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Beam Shaping Technique for 5-mm Fiber-coupled Laser Diode Bars with Lens Group

Hind J Jawad
Department of Physics, University of Baghdad, Baghdad, Iraq

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Abstract

In the last few years, fiber-coupled diode lasers have shown massive applications in many fields of communication and scientific research. Particularly, the pumping of solid-state lasers is a key application for more powerful diode lasers enabling good solutions in various laser micro methods like metal cutting, sintering, structuring as well as drilling. In this work, a simple beam shaping method is demonstrated for coupling a high-power semiconductor laser diode into multi-mode fiber optic using optical lenses. The optical lenses as beam transformation components are utilized to reshape the asymmetrical irradiation of the diode laser bar and to circularize the laser beam. Using this simple method, compact, high-output-power, and high-brightness fiber-coupled laser diode systems are achieved. The obtained results show that the entire optical coupling efficiency of the system is more than 65%.

Keywords: Fiber-coupled, Beam shaping method, Multimode optical fiber, High-power diode laser, bars, and stacks.

تقنية تشكيل الشعاع لأشرطة دايود الليزر المقترنة بالألياف 5 مم مع مجموعة العدسات

هند جاسم جواد
قسم الفيزياء, كلية العلوم, جامعة بغداد, محافظة بغداد, العراق

الخلاصة

في السنوات الأخيرة ، أظهر ليزر دايود المقترن بالألياف تطبيقات كثيرة في العديد من مجالات الاتصالات والبحث العلمي. يعد ضخ ليزر الحالة الصلبة هو التطبيق الرئيسي لليزر الدايود عالي الطاقة على وجه الخصوص والذي يوفر حلولًا جيدة في العديد من عمليات الليزر الدقيقة مثل قطع المعادن والتلبيد والهيكلة وكذلك الحفر. في هذا العمل، قدمنا طريقة بسيطة لتشكيل الحزمة لربط ليزر ديود عالي الطاقة بألياف متعددة الأوضاع باستخدام العدسات البصرية. تستخدم العدسات البصرية كعناصر تحويل الحزمة لإعادة تشكيل الحزمة غير المتماثلة لشريط ليزر الدايود ولتعميم شعاع الليزر. بأستخدام هذه الطريقة البسيطة، تم تحقيق أجهزة ليزر دايود مقترنة بالألياف المدمجة عالية الطاقة وعالية السطوع. أظهرت البيانات التي تم الحصول عليها أن كفاءة الاقتران الكلية تزيد عن 65٪.

1. Introduction

High-power laser diodes have played a vital role in communication and defence and have become much more attractive in the market due to their small size, compact design, high

*Email: hindjassim1980@yahoo.com

optical efficiency, low-price and simple compaction [1][2][3][4][5][6]. Over the past few years, the main application for high output power laser diodes has been for pumping of solid laser diode and printing applications. Nonetheless, recently with improved laser diode efficiency especially at near-infrared wavelengths (NIR) and with the developing technology, many researchers guide to use continuously and in wide range for many applications especially in medical and material processing areas. With the current increasing demand for high-power semiconductor lasers and the extension of related application fields, research has focused on high-power laser diodes and their fiber coupling technology. In order to use the high-power laser diodes in these applications, coupling is often required to guide the laser beam into an optical fiber. This led to advancement in the handling of the laser for biomedical applications and environmental monitoring [7][8][9][10].

Laser diode source primarily contains single-emitter, bar (multiple emitters), and vertically stacked (multiple bars). Scientific researches currently utilize bar or vertical stack to couple and then to focus into the optical fiber. Single laser diode contains one active layer which consists of a p-n junction between two thin semiconductor layers. These thin layers are fabricated in a professional way to obtain good p-n junction. A single emitter can run without requiring any cooling system and produce a few watts of power with high brightness. However, to increase the power efficiency with low brightness, enormous number of emitters are combined to create a single diode bar as linear array with high power and low brightness.
Laser diode bar often contains 19-40 of individual emitters [2][11][12]. The entire emitting size of the diode bar is approximately (5-10) mm width and (2-8) µm height [13][14][15]. Because of the very small height of the active layer, the divergence angle is very large in the fast direction axis compared with a small angle in the slow direction axis. It produces combined output beam of poor beam quality in both axis directions [16][17][18][19][20]. Nonetheless, with developing technology, there are micro cylindrical lenses that can be used to overcome the problem of large divergence angles. In order to achieve energy greater than 150 µJ, multiple diode bars (arrays), approximately 8-12 bars, are gathered to generate high energy.

Even though the semiconductor laser diode has some drawbacks including relatively small output energy, and large divergence angle, it has enormous applications in distinct fields, due to its unique advantages including small, compact structure, high optical efficiency, inexpensive and higher pulse repetition rate. With near-infrared and middle-infrared wavelengths, current semiconductor laser diodes can be very useful and important in biomedical applications and environmental monitoring.

To enable focusing a diode laser beam to the small diameter of an optical fiber, it is necessary to utilize optical beam shaping elements that improve the laser beam quality factors in orthogonal planes without significantly decreasing its intensity. Up to now, numerous beam shaping elements that try to solve this issue have been testified including coupling into optical fiber bundles, using diffractive optical elements, micro-optical elements, and multiple mirrors or prisms [21][22][23][24][25][26][27][28][29][30]. Many of these optical elements are hard to fabricate and difficult to align to the required systems.
A simple laser beam shaper for coupling the linear output of high-power laser from a semiconductor diode into a multi-mode optical fiber, with high coupling efficiency and easy alignment requirements, is revealed here using a single fiber, with core diameter of up to 600 µm, and a pair of lenses.

2. Beam shaping method

A beam shaping optics for fiber-laser diode bar coupling was developed in this study. The spot size of a high-power diode laser bar is very important in the coupling process. Laser diode systems based on standard 5 mm bar need beam transformation optics to re-homogenize the highly asymmetrical field distribution of the laser diode bar. Using beam transformation elements (e.g. prisms, cylindrical microlenses, mirrors) are particularly important to circularize the diode laser beam and to correct astigmatism [6][31][32][33][34][35][36]. Some of these micro-lens elements, such as ball shape, hemi-spherical, semi-ellipsoid, and gradient index lenses, are mainly used for coupling the output laser diode beam into an optical fiber without astigmatism correction [37][38][39]. However, these elements are expensive and become more inefficient with increasing intricacy.

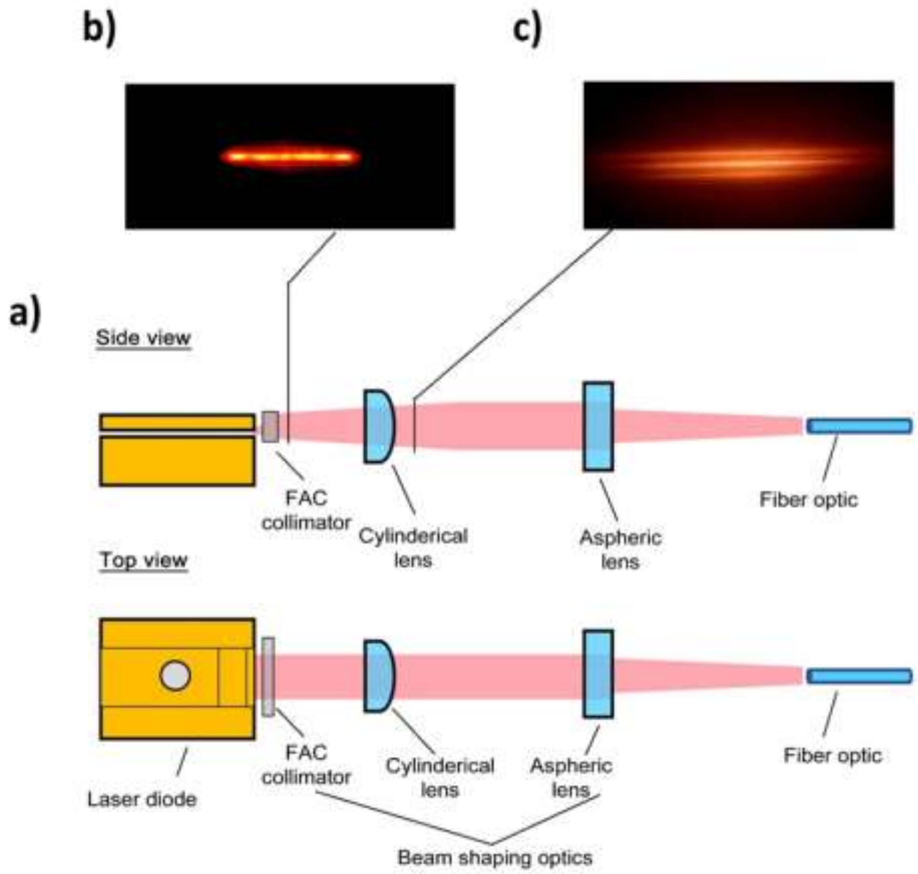

Figure 1: (a) Fiber coupling optical system and the beam profiles (b) collimated beam profile after the FAC collimator and (c) beam profile after the collimation.

A simple beam shaper with a group of lenses was proposed to symmetrize the laser beam quality and narrow the beam spot. This scheme design (illustrated in Figure 1a) is very simple, comprising of only two optical lenses, parallelly aligned with a slight distance apart. In this optical design, single emitters with 915 nm wavelength were chosen for this work. The emitters were independently collimated in the fast direction axis using a fast axis collimator (FAC). To reduce the divergence angle of the laser beam in the slow direction axis, a cylindrical lens (LI1328L1-B; focal length: 13.7 mm, Thorlabs Inc., NJ) was used as a slow axis collimator (SAC). To focus a laser beam in the longitudinal and the transverse directions, a condenser aspheric lens (ACL1512U-B; focal length: 12 mm) was chosen. Then, a laser beam was coupled into an optical fiber (M35L01; core diameter: 1000 µm, 0.39 NA). Table 1 shows the main parameters of single emitter laser diode.

Table 1: Laser diode bar parameters

Parameter	Value
Divergence angle in fast axis	40^0
Divergence angle in fast axis after FAC	2^0
Divergence angle in slow axis	10^0
Laser wavelength	915 nm
Maximum optical energy	40 µJ

3. Optical System Design and Results

The optical fiber coupler developed in this work is presented in Figure 1a. Large diameter optical fiber was chosen in this work for the following reasons: high power laser diode, large beam size, compact size and less energy loss by means of multiple reflections. An optical fiber with a high numerical aperture has a great acceptance angle to couple the radiation of the laser diode. A large diameter of an optical fiber makes the alignment less critical, but results in a big circular beam size. Thus, the technique is simple and of low cost while the coupling efficiency remains reasonably good.

Good efficiency of the fiber coupler is dependent on a number of factors, like good alignment, laser and fiber characteristics, and losses in the fiber. The optical elements in this system were aligned very well for collecting the laser beam optical power into the optical fiber.

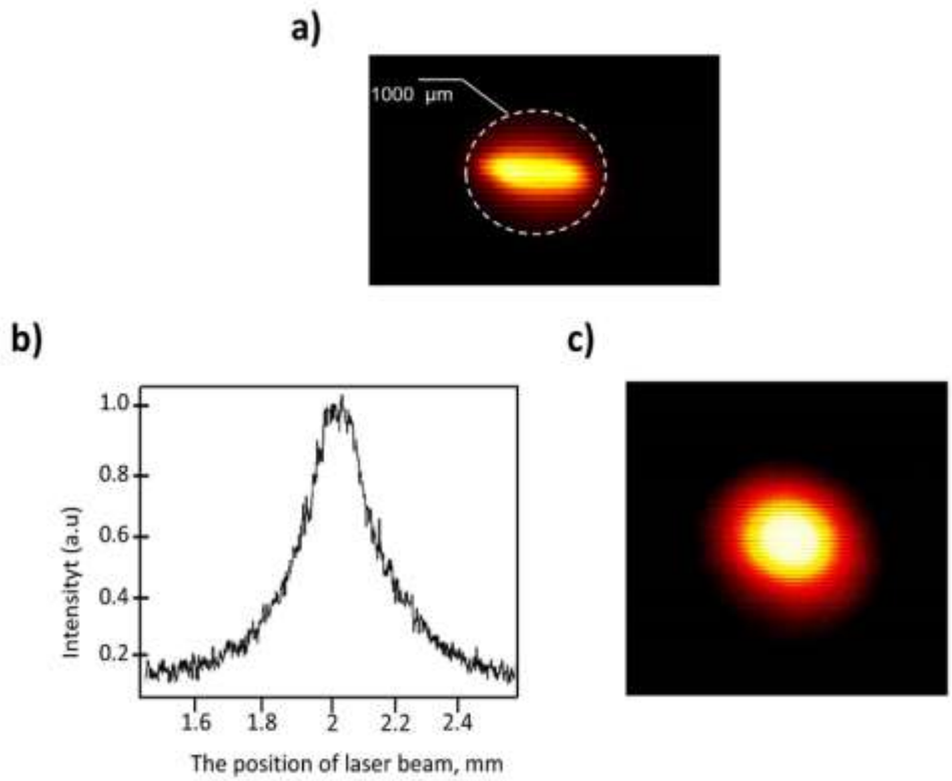

Figure 2: Spot diagram of the laser beam (a) Focusing laser spot on the fiber facet. (b and c) Near-field intensity distribution of the fiber output

At the beginning of the optical system, a cylindrical lens was employed to collimate the laser beam along the slow direction axis. The slow and fast axis of the diode laser bar were focused onto the entrance surface of the optical fiber by a condenser aspheric lens (see Figures 1).

The results in Figure (1c) shows that the intensity distribution of the output diode laser beam is not uniform along the slow direction axis; uniformity can be improved with a simple optical focusing lens (aspheric lens), as shown in Figure (2a). The intensity distribution of the laser beam at the focus area after passing over the optical fiber is indicated in Figures (2b) and (2c). This optical system generated a circular laser beam with dimension of (3 × 3) mm. The divergence angle in the slow axis was greater than that in the fast axis, this causes beam waist in the slow axis larger than the beam waist in the fast axis on the emitter surface. The entire transmission efficiency of this scheme was 69%. A 26 µJ from 40 µJ of total laser energy was obtained. The beam intensity distribution on the entrance end of the optical fiber is presented in Figure 2a.

4. Conclusions

In this study, compact, high-power, and low-cost fiber coupled laser diode module was developed. The optical coupling efficiency was 69% at 40 µJ optical energy from 1 mm 0ptical fiber . This module is significantly useful for fiber laser pumping, solid-state laser pumping, and medical applications because of its high efficiency, compact, and cost. For many biomedical applications, it is appropriate to couple the output of a high-power laser diode into an optical fiber in order to deliver the laser to the area where it is needed.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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