Study on the Technique of Beam Coupling for High Power Diode Laser Stack

Yuanyuan Gu¹, Yueming Fu¹, HuiLu, Yan Cui¹
¹Tianhua College of Shanghai Normal University, Section of Practice and Training, Shanghai, 201815, China

Abstract. High-power lasers based on GaAs bars meanwhile are well established as reliable and highly efficient laser sources. Continuous improvement of the material itself, mounting and cooling techniques during the last years have led to increased output power and high lifetimes. This paper summarized beam shaping technology of high-power lasers and evaluated these advantages and disadvantages. The beam coupling methods of the high power laser array were expatiated and a new beam coupling structure was present in the paper, also as the results and analysis of polarization coupled experiment.

1. Introduction

In many cases high power lasers are on the way to replace flashtubes for solid state laser pumping. By realizing arrangements of many high-power laser elements, e.g. laser stacks, the overall output power can be increased further up to the kW range. In this power level, we can have many important applications, such as surgery, welding of polymers, soldering, coatings and surface treatment of metals. pumped alkali vapour lasers (DPALs) have attracted increasing attention in the last decade [1]. As sources of such pump-modules Broad-Area (BA) -lasers are normally used because of power scalability [2]. depending on the device geometryThe demand is application driven and has been growing for past few decades thanks to improvements in power rating, efficiency, reliability, and production costs [3]. So all developed countries have attached great importance to high-power laser system and its applications. Germany is developing initiative "BRIOLAS" (brilliant lasers) program, the German Federal Ministry of Education and Research (BMBF) is supporting the BRIOLAS-initiative with about 30 M€. Using coarse wavelength multiplexing, BPP in the range of 20 mm-mrad for kW-class lasers (corresponding to a 400µm core diameter output fiber with 0.1 NA) has been demonstrated [4-6]. However, significant improvement in BPP is still needed to address industrial applications requiring high brightness.

In these programs, it is one of the main goals improving the output power and the brightness. There are two ways to gain high power and high brilliance laser system. One way is taking high efficient beam shaping small spot, the other way is to couple the output beam of several laser arrays to the same optical path, thus, in the case that the beam quality was not changed the output power increases to the original several times; the same brightness at the same time increases the multiplier. So what kind of beam coupling technology is used to achieve high brightness high-quality laser output has become a key issue. Now there are three ways: spacial coupling, wavelength coupling and polarization coupling. Thus, very high power laser systems with stringent demands on the beam quality rely on one additional active laser cavity and, in some cases, additional power amplifying stages to improve the beam quality of the lasers, with fiber lasers and disk lasers being the two most prominent examples [7-
This paper proposes a new method of beam coupling method, which compared with the traditional coupling method the beam can be not only coupled but also collimation in the slow axis direction. It is propitious to focus into small spot. In addition, we make a series of polarization coupling experiment.

2. Beam coupling method for laser stack

For laser stack, it is generally done in the world by stacking 25 laser strips. This aspect is due to the limitation of heat dissipation. On the other hand, more laminated laser stacks have too much light-emitting area to facilitate focusing. Therefore, in order to further increase the output power and brightness, it is necessary to couple the output beams of the multiple array modules to the same optical path by means of beam coupling. At present, there are three main types of beam coupling methods used abroad: spatial coupling, polarization coupling, and wavelength coupling.

Spatial coupling often requires relatively complex optics, requiring small dimensional tolerances on the prism sheets and high flatness requirements on the end faces to achieve high coupling efficiency; this requires high coating processes. In addition, spatial coupling requires relatively high adjustment of the optical path. Therefore, achieving spatial coupling has certain technical difficulties.

Although the wavelength-coupled device is simple, it couples beams of two different wavelengths. The coupled beam is not a single wavelength, which is not suitable for laser applications requiring a specific wavelength. For the case where the beam of the laser has a certain spectral line width and a wavelength-to-temperature drift, the beam coupling efficiency of the wavelength coupling is high without the polarization coupling.

The polarization coupling can complete the merging of the laser beams of the same wavelength, and can be combined by the reverse direction of the polarization beam splitting prism, and the device structure is simple and the coupling efficiency is high.

So in summary, we first carried out theoretical and experimental research on polarization coupling technology.

3. Thin film interference type polarization beam splitter

The polarizing beam splitter is alternately plated with high and low refractive index films on the slopes of two right angle glass prisms, as shown in figure 1. The natural light is incident on the multilayer film system at an angle of 45 degrees. After the multilayer film is deflected, the linearly polarized light whose two vibration directions are perpendicular to each other is output in the positive direction, and the aperture angle of the device is 5 degrees. When the four-layer film is plated, the splitting ratio is close to one.

![Figure 1. Thin film interference type polarization beam splitter.](image1)

![Figure 2. Cubic polarization beam splitting prism.](image2)
The relationship between incident angle $\theta_p$ and film thickness $u$ of the double-sided coating is calculated by the following formula:

$$\theta_p = \arcsin \left( \frac{1}{u^2} \right)$$

(1)

Where,

$$au^2 + bu + c = 0$$

(2)

$$a = n_1^4 - n_2^4, b = 2n_1^2n_2^4 - n_1^4(n_2^2 + 1), c = n_1^4n_2^2(n_1^4 - n_2^4)$$

(3)

Film thickness $d_p$ is

$$d_p = \frac{1}{4} \left( n_1^4 - u \right)^{\frac{1}{2}}$$

(4)

Ratio of reflectance is

$$R_s = \left[ \frac{n_1^4 - n_2^4}{n_1^4 + n_2^4} \right]^{\frac{1}{2}}$$

(5)

Splitting angle is

$$\alpha = 180 - 2\theta_p$$

(6)

The commercially available thin film interference type polarization beam splitter has an anti-damage threshold of more than 2 kW/cm² for continuous laser and 1 J/cm² for a pulsed laser damage threshold of 10 ns, which can meet the requirements of polarization coupling for damage threshold.

For the interference type polarization beam splitter, it is divided into a single wavelength polarization beam splitter and a wide band polarization beam splitter. Although a single-wavelength polarizing beam splitter can achieve higher $P$-polarized transmittance and $S$-polarized reflectance, a laser has a certain spectral line width ($\pm 3-5$ nm), and there is a case where the wavelength drifts with temperature, and the width is wide. The band polarization beam splitter is also very efficient and can meet the needs of polarization coupling, so a wide-band polarization beam splitter should be chosen.

4. Application of a cube polarizing beam splitter

A cube-polarized beam splitting prism (PBS) is used as a polarization-coupled beam-forming device, as shown in figure 2, which is a cube made of two isosceles right-angled triangular prisms coated on a slope of a triangular prism to make $P$ The polarized light is totally transmitted by being incident on the inclined surface at 45°, and the $S$-polarized light is totally reflected by being incident on the inclined surface at 45°. In this way, the two beams whose polarization directions are perpendicular to each other are incident perpendicularly to the two surfaces of the PBS, and meet on the opposite side, and are merged and inverted to achieve the combination. The angle of incidence of the incident light is 5 degrees, the splitting angle is 90 degrees, and the four surfaces of the light passing through are coated with an anti-reflection film, and the surface reflectance is less than 0.25%.

Figure 3 and figure 4 show the PBS transmittance versus wavelength for the polarization coupling of 808nm and 980nm lasers. It can be seen that the $P$-polarized light transmittance exceeds 95% and the $S$-polarized light reflectance exceeds 99%. They are all effective over a wide wavelength range, so in practice we can polarize the coupling of two different wavelength lasers in a certain wavelength range.
5. Polarization coupling experiment of 808nm seven bar laser array

The laser source parameters used in this experiment are as follows:

- Center wavelength: 808nm
- Output power: 100W/bar (QCW)
- Duty cycle: 20%
- Number of bar: 7
- Array length: 10mm
- Polarization Mode: TM
- Heat sink thickness: 1.8mm
- Beam divergence angle (FWHM): the divergence is 36degree in fast axis, and 10degree in slow axis.

Due to the large number of layers of the laser array, a single cylindrical lens does not achieve a good slow axis collimation effect. As shown in figure 6, after the two beams are coupled in the same optical path, we use a telescope consisting of two cylindrical lenses. The system expands and collimates the slow axis direction of the beam, and finally focuses it with a ball lens to obtain a 4.5*4.5mm² spot as shown in figure 5 with an efficiency of 67%.

6. Analysis of results

The energy loss in the analysis experiment mainly includes the following aspects: the beam of the laser is not the energy loss caused by the complete linear polarization, the degree of polarization is generally in the range of 95%-98%; the incomplete reflection of the polarized light on the PBS And the energy loss caused by transmission; since the beam is not collimated by the slow axis before the polarization coupling, part of the light is not incident on the opposite side of the polarization beam.
splitting prism at 45O, and the P-polarized transmittance and the S-polarized reflectance are made. Decrease, causing energy loss; the loss of the beam through the optical components during the propagation process, the focusing ball lens we use is not coated with an anti-reflection coating, and its transmission efficiency is less than 90%, while the actual optical device is transparent. The overshoot can reach more than 95%; the deviation of the optics position adjustment also causes the loss of energy. In the experiment, we make the system as compact as possible to reduce the energy loss caused by the beam divergence.

The reason for analysing the large spot size is as follows: First, we use the micro fiber column as the fast axis collimating mirror. Although the divergence angle can be reduced to about 8 mrad, it cannot solve the inherent astigmatism problem of the laser (the fast and slow axis beam is not in the same position) Therefore, it is not easy to focus to obtain a small spot. This problem can be solved by using a graded index lens; the beam quality of the fast and slow axis is not uniform, and the single Bar slow axis optical parametric product (BPP) is several hundred times faster than the fast axis. The solution is to utilize Various beam shaping methods tend to make the fast and slow axes BPP consistent. In addition, the focus lens should be optimized to eliminate aberrations, which is conducive to gathering to obtain small spots.

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