

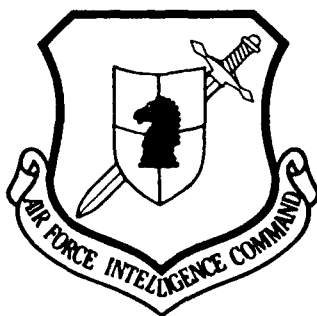
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by

Guo Zhenhua, Xia Zhizhong, et al.



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ALIGNMENT FOCUSING SYSTEM FOR HIGH-POWER LASER BEAM

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Abstract

To produce the high-power density of 10,000 watt class CO₂ laser beams for research on the interaction between high-power lasers and matter as well as far-field experiments, a high-power laser alignment focusing system was developed based on infrared materials available in China. The system has been operated to improve the properties of high-power lasers. These experiments are open to visiting scholars from elsewhere.

I. General Description

In China, the continuous wave high-power CO₂ laser devices have reached a 10,000 W power level. This technology level creates new conditions for industrial processing, synthesis of new materials, medical applications, atmospheric transmission of high-power lasers, mechanism of destroying battlefield targets, and outdoor far-field experiments, among other areas. Multiple aspects of military and civilian research [1-5] on high-power CO₂ laser applications are currently underway in the United States, Soviet Union, United Kingdom, Germany and Japan. Currently available 10,000 W class laser devices in China have a large angle of divergence at high-power output, are relatively poor in light beam quality, and serious thermal focusing effect at the output window. These shortcomings lead to major restraints on the applications of high-power laser devices. These shortcomings are not easy to overcome because there are great dangers in

handling high-power laser beams; moreover, reference data are in short supply. In addition, there are relatively unique requirements with quite a few unsolved problems in selecting the optical materials as well as processing and manufacturing. Thus, after many years of adjustment and research by the authors, a continuous wave high-power CO₂ laser space wave filtration--alignment--focusing system (Fig. 1) was developed by using materials available in China. In field conditions, a continuous-wave CO₂ laser beam of several thousand watts was transmitted over a distance greater than 100 meters.

II. Space Filtration Wave--Alignment--Focusing System

In the general situation, alignment of Gauss type laser beam utilizes the optical system to compress the divergence angle. By using a short focal length positive lens, the laser beam is focused into a light spot as small as possible. Next, a long focal length positive lens is used to couple the focusing plane and light spot; thus, a better alignment effect can be attained for the image. This is the so-called inverted telescope system; the alignment power M' is

$$M' = \frac{F_2}{F_1} \sqrt{1 + \left(\frac{\lambda l}{\pi w_0^2} \right)^2}$$

In the equation, F_2 and F_1 are, respectively, the focal distance of principal lens and auxiliary lens; l is the distance from the waist of the light beam to the auxiliary lens; w_0 is the dimension of beam waist. It is apparent that desirable and undesirable laser beam alignment is related not only to the structure of the optical system, but also to laser beam parameters. For a stable chamber 10,000 W class continuous wave CO₂ laser device, the laser beam waist w_0 is approximately 3 cm; generally, l is approximately 5 m. Thus, it can be estimated that the term $\left(\frac{\lambda l}{\pi w_0^2} \right)^2$ in Equation (1) is approximately 2.25×10^{-4} . Therefore, this term can be neglected. It is sufficient only by using the geometric compression ratio

$M = F_2/F_1$ to compute the alignment power. For a high-power unstable chamber laser device, generally the output light beam is a spherical surface wave. Therefore, the alignment power of the inverted telescope can be directly expressed in terms of M .

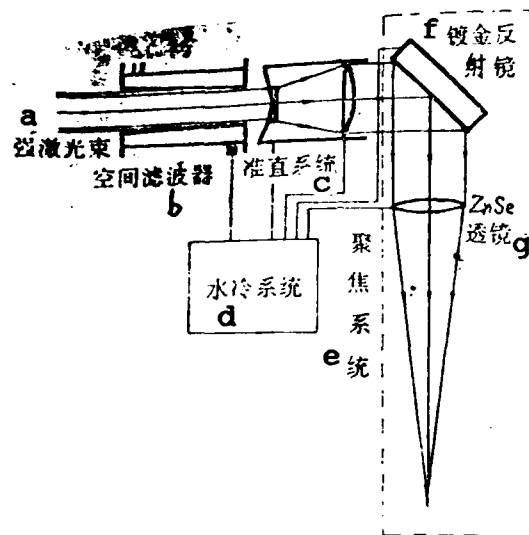


Fig. 1. Schematic diagram for a space system of wave filtration--alignment--focusing

KEY: a - high-power laser beam b - space filter c - alignment system d - water cooling system e - focusing system
f - gold-coated reflective mirror
g - ZnSe lens

Now the primary contradiction is that there is major difference in handling a continuous-wave high-power laser beam and in handling a low-power laser beam. First, when a space laser device is used to optimize light beam quality or to select a mode, the filtered power of the laser margin does not allow it to scatter in many directions in space as in the case of a low power laser because the very high scattered power will cause damage to environment and personnel. Therefore, these stray light beams should be collected. Secondly, the excess laser

energy collected will cause a temperature rise of the device with denaturation. Therefore it is necessary to remove such energy. Thirdly, in optimizing the light beam, the irreversible nonlinear effect should be avoided as much as possible because such effect will lead to damage function that drastically use up power. In the following, the authors discuss the solving of these problems of contradiction and in presenting results thus obtained.

1. Space filter

With the multimode output of CO₂ lasers, some high-order modes can be eliminated and light beam quality can be enhanced by using the method of space wave filtration. When the laser device generates annular light spots by using an unstable cavity, the filter can remove the irregular pattern at the ring periphery; moreover, the divergence angle of the light beam can be kept within a certain range. Thus, the output light beam from the filter can be closely coupled with the alignment system.

The filter structure is shown in Fig. 1 in a schematic diagram. Since a high-power laser beam is being handled, safety is the primary concern. It should be ensured that the largest light spots should enter the filter in its entirety. Therefore, the light entrance aperture is selected as 50 mm; in addition, a black backplate is attached to absorb the diffracted light. The aperture of light exit from the filter is 40 mm, such that optimal coupling can be realized with the light entrance of the alignment system. Based on the requirements of heat dissipation, the heat energy converted from the laser, which is absorbed by the filter, is carried away by a rapid stream of cold water. The filter material can be graphite or cast iron. For convenience in machining, steel can also be used.

2. Alignment system

The alignment of a high-power laser is really a dangerous and difficult task. The approach of re-expanding the beam after

focusing with the lens must not be used; otherwise, serious nonlinear effects will result. Even worse, an air puncture may occur in the focus region. The authors selected a coupling method (Fig. 1) based on a concavoconvex lens. The virtual focus of the auxiliary lens overlaps with the focus of the principal lens; this is a deformed inverted telescope system.

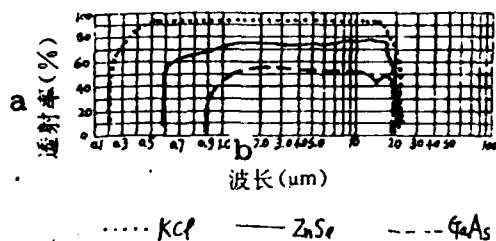


Fig. 2. Comparison of transmissibility of several materials
KEY: a - transmissibility (%) b - wavelength (micrometers)

Since a high-power laser should pass through inside the lens, it is important for absorption by material. Fig. 2 presents the transmission curves of three kinds of materials. At a wavelength of 10.6 micrometers, the transmission coefficient of KCl is the highest, at 94%. However, KCl easily leads to deliquescence and cracking due to explosions; thus KCl is not suitable in rainy and moist areas. GaAs (available in China) material has progressed to a relatively mature stage, but its transmission coefficient is relatively low, easily causing serious heat anomalous variations in addition to its shortcomings of being opaque to visible light and causing difficult adjustment of the light passage. Therefore, finally ZnSe (with the largest dimension of 80 mm outside diameter available in China) was selected as the lens material. Its refractive index is 2.403; it is transparent to visible light. After coating with a transparency enhancement medium film, it was measured with small

signals showing that the transmissibility is 99 percent. In the alignment system, the auxiliary lens has a diameter of 50 mm; the focal distance is negative 247 mm; the principal lens diameter is 80 mm (focal length is 420 mm and the alignment power is 1.7). The distance between the principal and the auxiliary lenses can be continuously microadjusted. All lenses are cooled with flowing water, thus effectively eliminating thermal effects.

3. Reflection--transmission focusing system

To conduct high-power density experiments on a laser beam outputted in the near-field from alignment system or directly from a high-power laser device, these experiments can be accomplished through a reflection--transmission focusing system. By using a 45 degrees total-reflection mirror to change the light beam direction, it is convenient to conduct experiments on a horizontal working platform. Oxygen-free copper was selected to form the base of the reflective mirror; the surface was coated with a gold film. Within the 2.0-11 micrometer waveband, the reflective index can be higher than 99 percent (Fig. 3). If a protective film is added on top of the gold film, contamination by the gold film can be prevented; however, the reflective index is lowered to some extent (Fig. 3). In the high-power state, it can be ensured that the best reflective index should receive paramount emphasis.

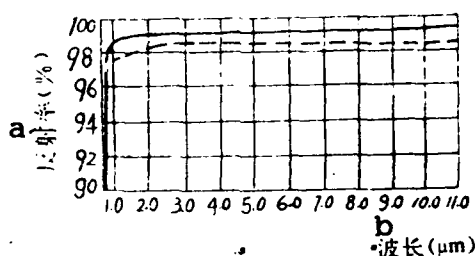


Fig. 3. Reflective index curves of gold-coated film layer (0° for incident angle)

LEGEND: Solid line - no protective film

Dashed line - with protective film

KEY: a - reflective index (%) b - wavelength (micrometers)

ZnSe material with low absorptivity is still used to make the focusing lens coated with a transmission enhancement film. The aperture of the effective light passage has an outside diameter of 72 mm; the focal distance is 600 mm; and the small-signal measurement transmissibility is 99 percent. The entire device is cooled with flowing water.

As mentioned above, this system can be used for research on laser transmission and far-field target hitting. Also, the system can be used for near-field high-power density experiments.

III. Study of Practical Applications

The authors conducted multiple long-term observations on indoor near-field and outdoor far-field properties. The coaxiality of the output light beam was adjusted with the He-Ne laser. This is one of the advantages of ZnSe material over GaAs material.

Fig. 4 shows a set of typical light-spot pattern diagrams in field observations made during the forenoon of 24 October 1990. Fig. 4a is the near-field original light spot at 1 m from the output window. The diameters of inner and outer rings are, respectively, 25 and 45 mm. The near-field divergence angle is approximately 2.1 milliradians; the distribution at the ring is not uniform; there are very bright light regions in local areas of the second and the fourth quadrants.

Fig. 4b shows the light spots after space wave filtration. Stray light and irregular distribution at the outer periphery of the original light spots are filtered out. Thus, the outer fringe is regular and uniform. These light spots can be closely coupled with the alignment system.

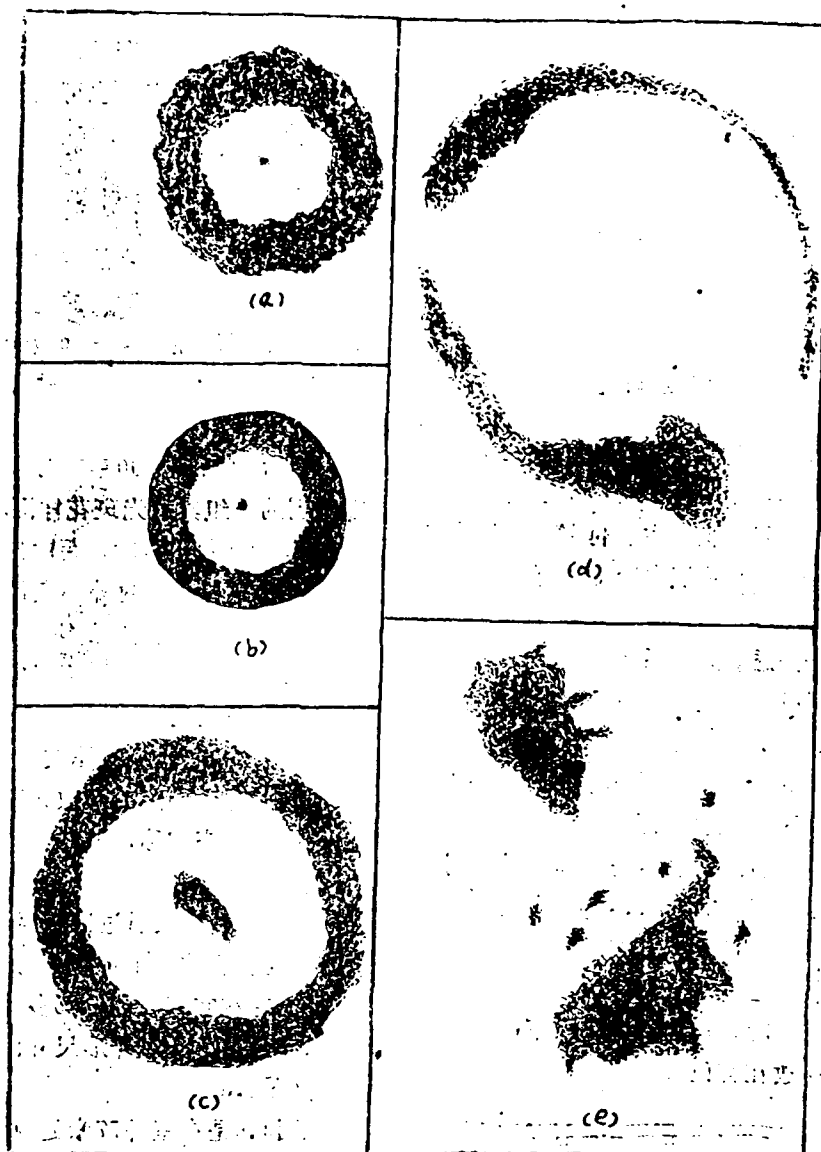


Fig. 4. Alignment situation of high-power laser beam

LEGEND: a - original light spots outputted by laser device b - light spots after passage through a space filter c - light spots after passing through an alignment system d - shape of light spots at 10 m from the alignment system e - far-field light spots (at 77 m from the laser device)

Fig. 4c shows the light spots after passing through the alignment system with a gain of 1.7 based on the design

indicators. This is a relatively regular circular ring. The circular ring outline is still maintained after transmission in the air for more than 10 meters; however, the dimensions of the exterior shape are enlarged. The light intensity weakens (Fig. 4d).

Fig. 4e is a light-spot diagram observed at a distance of 77 m outdoor. The diagram was recorded after about 8-s irradiation as displayed on a receiving plate. Within a short time, the area with weaker light intensity becomes obscure. The variation in the light spot shape is relatively high; the exterior dimension of the entity is 180 mm across. During the experiment, the weather was sunny and breezy; the atmospheric temperature was 25 degrees centigrade. Atmospheric effects on a high-power laser beam are very serious; therefore, on-site field studies using this system can be conducted on the thermal effects and others as the high-power laser beam passes through a turbulent flow atmosphere.

By using the authors' reflection--transmission focusing system, a high-power laser beam can be effectively focused into small light spots. When the divergence angle of the light beam is 3 milliradians, the diameter of light spots at the focal plane is 1.8 mm. When the divergence angle is 1 milliradian, the diameter of light spots is approximately 0.5 mm. In the situation of a single-mode 6 kW output, a power density of $1,000,000 \text{ W/cm}^2$ can be obtained. This power density is very useful for smelting, gasification or metallurgical smelting of special materials.

With cooperation between the authors and outside work units, experimental studies were conducted on tens of material specimens by using focusing light spots of different dimensions. Fig. 5 shows a picture of disintegrating target material. Within the



Fig. 5. Photograph showing high-power laser damage experiment



Fig. 6. Target material specimen irradiated with high-power laser

off-focus region, the controlled light spot diameter is 10 mm and the power density is 1 kW/cm^2 ; the specimens exploded immediately. It is possible that the effect [4] was caused by thermal impact and mechanical wave. By using a high-speed camera, the time period for the specimen to arrive at the explosion stage is approximately between 50 and 500 milliseconds for different power densities. Fig. 6 shows the situation of violent rearward injection of particles when the power density is at 7 kW/cm^2 per square centimeter for another specimen in the vicinity of the focal plane. At that time, the specimen did not disintegrate by explosion. Instead, it was punctured with the injection of plasma and matter in microparticles, releasing bright flames.

Generally speaking, when the high-power laser alignment focusing system as mentioned above is used, marked improvements can be made in the quality of high-power CO_2 laser beams; the system can operate continuously all day long for repeated operations. The entity wearing is about 10 percent with stability and reliability. This creates very useful conditions for studies on the interaction between laser and matter.

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*These marked authors are visiting scholars at the laboratory as sent by the Wuhan Institute of Seismic Research.

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