A new circulating two-cell structure for stimulated Brillouin scattering phase conjugation mirrors with 1-J load and 10-Hz repetition rate

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A new approach to realize high-energy and high-power stimulated Brillouin scattering phase conjugation mirrors (SBS-PCMs) is described. The reflectivity of SBS-PCM is investigated under a 10-Hz repetition rate and a high energy load. The relationship between reflectivity and input energy is examined experimentally with different PCM structures, focus lengths, and medium cell structures. A medium cell with a circulating structure is designed, and its advantage is demonstrated through an experimental comparison with traditional PCM structures. The 30-cm focus lens and 150-cm collimation lens are optimized when the input energy reaches 1010 mJ at 10-Hz repetition rate. Therefore, a reflectivity of 84.7% and a higher energy load using the circulating two-cell structure are achieved.

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Diode-pumped solid-state lasers (DPSSLs) have rapidly become a promising laser source in many applications because of their high average power. However, under high power and high repetition rate conditions, the thermal accumulation of the active medium increases[1−4], so dynamic wave front aberrations are induced[5]. These aberrations affect the optical quality of DPSSLs directly, as well as the performance of the lasers. Stimulated Brillouin scattering phase conjugating mirrors (SBS-PCMs) have very high energy conversion efficiency[6−8], which can compensate for the wave front distortions both at the dynamic and static states[9], as well as improve the output beam quality and focus intensity[10−12]. Therefore, they have become significant in high-power and high-energy DPSSLs. However, their applications in high power lasers are limited by other nonlinear effects, such as optical breakdown[13]. To date, SBS used in high-power and high-energy laser systems always works at a low repetition rate (<1 Hz)[14,15]. However, the high-power load capability of a SBS-PCM with a repetition rate of over 10 Hz is necessary in many applications[16]. Under this condition, the intensity of the input beam is always kept several decade or hundred times that of the SBS threshold, and optical breakdown easily takes place. In addition, the thermal effect in the SBS cell resulting from the absorption of a medium degrades the performance of PCM. In this letter, the possibility of high power loading of SBS-PCM is investigated by considering the parameters such as the medium and the lens, which are the most important factors affecting the performance of SBS-PCM. A method to realize SBS-PCM using liquid media that efficiently works at 10 Hz is utilized. The improvement and optimization of SBS-PCM are accomplished based on the traditional PCM. The circulating two-cell SBS-PCM is designed under the condition of 10-Hz repetition rate and 1-J input energy. High energy reflectivity and stability are achieved experimentally.

The optical layout of a circulating two-cell SBS-PCM is shown in Fig. 1. Thermal accumulation can be effectively removed and reduced in the focal area by ensuring that the medium flows steadily in a circulating cell. Consequently, the energy reflectivity and load capability are significantly enhanced. L_1 represented a long-focus lens for collimating and L_2 represented a short-focus lens in front of the SBS generator. Both the generator and the amplifier were filled with FC-72 (a heavy fluorocarbon liquid with low absorbtion coefficient, high breakdown threshold, and high gain); the lengths of the generator and amplifier were 30 and 45 cm, respectively. To observe the influence of the lens focus on energy reflection and to optimize the arrangement, the chosen focus lengths for L_2 were 7.5, 20, and 30 cm, while the chosen collimation lens lengths for L_1 were 75, 100, and 150 cm, respectively. The laser was a linearly polarized Q-switched Nd:YAG oscillator with a single frequency TEM_{00} mode injected seed and a repetition rate of 10 Hz at a pulse duration of 8 ns. The laser was divided into two beams by a $\lambda/2$ waveplate and a polarizer P_1. One beam was reflected to energy meter E_1 (PE50DIF-ER, Ophir, Israel) to measure the input energy; the other beam passed through polarizers P_1, P_2, and $\lambda/4$ waveplate, and was injected into the circulating two-cell SBS-PCM. The backward Stokes beam was reflected by P_2 after traveling through the $\lambda/4$ waveplate twice and was detected by E_2 (PE50DIF-ER, Ophir, Israel) to measure the energy of the Stokes pulse. The energies of the input beam and the Stokes beam were detected at the same time by E_1 and E_2. From the ratio of E_2 to E_1, SBS-PCM reflectivity and stability can be obtained.

Figure 2 shows the reflectivity of the comparison between the circulating structure and the regular structure. The nonlinear medium is FC-72 filtered with a 0.22-μm membrane. The focus length of the lens is 20 cm. Figure 2 demonstrates that a difference in significant reflectivity appears between the two structures when the input energy is higher than 300 mJ. The energy reflectivity of the

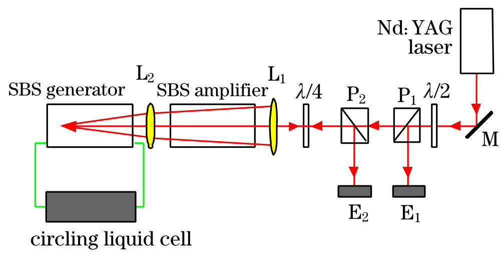

Fig. 1. Experimental setup of the circulating two-cell structure.

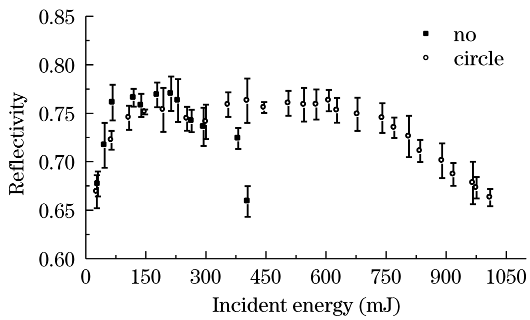

Fig. 2. Reflectivity of the circling and no circling SBS-PCM system.

circulating structure is within the range of 72.0%–74.3%. At 72.1%–77.3%, the energy reflectivity of the regular structure is almost the same as that of the circulating structure. However, when the input energy increases to 300 mJ, the reflectivity of the regular structure begins to decrease dramatically to 65.7% until the energy reaches 400 mJ. At the same time, the reflectivity of the circulating cell remains above 75% until it reaches 700 mJ. The reflectivity then begins to drop. When the input energy increases to 1 J, the reflectivity remains at 68.3%. Optical breakdown occurs in the regular cell when the input energy increases to 350 mJ, whereas it occurs in the circulating cell at 700 mJ.

The initial SBS threshold of the liquid is within the range of 0.1–13 GW/cm^2[17], and the optical breakdown threshold is less than 100 GW/cm^2[18]. The focus length of the lens is a direct factor that influences laser intensity in the focus area. When the intensity is approximately 2–4 times that of the SBS threshold, the fidelity of phase conjugation reaches its maximum value; however, the energy reflectivity is very low due to the low value of the SBS gain, i.e., $G = gIL$[19], where g is the Brillouin gain coefficient, I is the laser intensity, and L is the interaction length. The intensity of the input beam is kept several decade or hundred times that of the SBS threshold but not more than the optical breakdown threshold to obtain a high energy reflectivity. The energy reflectivity of the circulating SBS-PCM is investigated through different focal lengths, namely, 7.5, 20, and 30 cm (Fig. 3). Figure 3 indicates that the reflectivity grows as the focus length increases. The reflectivity of the 7.5-cm lens remains within the range of 65.8%–71.6% when the input energy increases from 50 to 870 mJ. The reflectivity of the 20-cm lens remains at approximately 75% when the input energy varies from 150 to 750 mJ. The reflectivity of the 30-cm lens remains within the range of 75.7%–78.1% when the input energy increases from 150 to 800 mJ. When the input energy is 1 J, the energy reflectivity of SBS-PCM with focal lengths of 7.5, 20, and 30 cm is 63.0%, 67.3%, and 70.4%, respectively. With the same input energy, the shorter lens length easily causes optical breakdown because of its higher intensity in the focus area, which results in a lower energy reflectivity. In contrast, a longer lens length cannot achieve high reflectivity because of its lower gIL gain. The experimental results indicate that the focal length exerts a significant influence on energy reflectivity in the circulating system and that the highest reflectivity can be achieved by a 30-cm-long lens.

According to the results, a circulating cell has the capability to bear a higher energy load as well as abate the thermal effect, whereas optical breakdown still occurs when the input energy is more than 700 mJ. Considering that a two-cell SBS-PCM can help improve high load performance, the energy reflectivity of a circulating two-cell system compared with a circulating single-cell system is investigated (Fig. 4). When the input energy is below 500 mJ, the reflectivity of the circulating two-cell system is approximately 7.3% more than that of the circulation single-cell system. However, when the input energy increases to more than 500 mJ, the reflectivity of the circulating single cell system decreases dramatically. On the other hand, the reflectivity of the circulating two-cell system appears superior. When the input energy is 1014 mJ, the reflectivity of the circulating single-cell system is 64.7%, and that of the circulating two-cell system is at 81.3%; the difference is 17%. The two-cell structure has a higher energy reflectivity in a circulating system because of its own physical characteristics.

To achieve a high energy load and a high energy reflectivity, the influence of collimation lens L_1, which is

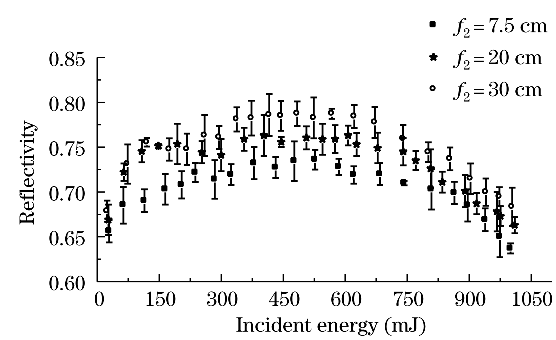

Fig. 3. Reflectivity of the system with different focus lengths of the lens.

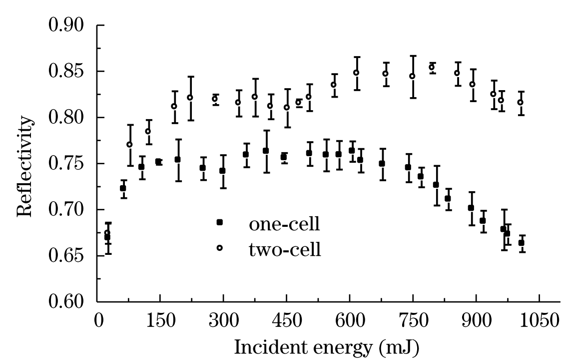

Fig. 4. Reflectivity of the circling system PCM in one-cell and two-cell structures.

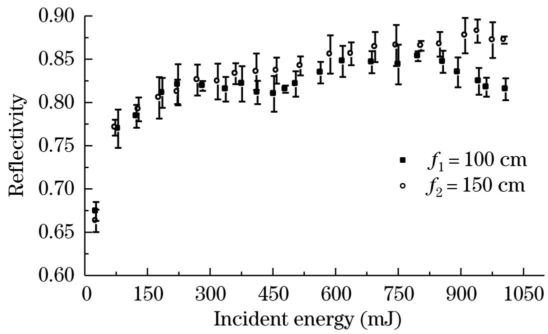

Fig. 5. Reflectivity of the two-cell circling system with different, longer length lenses.

located in front of the amplifier, should be interpreted. Figure 5 shows the performance of energy reflectivity in a 100-and 150-cm collimation lens. Figure 5 indicates that when the input energy varies from 100 to 850 mJ, the reflectivity of a two-cell circling SBS-PCM with a 150-cm lens is approximately 3% higher than that of a SBS-PCM with a 100-cm lens. When the input energy increases to more than 850 mJ, the reflectivity of SBS-PCM with a 100-cm lens begins to decrease because of obvious optical breakdown. Although the reflectivity of a 150-cm collimation lens increases along with input energy, its reflectivity remains at 84.7% even when the input energy is 1010 mJ.

A SBS-PCM with more than 1-J load, high reflectivity, and 10-Hz repetition rate is achieved through the method of a circulating two-cell system using the combination of a 30-cm focus lens and a 150-cm collimation lens. The curves of reflectivity show that the two-cell circling system is a promising method to attain a higher load.

In conclusion, a circulating two-cell structure has been designed. The two-cell structure comprises a regular amplifier and a circulating generator. Experimental results show that FC-72 is suitable to a high load system and that the circulating two-cell system performs better compared with the circulating single-cell and regular two-cell systems. The combination of the focus lengths is the main factor in the obtainment of a high energy reflectivity. In particular, a high reflectivity of 84.7% has been achieved through a circulating two-cell system that has the optimal combination of a 30-cm focus lens and a 150-cm collimation lens when the input energy is up to 1010 mJ at a 10-Hz repetition rate.

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References

1. S. Wang, H. J. Eichler, X. Wang, F. Kallmeyer, J. Ge, T. Riesbeck, and J. Chen, Appl. Phys. B **95,** 721 (2009).
2. S. Zhou, H. Zhao, and X. Tang, Chinese J. Lasers (in Chinese) **36,** 1605 (2009).
3. Y. Dong, Z. Zhao, C. Liu, and J. Chen, Chinese J. Lasers (in Chinese) **36,** 1759 (2009).
4. D. Jiang, W. Duan, X. Jian, X. Jiang, H. Yu, and M. Li, Chinese J. Lasers (in Chinese) **36,** 1831 (2009).
5. R. Zacharias, E. Bliss, M. Feldman, A. Grey, M. Henesian, J. Koch, J. Lawson, R. Sacks, T. Salmon, J. Toeppen, L. V. Atta, S. Winters, and B. Woods, Proc. SPIE **3492,** 678 (1999).
6. H. J. Kong, J. W. Yoon, D. H. Beak, S. K. Lee, and D. K. Lee, Laser Part. Beams **25,** 225 (2007).
7. W. L. J. Hasi, Z. W. Lu, S. Gong, S. J. Liu, Q. Li, and W. M. He, Appl. Opt. **47,** 1010 (2008).
8. Y. L. Wang, Z. W. Lu, S. Y. Wang, Z. X. Zheng, W. M. He, and D. Y. Lin, Laser Part. Beams **27,** 651 (2009).
9. S. Jackel, I. Moshe, and R. Lavi, Appl. Opt. **42,** 983 (2003).
10. M. S. Mangir and D. A. Rockwell, J. Opt. Soc. Am. B **10,** 1396 (1993).
11. T. Riesbeck, E. Risse, and H. J. Eichler, Appl. Phys. B **73,** 847 (2001).
12. P. Kappe, M. Ostermeyer, and R. Menzel, Appl. Phys. B **80,** 49 (2005).
13. Y. L. Wang, Z. W. Lu, Y. Li, P. Wu, Z. X. Zheng, and W. M. He, Appl. Phys. B **98,** 391 (2010).
14. V. Kmetik, H. Yoshida, H. Fujita, M. Nakatsuka, and T. Yamanaka, Proc. SPIE **3889,** 818 (2000).
15. Y. L. Wang, Z. W. Lu, W. M. He, Z. X. Zheng, and Y. H. Zhao, Laser Part. Beams **27,** 297 (2009).
16. M. Ostermeyer, H. J. Kong, V. I. Kovalev, R. G. Harrison, A. A. Fotiadi, P. Megret, M. Kalal, O. Slezak, J. W. Yoon, J. S. Shin, D. H. Beak, S. K. Lee, Z. Lu, S. Wang, D. Lin, J. C. Knight, N. E. Kotova, A. Straber, A. Scheikhobeid, T. Riesbeck, S. Meister, H. J. Eichler, Y. Wang, W. He, H. Yoshida, H. Fujita, M. Nakatsuka, T. Hatae, H. Park, C. Lim, T. Omatsu, K. Nawata, N. Shiba, O. L. Antipov, M. S. Kuznetsov, and N. G. Zakharov, Laser Part. Beams **26,** 297 (2008).
17. C. B. Dane, L. E. Zapata, and W. A. Neuman, IEEE J. Quantum Electron. **31,** 148 (1995).
18. H. Yoshida, V. Kmetik, and M. Nakatsuka, Appl. Opt. **36,** 3739 (1997).
19. J. Yang and S. Meng, Acta Opt. Sin. (in Chinese) **12,** 233 (1992).