IOP Conference Series: Materials
Science and Engineering

High Power High Efficiency Diode Laser Stack for Processing

IOP Conf. Series: Materials Science and Engineering **317** (2018) 012008 doi:10.1088/1757-899X/317/1/012008

High Power High Efficiency Diode Laser Stack for Processing

Yuanyuan Gu[1], HuiLu[1], Yueming Fu[1], Yan Cui[1]

[1]Tianhua College of Shanghai Normal University, Section of Practice and Training, Shanghai, 201815, China

Abstract. High-power diode lasers based on GaAs semiconductor bars are well established as reliable and highly efficient laser sources. As diode laser is simple in structure, small size, longer life expectancy with the advantages of low prices, it is widely used in the industry processing, such as heat treating, welding, hardening, cladding and so on. Respectively, diode laser could make it possible to establish the practical application because of rectangular beam patterns which are suitable to make fine bead with less power. At this power level, it can have many important applications, such as surgery, welding of polymers, soldering, coatings and surface treatment of metals. But there are some applications, which require much higher power and brightness, e.g. hardening, key hole welding, cutting and metal welding. In addition, High power diode lasers in the military field also have important applications. So all developed countries have attached great importance to high-power diode laser system and its applications. This is mainly due their low performance. In this paper we will introduce the structure and the principle of the high power diode stack.

1. Introduction

Many volume industrial applications call for high power efficiency laser sources. The new product line by IPG offers fiber lasers with wall plug efficiency in excess of 50%, with output power ranging from 1kW to 10kW. This ECO-laser product line is based on the improved or redesigned set of optical and electronic components. In the case of single emitter pumps the ex-fiber power efficiency has been increased up to 68% from the industry standard of 50-60%. Similar progress has been done in the development of fibers, fiber blocks and other optical components. Several applications in the field of material processing – for instance sheet metal cutting and deep penetration welding –require laser systems with both high output power and high brightness [1, 2]. Cutting machines for high quality cutting are usually equipped with 2 kW to 8 kW of optical output power [3, 4] and a beam parameter product in the range of 4 mm mrad. Due to the limited brightness of state of the art direct diode lasers, today's cutting machines are equipped with disk, fiber or CO2 lasers [3, 4], all developed countries have attached great importance to high-power diode laser system and its applications. Germany is developing initiative "BRIOLAS" (brilliant diode lasers) program, the German Federal Ministry of Education and Research (BMBF) is supporting the BRIOLAS-initiative with about 30 M€. The United States has launched "SHEDS" (High Efficiency Diode Sources) from 2005. Now Germany laser line corporation has products, that direct diode laser system has the largest output power of 10000w, and fiber coupled diode laser system have the largest output power of 8000W into the fiber, with the1.5mm diameter [5].

2. The Principle of the Laser Diode Stack

Stimulated radiation in a certain frequency, reflected back and forth between the two cleavages, the formation of the two columns in the opposite direction of propagation wave superposition, finally forming a standing wave in the resonant cavity. A resonant cavity length, refractive semiconductor crystal rate of N, then lambda /n laser propagation in a semiconductor crystal when the wavelength of the resonator, the result is the presence of standing wave is allowed only semi integral multiple of wavelength is exactly equal to the harmonic cavity length, the condition is

$$m(\frac{\lambda}{2n}) = l \tag{1}$$

where m is integer.

Oscillation which does not meet this condition will gradually loss, where a series of specific wavelength meet stimulated radiation form a stable oscillation in the cavity [6].

If V is the positive voltage on the laser diode, I is the current of laser diode, P_{ex} is the output power of the laser diode, r is the series resistance of the laser diode, power efficiency η_p is

$$\eta_p = \frac{P_{ex}}{IV + I^2 r} \tag{2}$$

The internal quantum efficiency of the diode laser is

$$\eta_i = (1 + \frac{2\nu_r \tau_r}{d} + \frac{\tau_r}{\tau_{nr}})^{-1} \tag{3}$$

where τ_r the lifetime of carrier radioactive recombination is, τ_{nr} is the lifetime of non-radioactive carrier recombination, ν_r is the interface recombination velocity caused by the lattice mismatch, d is the active area thickness.

Because of the loss itself in cavity, the resulting photons are absorbed, and then define the external quantum efficiency η_{ex}

$$\eta_{ex} = \frac{P_{ex} / h\nu}{I / e} \tag{4}$$

The structure of laser diode stack

Welded several laser diode bars to one in the front of micro channel heat sink, the micro channel heat sinks are arranged vertically, thus forming a diode laser stack. At present, the main problem of high power diode laser stacks is heat dissipation, where the micro channel heat sink cooling technology is one of the most advanced stack packing technology.

The micro channel heat sink was realized early in silicon, initially mainly used in microelectronic integrated circuit radiator. For high power diode laser stack, oxygen free copper is usually used as the material of the micro channel heat sink with water as the coolant. The utility model had the advantages of expanding the area of the solid - liquid contact surface, improving the heat conduction efficiency. Micro channel orientation and the laser stack strip are transversely vertical; the structural parameters between two layers of micro channel designed same, so that the laser stack strip was as uniformly as possible refrigeration. The micro channel heat sink of the thickness was approximately 1.2-2.5mm. When water flowed in micro channel, heat was taken away which generated by diode laser in order to protect the mirror catastrophic thermal injury by diode laser bar. As the micro channel heat sink thermal impedance is very low, which could achieve 4.982×10^{-3}K·cm^2/W, the heat transfer efficiency is dozens of times of the ordinary cooler. Therefore, endurance the thermal stability of diode laser bar, output power of high power diode laser stack wouldn't loss energy because of integrated diode laser bar, but directly proportional to the number of semiconductor laser bar, the micro channel structure diagrams are shown in figure 1 and figure 2.

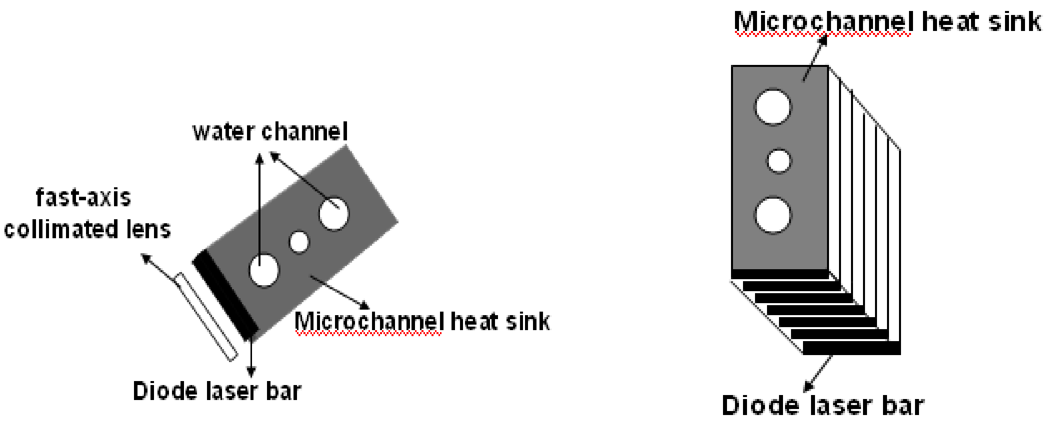

Figure 1. Scheme of a diode laser bar (left) and a diode laser stack (right). The diode laser bar is mounted p-side down to the edge of an actively cooled Cu microchannel heatsink. The n-contact is realized by a Cu foil, a fast-axis collimated lens is placed in front of the diode laser bar.

The basic elements of high power diode lasers are laser bar, mounted onto water-cooled heat sink (shown in figure 1). The microchannel cooling technology was originally based on silicon anisotropic etching; today these heat sinks are typically manufactured from copper. They contain a network of small channels. Water is driven through these microchannels, removes the excess heat, thus, prevents the bar mirror facets from thermal destruction. The efficient cooling is the precondition for high average output power and high long-term stability. The output power of single laser Bar of 1cm width is in the general 40-100W range. Now many of the German company's products can achieve the lifetime of 20,000 hours or more. Each microchannel heat sink is then vertically stacked into a rigid structure to produce the final two-dimensional high power diode laser stack. From one bar to thirty bars in a variety of configurations are readably available. The high-power output of laser stack does not necessarily reduce, but it is directly proportional to the number of laser bar [7].

3. Accurate Positioning Designed among Stacking Layers

Laser stack overlapped by several to dozens of micro channel cooling diode laser bars, layers in the vertical, horizontal direction need accurate positioning. If there was location error between layers, fast and slow axis beam collimation would cause directivity deviation, such as shown in figure 2 and figure 3, where, (a) expressed without positioning error of beam alignment between vertical stack, graph (b) indicates the presence of positioning error of beam alignment between the vertical direction of the lamination.

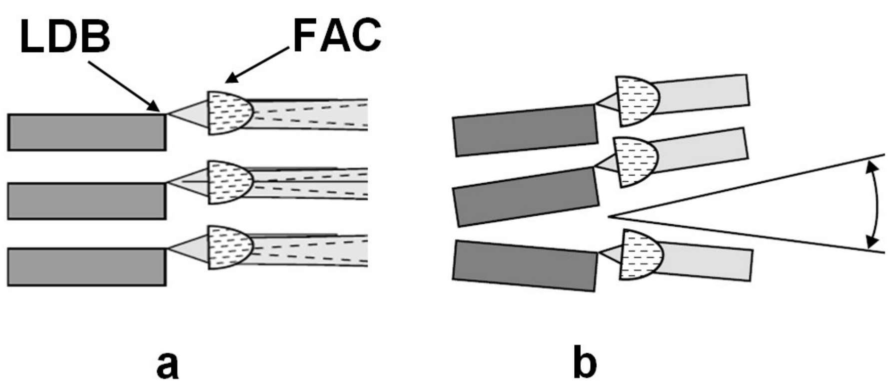

Figure 2. Positioning error among layers in the vertical stack.

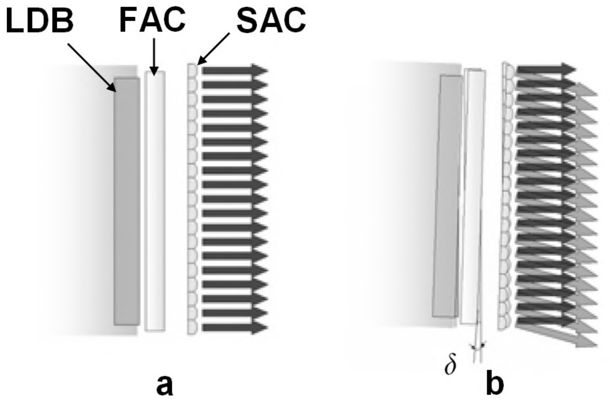

Figure 3. Positioning error among layers in horizontal stack.

The laser emission direction is inconsistent among the stack, and this deviation would be further increased by the laser propagation, resulting in decreased overall laser stack beam quality, which was difficult for the beam shaping focus. In order to improve the positioning precision of stack in the vertical direction, two location of a top wire was applied based on positioning screw, at the bottom of the top stack, respectively.

To ensure accurate positioning laminated horizontal direction, two positioning column were applid in the lateral plate stacked array so that precise positioning was done in the horizontal direction of the laminate

4. Conclusion and Outlook

The paper proceeds from the principle of high power diode laser stack, the analysis of the main performance parameters of diode laser stack, around the high power diode laser stack package, heat dissipation and positioning design difficulty gradually introduced, expounding the importance of micro channel heat dissipation

At present, we plan to make polarization coupling experiment for the laser diode laser stacks which contain more diode laser bars and try other kinds of beam coupling methods. We continue to bend ourselves to improve the coupling efficiency. In addition, we are also studying on the diode laser beam shaping, expecting the consistent beam quality of fast axis and slow axis by rearrangement of beam and focusing the beam into single fiber.

References

[1] Hengesbach S, Poprawe R, Hoffmann D 2015 *SPIE Proc.* **93480B** doi: 10.1117/12.2085068.
[2] Brauch U, Loosen P and Opower H 2000 *High-Power Diode Lasers for Direct Applications*, Springer, Berlin & Heidelberg, 303–368.
[3] Bystronic Laserquellen, http://www.bystronic.ch/de/produckte/laserchneidsysteme/bylaser. php (1 August2016).
[4] TRUMPF Werkzeugmaschinen GmbH + Co. KG, [TruLaser: Cost-effective cutting through thick and thin] (2016).
[5] Berk Y. et al., 2011 *Proc. SPIE* **7918** 79180W-1—W12.
[6] Friedheim D, Franz X. Daiminger, Petra H, Veit B 2000 *Proc. SPIE* **3889** 45-53.
[7] www.laserline.de.