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Incoherent and coherent beam combination for master oscillator/power amplifier system with stimulated Brillouin scattering mirror

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In this paper, we studied incoherent and coherent beam combining for the master oscillator/power amplifier (MOPA) system with stimulated Brillouin scattering (SBS) mirror. Optic field intensity distributions in the near and far field are numerically calculated for the two kinds of system. The results show that good beam quality in the far field could be obtained. It provides a theoretical basis for experimental research in the future.

Keywords: combination of incoherent and coherent beams, master oscillator/power amplifier, stimulated Brillouin scattering

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1. Introduction

Multi-kW output power from a solid laser system has been attained by using a master oscillator/power amplifier (MOPA) with multi-rod cavity arrangement.[1,2] It is necessary to increase the number of rods to achieve higher power. However, the arrangement of large number of rods has many problems, such as beam deterioration due to accumulated thermal distortion in laser crystals, severe alignment in the long chain of amplifiers, large output power saturation. Therefore, the laser output power is limited and the beam quality is also poor for high laser power. To obtain higher output power, parallel laser arrangement or serial/parallel laser arrangement is developed, but the beam quality is also poor. The beam distortions are generated by thermally induced lensing and stress birefringence in the active material. Using phase-conjugating stimulated Brillouin scattering (SBS) mirrors, the phase distortions can be perfectly compensated and the beam quality can be improved to the theoretical diffraction limit. Numerous reports have described the benefits of MOPA systems with SBS-mirror.[3−9] In order to obtain high power and high beam quality laser, we have designed two kinds of MOPA systems with SBS mirrors. One is coherent-beam combination and the other is incoherent-beam combination. Their optic field distributions for the output laser were calculated numerically.

2. Incoherent-beam combination for MOPA with SBS mirror

At present, a polarizer is often adopted for incoherent combination based on MOPA.[10−13] Two laser beams with perpendicular polarization directions are coupled into a polarizer. One beam passes through the polarizer and the other reflects by the polarizer. Both beams can be combined into one incoherent beam. To obtain high beam quality, each beam should be high beam quality and in the same direction. The reported average output power for incoherent-combined MOPA system with SBS mirror could be up to 500W and the beam quality was about 5 times the diffraction limitation.

It is difficult to improve the output power for incoherent combination by a polarizer, since only two-beam combination could be realized. In order to increase the number of the laser beams for combination, we design a multi-laser-beam combination by multi-surface reflected prism based on MOPA with SBS mirrors. There can be many surfaces for a prism, and each laser beam is reflected by a surface. Therefore, three,

four, five, or more laser beams could be combined together into one. The output power obtained could be more than 1 kW. However, the polarization direction of the beams should be at the same angle with respect to each other to avoid interference.

As an example, Fig.1 shows the design of four-beam-combined MOPA system with phase conjugate mirrors (PCMs). The MOPA system consists of an oscillator, eight amplifiers and four PCMs. The beam from the master oscillator is divided into four parts and each of them is coupled in a serial arrangement with two amplifier rods. After one laser beam passes through each double-amplifier rod two times, the phase distortions could be compensated by the reflection of the PCM. The laser profile from the oscillator could be reproduced at the four-surface prism. The four laser beams are reflected by the prism and combined into one beam with high power in the far field. In order to avoid coherence of the four beams, the polarization directions of the beams should be 45° angle with respect to each other. It could be realized by Faraday rotators.

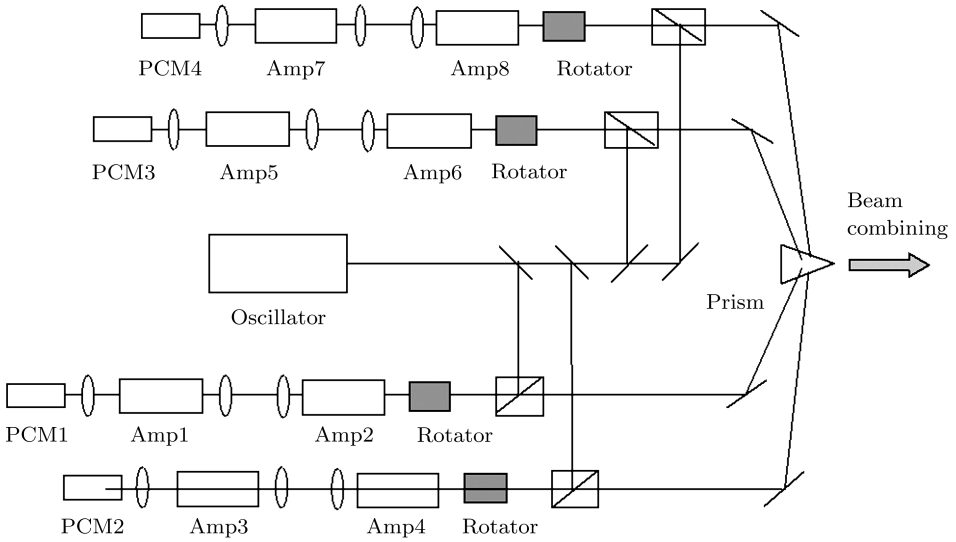


Fig.1. Schematic of experimental setup of MOPA system with a four-surface prism.

Numerical calculation of laser output intensity distribution is made for this kind of laser construction. Assume that the laser from the oscillator is a Gaussian beam and the PCM could compensate all kinds of distortions induced by the amplifier rods, the beam profile in front of the prism should be the same as that from the oscillator. The laser intensity distribution in the near field reflected from the prism can be expressed as

$$E(x,y)=\sum_{i=1}^{4}E_{0i}\mathrm{e}^{-\left[\frac{(x-x_{0i})^2+(y-y_{0i})^2}{\omega^2}\right]}\mathrm{e}^{\mathrm{i}\phi_i}, \qquad (1)$$

where ω_x is the Gaussian beam waist, E_0 is the amplitude of the beam, x_{0i} and y_{0i} are the central coordinates of the ith beam, ϕ_i is the phase of the ith beam. The near-field distribution described in Eq.(1) is plotted in Fig.2. It includes four independent beams. These four beams are incoherently combined into one beam in the far field. Its field distribution is shown in Fig.3; it is nearly a Gauss profile. The result shows that high beam quality can be obtained by multi-beam laser incoherent combination using a multi-surface prism. This may be a direction for developing high power and high beam quality lasers.

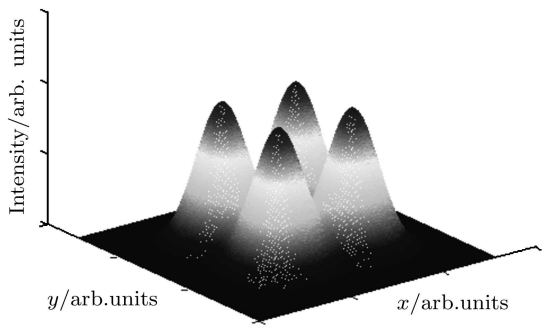


Fig.2. Optic field intensity distribution in the near field for incoherent four-beam combination.

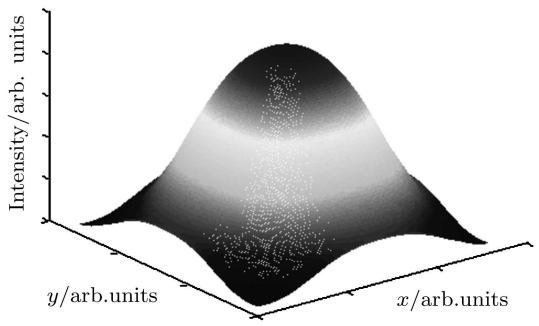


Fig.3. Optic field intensity distribution in the far field for incoherent four-beam combination.

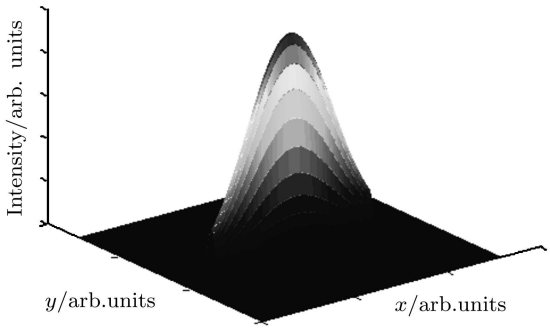


Fig.5. Output laser intensity from the main oscillator.

3. Coherent beam combination for MOPA with SBS mirrors

Coherent beam combination allows laser energy scaling beyond traditional limits imposed by the maximum available volume of a single active medium. It is a good method to obtain high power and high beam quality lasers.[14−16] In this section, we make a numerical calculation for coherent coupling based on MOPA with SBS mirrors. The block diagram of the laser is shown in Fig.4. Slab construction is adopted for the main oscillated laser. The laser output is assumed to be elliptical Gaussian beam

$$E(x,y) = E_0\mathrm{rect}(x-w) \times\mathrm{rect}(y-h)\mathrm{e}^{-\frac{x^2}{\omega_x^2}}\mathrm{e}^{-\frac{y^2}{\omega_y^2}}\mathrm{e}^{\mathrm{i}\phi}, \quad (2)$$

where rect represents rectangle function, the beam width is w and the beam height is h, ω_x and ω_y are the Gaussian beam waist in x and y directions, and ϕ is the phase. The near-field distribution described by Eq.(1) is plotted in Fig.5. The beam is reflected by a polarizer and divided into four parts by four zigzag reflectors,

$$E_i(x,y) = E_0\mathrm{rect}(x-w_i) \times\mathrm{rect}(y-h)\mathrm{e}^{-\frac{x^2}{\omega_x^2}}\mathrm{e}^{-\frac{y^2}{\omega_y^2}}\mathrm{e}^{i\phi}, \quad i=1,2,3,4 \quad (3)$$

where w_i is the width of the ith beam. Each of the beams passes through a Faraday rotator and an amplifier. Following the amplifiers, the four beams are aligned parallel and focused into the same region of a phase-conjugate mirror. The phase-conjugated beams through the SBS process retrace their respective paths through the amplifiers, where they are amplified a second time. Following a second pass through the Faraday rotators, the beams are now horizontally polarized and pass through the thin –film polarizer with no loss. According to the scalar diffraction theory, the light propagation is the diffraction of electromagnetic wave in space. The electric field in a plane at $z =$ const is given by

$$E(x,y,z) = \Re^{-1}\left\{\Re\{E_0(x_0,y_0)\} \times\exp\left[\mathrm{i}kz\sqrt{1-(\lambda f_x)^2-(\lambda f_y)^2}\right]\right\}, \quad (4)$$

where $\Re$ and $\Re^{-1}$ are the Fourier transform and the inverse Fourier transform; k is wave number, and λ is the light wavelength; f_x and f_y are the spatial frequencies. The optic field intensity distribution in the near field for the four returned beams is shown in Fig.6. It can be seen that the returned beam is different from the input beam and consists of four parts. The far field intensity distribution is shown in Fig.7. Because

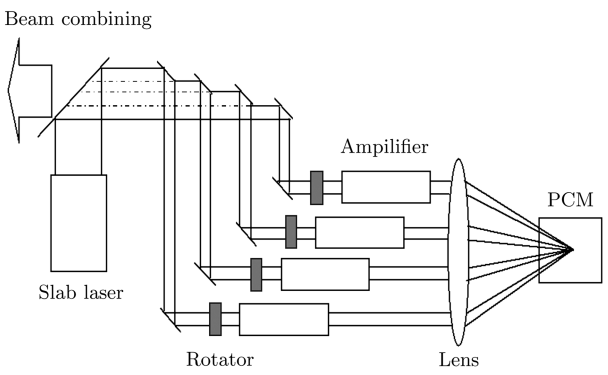


Fig.4. Schematic of the setup of coherent beam combination system with PCM.

of the coherence in the four returned beams, interference effects occur and produce a main peak in the centre and several small side peaks beside the main peak. The relative intensity is thus increased in the main and side peaks with the increase of laser transverse distance. This result shows that a good beam quality can be obtained according to the design in Fig.4. Sumida *et al*[17] performed an experiment similar to that in Fig.4. The experimental results indicate that the optic field intensity distribution in the far field is consistent with Fig.7.

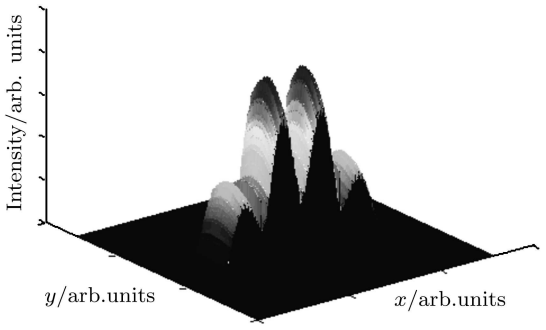


Fig.6. Optic field intensity distribution in the near field for coherent beam combining.

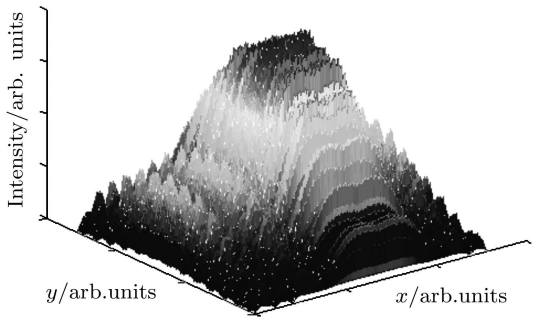


Fig.7. Optic field intensity distribution in the far field for coherent beam combining.

Up to now, efficient and safe SBS media have been developed for the high-power laser system.[18−20] The laser intensity in a SBS medium is especially high for coherent beam combination system. Fluorocarbons have the advantages of excellent optical quality, low absorption in a wide spectral region from ultraviolet to infrared, high optical breakdown threshold, good thermodynamic properties, and desirable chemical stability.[21] It is suitable to use them in this kind of system.

4. Conclusion

Numerical calculations have been made for two kinds of MOPA system with SBS mirrors (i.e. incoherent and coherent beam combination systems). Multi-surface reflected prism is used for incoherent system, so that multiple independent beams could be combined into one beam in the far field. Compared with the reported beam combination method with a polarizer, the incoherently combining by using a multi-surface reflecting prism could increase the output power greatly. Optic field intensity distributions in the near and far fields are numerically calculated for the incoherent beam combining system, and the results show that good beam quality in the far field could be obtained. We also made a numerical calculation for a four-beam coherently combining system, which consists of a slab oscillator, four amplifiers and a SBS mirror. The ideal elliptical Gaussian beam from the oscillator is divided into four parts, each of them is reflected by the PCM and amplified twice, and the phases of the four returned laser beams could be locked in the far field. The laser intensity distributions in the near and far fields are calculated, showing that satisfactory beam quality in the far field could be obtained. Therefore, the incoherent beam combination system with multi-surface reflecting prism and coherent beam combination system based on MOPA with SBS mirrors could be the direction for obtaining high power and high beam quality for solid lasers.

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