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Far-field detection system for laser beam and crystal alignment

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Abstract. Laser beam far-field alignment as well as frequency-doubling and frequency-tripling crystal adjustment is very important for high-power laser facility. Separate systems for beam and crystal alignment are generally used while the proposed approach by off-axial grating sampling share common optics for these two functions, reducing both space and cost requirements. This detection system has been demonstrated on the National Laser Facility of Israel. The experimental results indicate that the average far-field alignment error is <5% of the spatial filter pinhole diameter, average autocollimation angle error of crystals is <10 μrad, and average frequency-tripling conversion efficiency is 69.3%, which meet the alignment system requirements on the beam direction and crystals. [DOI: 10.1117/1.OE.55.3.036108]

Keywords: laser technique; far-field beam alignment; crystal alignment; grating; frequency conversion.

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1 Introduction

Inertial confinement fusion facility is the largest and most complex high power laser.[1–3] With the development of laser fusion facilities, beam diameter, paths, and components increase greatly. Therefore, the space for laser beam and crystal alignment is limited.[4–9] General beam and crystal alignment systems cannot meet the space requirements anymore. A new far-field detection system for laser beams is designed to use the space flexibly and effectively.[10] This paper mainly discusses the far-field detection system. Separate systems for beam and crystal alignment are frequently used, whereas the proposed arrangement combines these two functions into a single system, saving cost and space.

2 New Far-Field Detection System

Far-field beam direction takes an important role in high power laser facility. Mechanical frame distortion, temperature changes, and output light excursion from the master oscillator all can cause the beams to deviate. Thus, it is necessary to adjust the beam direction.[11]

A general far-field detection system is usually coaxial with the main laser beam. In order to not affect the main beam, the general detection system is often placed behind a spatial filter. A charge-coupled device (CCD) detects laser signals using a lens as Fig. 1 shows. The solid and black dot denotes the stepper motor that drives the movement of the mirror IM2 to change the main laser beam's direction.

Owing to the space limitation, a new far-field detection system as Fig. 2 shows is proposed. The new far-field detection system is based on a diffraction grating. A CCD detects the diffracted laser light at the far-field position. Therefore, laser beam diameter is small, which can save space for the laser facility.

In Fig. 2, the black dotted rectangle box denotes the spatial filter. The mirror IM2 is mounted with two stepper motors. The mirror IM2 is used for adjusting the laser beam's direction. A light-emitting diode (LED), grating, shutter, attenuator, and CCD make up the optical image system to image the grating marks.

The adjustment process of the new far-field detection system is as follows:

1. The inserted grating should be aligned to the reference position of far-field, namely the central position of a pinhole in the spatial filter. First, the inserted transmission grating is placed behind the pinhole closely and a concave lens is inserted into beam path before the pinhole, as shown in Fig. 2. The main laser passes through the concave lens and illuminates the whole pinhole. Then, the LED is opened to illuminate the inserted grating. Thus, pinhole outline and alignment features on the grating are both imaged to the CCD. Finally, the pinhole can be made to overlap alignment features on the grating by moving the grating laterally.
2. The central position of the focused laser light should be found. First, the concave lens is moved out. The main laser beam, as the arrowed line shown in Fig. 2, enters into the spatial filter. Further, the focused laser light passes through the pinhole and the grating. Then, the image of the focal spot is captured by the CCD through the first order of the grating diffracted light. Finally, a computer calculates the position error between the focal spot and the alignment features on the grating using an image-processing algorithm.

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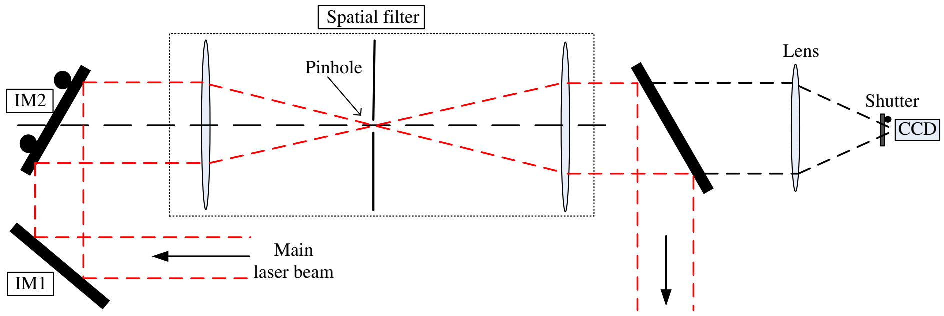

Fig. 1 General far-field detection system.

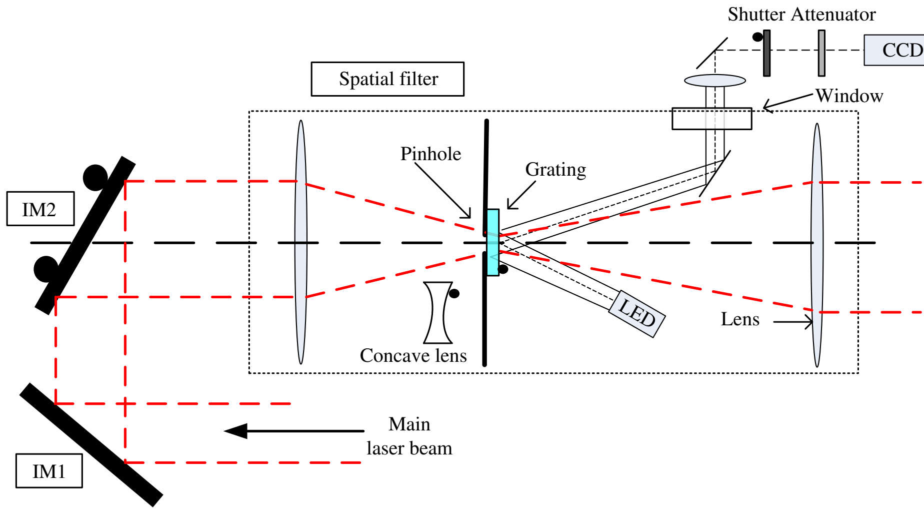

Fig. 2 New far-field detection system.

3. The laser beam's direction should be aligned. Adjusting mirror IM2 until the position error is minimized (1 pixel). Then, the focused laser light is made to overlap the alignment features on the grating. Thus, far-field beam direction alignment is complete.

The new far-field detection system occupies small space in the spatial filter using off-axial grating sampling. It can use the stereoscopic space in the spatial filter and is flexible.[12]

3 Alignment System of Crystals

Harmonic conversion is an important process for high power laser facility. It influences the output and character of the facility directly. The angle adjustment of frequency conversion crystals affects the frequency conversion efficiency greatly. Careful alignment of the crystals before firing the laser results in higher-frequency conversion efficiency.[13] Crystals include a frequency-doubling crystal and a frequency-tripling crystal.

3.1 *General Alignment System of Crystals*

A general alignment system of crystals is shown in Fig. 3. A far-field lens and a CCD make up the optical image system. A frequency-doubling crystal and a frequency-tripling crystal have two stepper motors to adjust the crystals. For the general alignment system, the reference position is a necessary factor. First, a corner cube reflector is inserted into beam path before the crystals, which can make the laser beam go backward. Then, the CCD detects the position of the laser beam, namely the reference position. Next, the corner cube reflector is moved out the beam path. The laser light reflected by the crystals can pass through leaking mirror IM4, and the CCD detects it using the far-field lens. The two crystals are adjusted by the stepper motors until the laser beam is overlapped with the reference position.

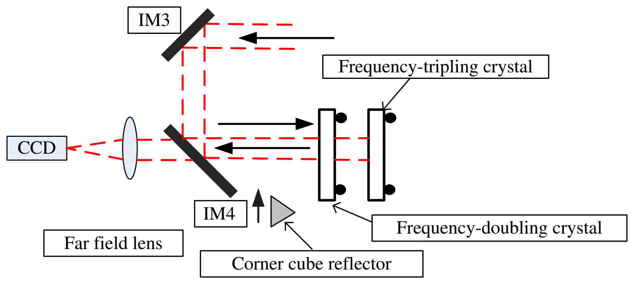

Fig. 3 General alignment system of crystals.

The general alignment system of crystals is large in volume because the beam diameter of crystals must be big, which demands large space and cost much expense. A new alignment system of the crystals is proposed to avoid these disadvantages. Moreover, the new alignment system of crystals can share its optical image systems and CCD cameras with the new far-field detection system presented in Sec. 2.

3.2 *New Alignment System of Crystals*

The new alignment system of crystals is shown in Fig. 4. In this figure, it is clearly shown that this system is based on a diffraction grating in the spatial filter and has the same optical image system as the new far-field detection system presented in Sec. 2. It means that this system can align the direction of high power laser facility beams as well as autocollimation angle of frequency-doubling and frequency-tripling crystals.

The grating is interrupted to form five circular, groove-free features, which are used for alignment. Figure 5 shows the grating with five circular, groove-free zones. The size of the grating is 37 mm × 37 mm, the diameter of four circular, groove-free zones in the middle of the grating is 0.9 mm, and the diameter of the bigger circular, groove-free zone is 1.0 mm. The grating etching stripes are perpendicular to the line AB, which is between the bigger circle's center (point B) and the center of four circular zones (point A). For the incident laser, which is perpendicular to the grating, the plane with the laser light and the diffraction light should be parallel to the line AB. The four circular zones with same size are designed for aligning. Under the small energy laser circumstances, the grating is moved to make the center of four circular zones coincident with the pinhole. And the bigger one groove-free circle is designed to protect the CCD camera. When the energy of the reflected laser light from crystals is too small to be captured by CCD camera, the incident laser energy should be increased during adjusting process. However, once the energy of the incident laser is up to damage threshold of the CCD camera, the CCD camera cannot work anymore. So the bigger circle is designed to make bigger energy incident laser light pass through it instead of the etched zones on the grating. In this case, the bigger circle on the grating is moved to be coincident with the pinhole before opening the bigger energy laser. The focal length of the output lens located in the spatial filter, as Fig. 4 shows, is 10 m. In order to meet the imaging requirement, a high-resolution CCD camera should be used. The size of the CCD effective photosensitive area is 15 mm × 15 mm. The resolution is 2048 (pixel) × 2048 (pixel), so the size of a pixel is 7.4 μm × 7.4 μm.

The alignment process of crystals is as follows:

1. The transmission grating is placed behind the pinhole closely, as shown in Fig. 4. The center of the pinhole should be consistent with the grating.

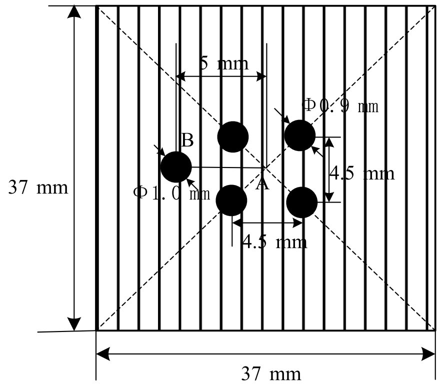

Fig. 5 Grating with five circular, groove-free zones.

2. A fiber laser with a coupling lens which is coaxial with main beam path is opened, as the arrowed line shown in Fig. 4. The focused laser light passes through the pinhole, the grating, and the spatial filter output lens. Then, the focused laser light illuminates the crystals. At last, the laser spot is reflected back by the crystals and imaged to the CCD.
3. The LED is opened, and the noncoherent light from the LED illuminates the grating. The first-order diffracted light provides the alignment features on the grating by the same CCD.
4. Looking at the CCD image, one can actuate stepper motors to move crystals until focused laser light is reflected back onto special alignment features built into the grating. Hence, the alignment of crystals autocollimation is complete.

The new alignment system of crystals occupies smaller space than a general alignment system of crystals, and it has other merits, such as simple devices, easy adjustment, and high precision. The most important fact is that it can share the common optics with the new far-field detection system of laser beams; thus space is saved and operating costs are reduced.

4 Experiments and Results

The new far-field detection system of laser beams with a diffraction grating, a set of optical imaging components, and a high-resolution CCD camera was demonstrated on the

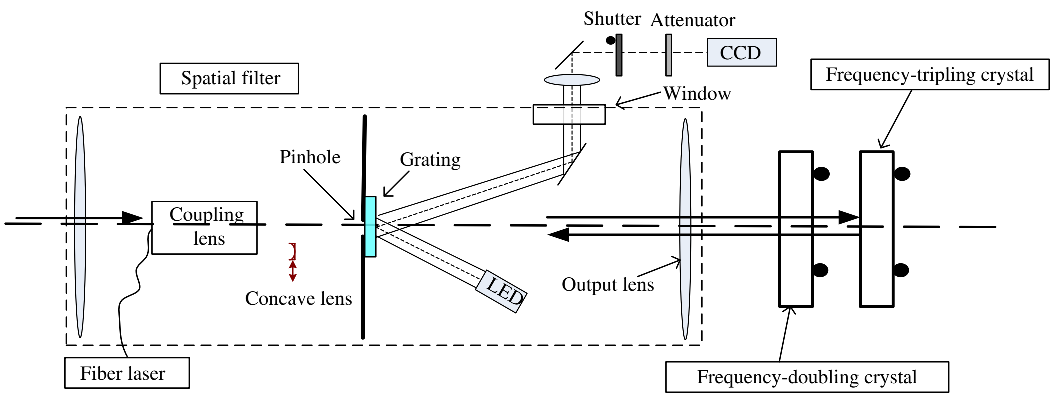

Fig. 4 New alignment system of crystals.

National Laser Facility of Israel. The experimental results show that the detection system can align the direction of high power laser facility beams as well as frequency-doubling and frequency-tripling crystals. The experimental results indicate that the average far-field alignment error is <5% of the spatial filter pinhole diameter, average autocollimation angle error of crystal is <10 μrad, and average conversion efficiency of frequency-tripling is 69.3%, which meet the alignment system requirements on the beam direction and crystals.

The figures below show the results of the alignment for the frequency-doubling crystal and frequency-tripling crystal, respectively. In Figs. 6(a) and 7(a), the black circle denotes the focused laser light reflected by the frequency-doubling crystal and frequency-tripling crystal, respectively. Before alignment, the focused laser light reflected by the frequency-doubling and frequency-tripling crystals is not overlapped with the focal spot of the main laser beam. However, the focused laser light reflected by the frequency-doubling and frequency-tripling crystals is overlapped with the focal spot of the main laser after alignment. These results show that the new far-field detection system can align the frequency-doubling and frequency-tripling crystals well.

During the experiments on the National Laser Facility of Israel, 12 shots with 1 ns high-energy were shot on the new far-field detection system. The results are shown in Fig. 8. E1w expresses the 1w at 1053 nm laser energy, E3w expresses the 3w at 351 nm laser energy, and η-3w expresses the frequency-tripling conversion efficiency. After adjusting the frequency-tripling crystal, the average conversion efficiency is 69.3%. However, more high-energy laser shots and more time are needed for finding the crystal angle with maximum conversion in general crystals alignment system. The lowest frequency-tripling conversion efficiency is 67% as Fig. 8 shows in the new alignment system of crystals. And average frequency-tripling conversion efficiency is 69.3%. These results indicate that unnecessary high-energy

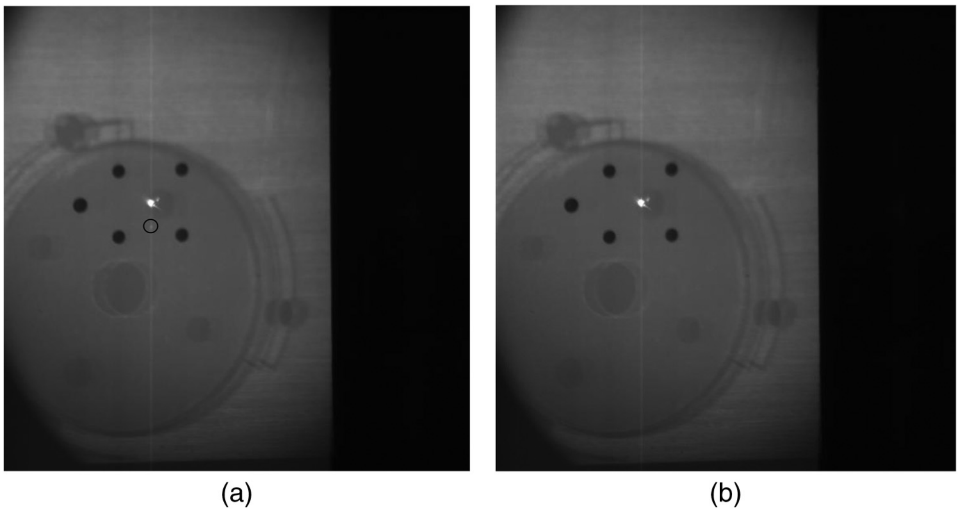

Fig. 6 Alignment images of the frequency-doubling crystal with the opened LED (a) before alignment and (b) after alignment.

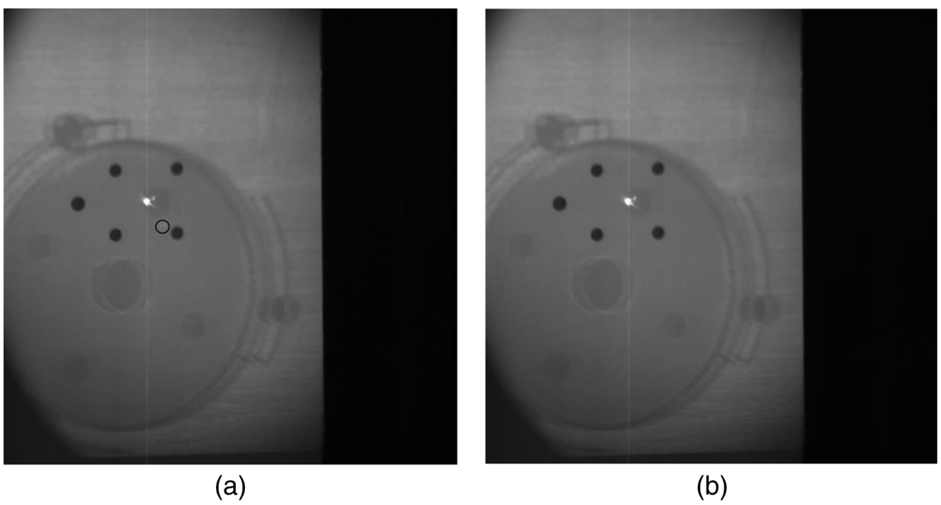

Fig. 7 Alignment images of the frequency-tripling crystal with the opened LED (a) before alignment and (b) after alignment.

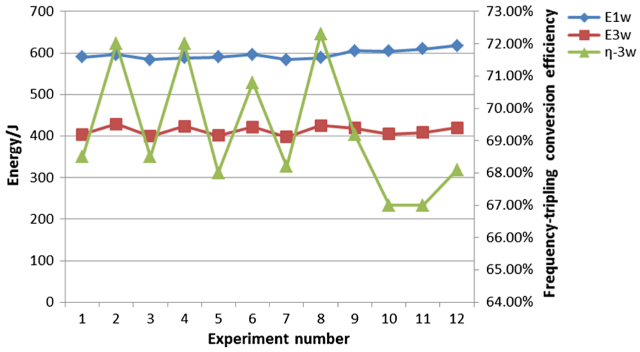

Fig. 8 Experiment results of the frequency-tripling conversion.

laser shots and time to find the crystal angle for maximum conversion are no longer wasted anymore, greatly saving cost and time.

5 Conclusions

Considering separate systems for beam and crystal alignment occupying large space, the paper proposes a new far-field detection system. The new far-field detection system not only can align the beam direction but also can adjust frequency-doubling and frequency-tripling crystals. It has been already demonstrated on the National Laser Facility of Israel.

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