid medium for its very high optical breakdown threshold and very low absorption coefficient by comparing several media. As FC-72 is chosen, the impurity of the liquid is the most remarkable factor which affects the reflectivity of PCM. The Millipore membrane filters with aperture of 0.22 μm was used to clean the liquid, and the reflectivity was evidently increased. Among the parameters of the SBS-PCM, the focal length of lens is one of the most important parameters related to the load ability. In the condition of the input laser of 1 J and 10 Hz, the appropriate focal length is proved to be 50 cm. As lens is chosen, the rotating wedge plate (RWP) is used to decrease the effects of optical breakdown and thermal effects in the condition of high power and stable reflectivity is achieved. Synthetically considering all the factors of medium and configuration, an energy reflectivity of 82% is achieved when the input energy is 0.94 J and the repetition rate is at 10 Hz.

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1 Introduction

To satisfy the need of IFE (Inertial Fusion Energy), the laser drivers have to work at high repetition rates, greater than 10 Hz [1]. But in the condition of high energy and high repetition rates, the thermal accumulation of optical amplifier would increase [2]; consequently the dynamic wavefront aberration would be induced consequently [3]. Besides, to realize high-energy and high-power output, large numbers of large-scale active media and optical components are used in the laser drivers [4]. However, the large-scale optical components, for instance, lens and mirrors have many aberrations caused by defects of polishing of the optical surfaces, and nonuniformities of the materials [5]. These dynamic and static wavefront aberrations affect the optical quality of the large-scale laser system directly and affect the performances of the drivers [6].

Stimulated Brillouin scattering phase conjugating mirror (SBS-PCM) has very high energy-conversion efficiency [7–10], which could compensate the wavefront distortions both at dynamic and static states [11]. This would improve the output beam quality and focus intensity [12–14] and evidently decrease the cost of the high-energy laser system [15, 16]. So SBS-PCM is significant to the IFE laser driver. However, SBS-PCM is limited in application for high-power lasers by other nonlinear effects, such as optical breakdown [17]. In addition, the energy reflectivity and wavefront distortion correction effect still cannot satisfy the need of IFE laser drivers. In this paper, the possibility of high-power loading of SBS-PCM is investigated by considering parameters such as the medium and lens, which are the most important factors to affecting the performance of SBS-PCM.

2 Experimental setup

Optical layout of researches on high-power load ability of SBS-PCM is shown in Fig. 1. The laser is a linearly polarized Q-switched Nd:YAG oscillator, with a single-frequency

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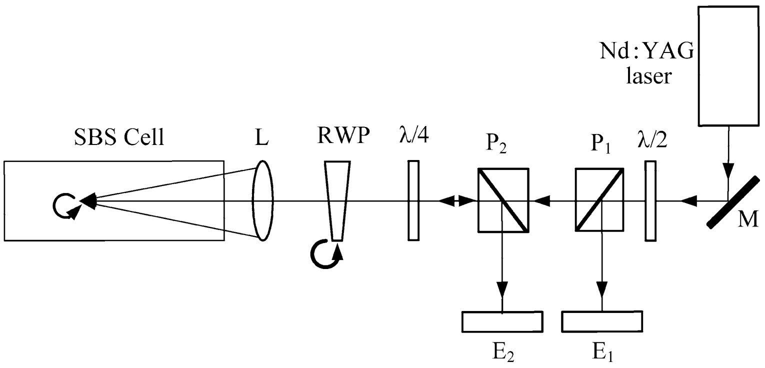

Fig. 1 Optical layout of research on high-power load ability of SBS-PCM

injected-seed and a TEM_{00} mode, the repetition rate is 10 Hz at pulse duration of 6 ns. The laser passes through a $\lambda/2$ waveplate and a polarizer P1 and is divided into two beams. One beam is reflected to energy meter E1 (PE50DIF-ER, Ophir) to measure the input energy, and the other beam passes through the polarizer P1, a $\lambda/4$ waveplate, and an RWP (Rotating Wedge Plate) and is injected into the SBS cell. The RWP injected inside the PCM is to rotate the focus point in the cell, which is used to decrease the possibility of optical breakdown and thermal accumulation at the focus points, which are induced by high repetition rates and high-power laser. Therefore, the RWP could improve the reflectivity and stability of PCM. The light through the RWP is focused by lens L to the SBS medium cell to produce SBS, and the Stokes beam turns back to P2. Because of transmitting twice through the $\lambda/4$ waveplate, the polarization condition of Stokes beam is rotated 90°. It is reflected to energy meter E2 (PE50DIF-ER, Ophir) by P2 to measure the energy of the Stokes pulse. By the ratio of E2 to E1, the SBS-PCM reflectivity and stability can be obtained. The energies incident into the SBS cell can be adjusted by the $\lambda/2$ waveplate and the polarizer P1.

3 Results and discussion

3.1 Research on SBS media

The medium is the crucial factor that affects the performance of SBS-PCM [18]. In order to obtain high reflectivity and fidelity, the choice of a suitable medium is very important. The gas media have to work at high pressure, and solid media are easily damaged [19]. In general, a liquid medium is a good choice for high-power SBS because of its large gain coefficient, low absorption and good stability [20].

The parameters that affect the reflectivity and fidelity of a liquid SBS medium at high energy and high power are optical breakdown threshold, gain coefficient, absorption coefficient, and so on. In this paper, to research the performance of SBS-PCM at high power, we select four kinds of media: acetone, CCl_4, FC-72, and HT-230. The different reflectivities at different input energy of these four media are shown in Fig. 2. The lens with 15-cm focal length is used in this experiment, and the laser system works at 10 Hz.

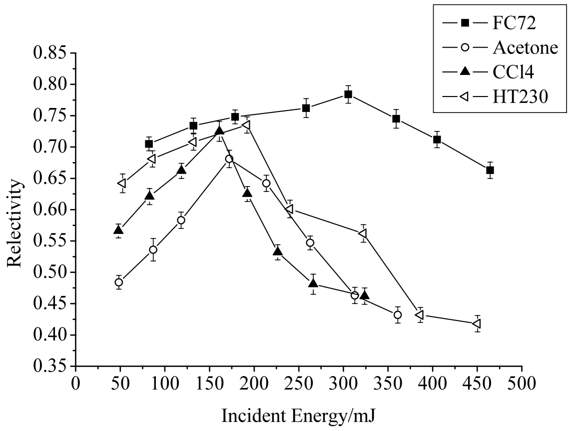

Fig. 2 Reflectivity of SBS-PCM with different materials

Figure 2 shows that acetone has the lowest reflectivity, only 48.4% at 50 mJ, and 43.2% at 350 mJ; this is because of its high absorption coefficient. So it is easy to get optical breakdown. The reflectivity of CCl_4 increases from 56% at 50 mJ to 71% at 150 mJ, but when the input energy is raised to 200 mJ, it gets optical breakdown which induces the decrease of reflectivity rapidly at high energy, and the reflectivity is only 46.2% at 350 mJ. HT-230 has high reflectivity at low energy, and close to FC-72, the reflectivity is 64.2% at 50 mJ and 73.5% at 200 mJ, but over 250 mJ, the reflectivity decreases rapidly and is only 43.2% at 350 mJ, so it is not the suitable medium for high-power SBS either. The reflectivity of FC-72 is obviously higher than for all the other media, the reflectivity is 70.5% at 100 mJ and up to 78.4% at 300 mJ. Furthermore, FC-72 has the highest breakdown energy; it does not breakdown until the input energy reaches 350 mJ. Because of the high breakdown threshold, the reflectivity is still high enough at high input energy, and the reflectivity is 66.3% at 450 mJ.

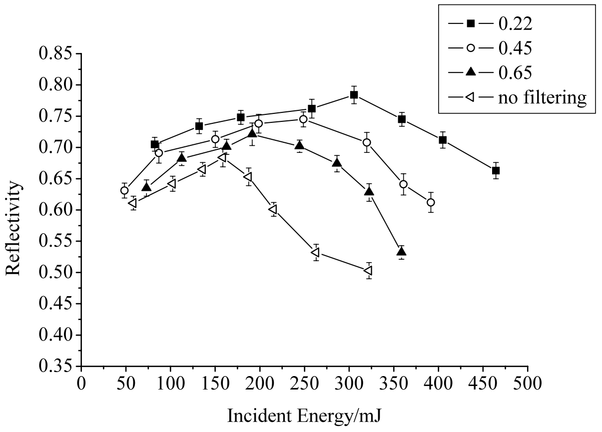

Fig. 3 Reflectivity of PCM system while FC-72 after different filtration

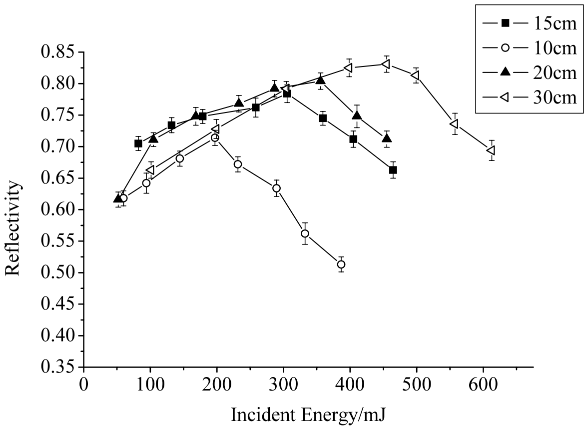

Fig. 4 Reflectivity of system with different focus length lens

This result shows that, because of low absorption coefficient, high breakdown energy, and large gain coefficient, FC-72 is a suitable medium for high-power SBS.

3.2 The load ability of SBS-PCM by the filtered medium

The interaction process between impurity particles in the medium and the laser beam is the primary factor which induces the temperature increase in local area in the medium. The optical breakdown threshold should be increased by filtering the medium. So the reflectivity and stability are improved obviously [21]. In this paper we use Millipore membrane filters with different apertures to filtrate the medium and the energy reflectivity of SBS-PCM in different filtrating conditions are investigated. The reflectivity of SBS-PCM in four different conditions (SBS medium FC-72 not filtrated, and filtered with aperture of 0.65 μm, 0.45 μm, and 0.22 μm, respectively) is shown in Fig. 3. The lens with 15-cm focal length is used in this experiment, and the laser system works at 10 Hz.

Figure 3 shows that filtration has nothing to do with the reflectivity at low energy, while it is totally different at high energy. Both the breakdown energy and the reflectivity are the lowest if the medium is not filtered. The breakdown is obvious at the energy of 160 mJ, and the reflectivity decreases rapidly with the increasing of energy. The reflectivity is only 50.3% at 300 mJ. However, the breakdown energy increases apparently after is medium filtrated with a filter aperture of 0.65 μm, 0.45 μm, and 0.22 μm. Thus the breakdown energy increases from 160 mJ to 220 mJ, 270 mJ, and 350 mJ, respectively. And consequently the reflectivity is up from 50.3% to 62.8%, 70.8% and 78.4% at 300 mJ consequently.

According to the results and the analysis, we can find that after filtration the reflectivity increases a little at low energy and increases rapidly at high energy, the breakdown energy enhances, and the breakdown reduces. This is because that the medium without filtration has some impurity particles in it, which would induce absorption from laser. This is the main reason for thermal problems. Big particles are usually accompanied by a long thermal relaxation time. Therefore, the temperature tends to increase quickly, and accordingly the optical ionization takes place easily. In contrast, small particles are accompanied by a short thermal relaxation time and thus lead to a small change in the temperature and little optical ionization. Therefore, high SBS reflectivity and stability are obtained.

3.3 The reflectivity of SBS with different focal length

The focal length is one of the most important factors that affect the performance of SBS-PCM. In order to research the affect of the focal length on the reflectivity of SBS-PCM, we observe the energy reflectivity of SBS-PCM with different focal lengths but other conditions remaining unchanged. The different reflectivity of SBS-PCM at different input energy with different focal lengths is shown in Fig. 4. In this experiment we used the filtrated FC-72 as medium, and laser system works at 10 Hz.

In this experiment, the lowest reflectivity occurred using a 10-cm focal length. The reflectivity increased from 61.8% at 50 mJ to 71.4% at 200 mJ, and then decreased rapidly to 51.3% at 400 mJ; the breakdown energy is 250 mJ. A better result was achieved using a 15-cm focal length. The reflectivity increased from 70.5% at 80 mJ to 78.4% at 300 mJ, and then decreased gradually to 66.3% at 450 mJ; the breakdown energy is 350 mJ. A much better result was achieved using a 20-cm focal length. The reflectivity increased from 61.6% at 50 mJ to 80.4% at 350 mJ, and then decreased rapidly to 71.2% at 450 mJ; the breakdown energy is 400 mJ. The best result was achieved using a 30-cm focal length. The reflectivity increased from 66.3% at 100 mJ to 83.1% at 450 mJ, and then decreased rapidly to 69.4% at 600 mJ; the breakdown energy is 500 mJ.

According to the results and analysis, it is certain that, after changing the focal length, the reflectivity does not change significantly when the input energy lower than 200 mJ. The reflectivity of a long focal length is higher than the short ones when the input energy higher than 350 mJ, and the results of the experiment are consistent with the theory. The size of the focus point is equal to $d = f \times \theta$, where f is the focal length, and θ is the divergence angle of the laser beam. The focal length is longer, so that we get the larger size of the focus point, the lower intensity at the focus point, and the higher breakdown energy. When the input energy is higher, the shorter focal length would induce serious optical breakdown, and the reflectivity would be decreased. It needs enough operating time and interaction length to produce and amplify the Stokes originated from the noise. Therefore, when the focal length is shorter, the SBS reflected light does not amplify enough, which would also induce the lower reflectivity. When the focal length is longer, which means the less optical breakdown, the backscattering Stokes light is amplified enough. The efficiency of converting energy is very high, and the reflectivity is also high since the input energy is transferred to the reflected light as much as possible. Of course, the longer focal length also has some disadvantages, because longer focal length would induce absorption, increase the length of the cell, and extend the scale of PCM. When the input energy is between 200 mJ to 600 mJ, the best choice of focal length is 30 cm. In the condition of higher input energy, longer focal length could improve the optical breakdown of the system, and enhance the energy reflectivity and stability of PCM.

4 The performance of SBS-PCM with high power

According to the above experimental results, it can be found that in high-power condition the reflectivity of SBS-PCM is directly affected by the medium and focal length. Among the medium parameters, the absorption coefficient and the optical breakdown threshold are the most important. Among the known media, FC-72 is the most suitable one to high-power SBS for its low absorption coefficient ($<10^{-5}$ cm^{-1}) and high optical breakdown intensity (>100 GW/cm^2). After ultra-filtration the optical breakdown threshold of the medium could be increased to twice the previous value. As the suitable medium is chosen, it is important for the designing of PCM configuration which includes the choice of focal length. To reduce the thermal fluctuation and optical breakdown which are induced by the absorption around the focus point, an RWP is introduced into the optical route. By this way the focus point could rotate according to the rotation of the RWP. It results in the reduction of thermal effect and improves the SBS reflectivity and stability. At the same time, according to the theory, simulation and experimental research, we find that the focal length of 30 cm is the most suitable for the input energy around 600 mJ, and the focal length of 50 cm is the most suitable for the input energy around 1 J. By choosing and cleaning the medium, and designing the RWP and choosing the right focal length, the high reflectivity of SBS-PCM with high power is obtained. The results are shown in Fig. 5. When the input energy is less than 0.94 J, the energy reflectivity increases as well as the energy increasing until it reaches 82%. When the input energy is close to 0.97 J, the reflectivity decreases rapidly with the obvious optical breakdown. Therefore in the condition that the input energy is close to 1 J, the repetition rate is 10 Hz, and the pulse duration is about 6 ns, a good result of high-power SBS-PCM is obtained.

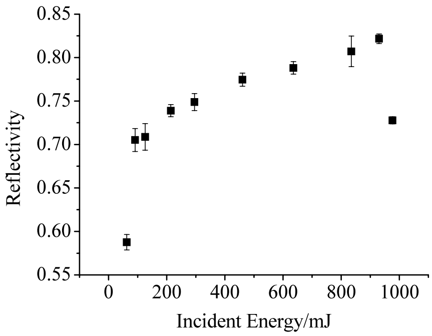

Fig. 5 SBS reflectivity of pump laser with high power

5 Conclusions

The experimental results of repetition rate of SBS-PCM show that FC-72 is suitable to work as the SBS medium in high-power condition. By using this medium the energy reflectivity of PCM could be stabilized above 70%, with high reflectivity and good stability. Cleaning the medium could increase the optical breakdown threshold, by using the membrane filters with aperture of 0.22 μm, the breakdown energy of SBS-PCM of FC-72 increases from 160 mJ to 350 mJ, and the reflectivity is about 78.4%. The optical breakdown energy of longer focal lengths is higher than the shorter ones; by using the focal length of 30 cm, the breakdown energy of SBS-PCM of FC-72 reaches 500 mJ, the reflectivity is about 80%; by using the RWP in the SBS-PCM, the reflectivity of PCM and stability are improved significantly. Considering the effects of the medium and the configuration to the high-power SBS-PCM, when the input beam is 0.94 J and 10 Hz the energy reflectivity of 82% is realized.

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