High Brightness, High Power Density Fiber Coupling of High Power Laser Diode

WANG Xiao-wei, XIAO Jian-wei, WANG Zhong-ming, MA Xiao-yu, LIU Zong-shun, FANG Gao-zhan, ZHANG Jing-ming and FENG Xiao-ming

(*National Research Center for Optoelectronic Engineering, Institute of Semiconductors, The Chinese Academy of Sciences, Beijing* 100083, *China*)

Abstract: The output radiation from the 100μm×1μm aperture of a high power Laser Diode (LD) is efficiently coupled into a 50μm multimode optical fiber. The fiber output of the high power LD with high brightness and high power density is achieved. The power density is up to $3.6\times10^4 W/cm^2$ and the coupling efficiency is 70%. The extreme divergence and the astigmatism of high power LDs require the optics with complex lens structures and high performance. A double-curved lens with two crossed cylindrical lenses structured on both sides of the glass substrate is used in the coupling system.

Key words: high power LD; double-curved lens; fiber coupling; high brightness; high power density
EEACC: 4320J
CLC number: TN248.4 **Document code**: A **Article ID**: 0253-4177(2001)09-1112-04

1 Introduction

High power LDs provide an efficient and compact technology for converting the electrical power directly into coherent light. The fiber output of the high power LD with high brightness, high power density and small aperture is needed in many fields, such as in medicine, materials processing, solid-state laser pumping, industry and aerospace[1-3]. However, because of the highly divergent and astigmatic radiation produced by these devices, it is problematic to couple their radiation into optical fiber efficiently. In recent years, owing to the development of modern technology of high-power LDs, many studies have been made of the improvement of the coupling radiation of LD into multimode optical fiber[4-6]. A lot of microoptical elements, such as a GRIN-rod, a ball lens and other separate lenses, are used in the high power LD to the multimode fiber coupling system on purpose to increase the coupling efficiency and achieve a compact and reliable high power LD module of the fiber output[7]. In these coupling systems, two or more microoptical elements are used, so it is difficult to align the microoptics. In this paper, two directions can be collimated by using a single microlens that is a double-curved lens with two crossed cylindrical lenses on both sides of the glass substrate. By coupling the 100μm source into 50μm

WANG Xiao-wei was born in 1973. She is now a PhD candidate, working in the high power laser diode array and fiber coupling of high power laser diode array to multimode fiber.

XIAO Jian-wei was born in 1954. He is now a professor of Institute of Semiconductors, The Chinese Academy of Sciences. His research interests include the quantum well laser diode and high power laser diode array.

WANG Zhong-ming was born in 1944. He is now a professor of Institute of Semiconductors, The Chinese Academy of Sciences. Currently, his main interest is in the fiber coupling including single mode and multimode.

Received 29 March 2001, revised manuscript received 27 April 2001

fiber, the power density of up to $3.6 \times 10^4 W/cm^2$ and the coupling efficiency of 70% are achieved.

2 Experiment

Because the width of the active layer of a quantum well LD (100μm) is much larger than its depth (1μm), the high power LD has two characteristics, asymmetry of the far-field pattern and astigmatism. The beam divergence angle (FWHM) in the direction perpendicular to the junction (fast axis) is about 30°—40° (NA: 0.26—0.34), while that in the direction parallel to the junction (slow axis) is 3°—8° (NA: 0.03—0.07). The axial astigmatism may be as much as 80μm[8].

The variation in angular divergence and the presence of axial astigmatism complicate the design of the coupling system. It is difficult for a symmetric optical system to compensate for the aberration. An anamorphic optical element, such as a prism or a cylindrical lens, can not obtain a circular spot. In our coupling system, a double-curved monolithic microoptic lens is used, which is designed to shape the beam of high power LDs.

Figure 1 shows the schematic diagram of the double-curved lens. This kind of fiber coupler combines two lenses aligned with respect to each other in one optical element, whose dimension ($L \times W \times T$) is 2mm × 2mm × 1mm. To minimize the spot

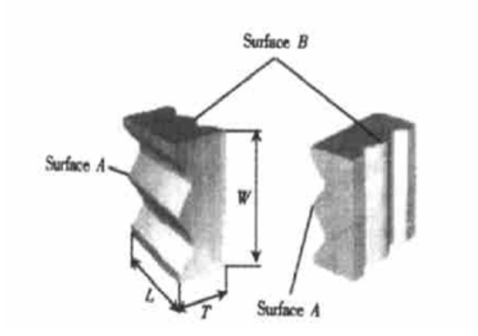

FIG. 1 Schematic Diagram of the Double-Curved Lens

size, the hyperbolic curvatures of the lens has to be optimized to reduce the aberrations and increase the transformation efficiency of the beam. Surface *A* collimates and focuses the beam of the high power LD in the fast axis, while surface *B* images the beam of the LD in the slow axis into the spot. In surface *A*, the focal length is 0.05mm and the curvature radius is 0.04 mm; while in surface *B*, they are 0.25mm and 0.2mm, respectively.

As shown in Fig. 2, besides the active optical areas (1, 2), there are additional surfaces and edges in a fiber coupler, making the mounting and positioning (3, 4) in a set-up easier.

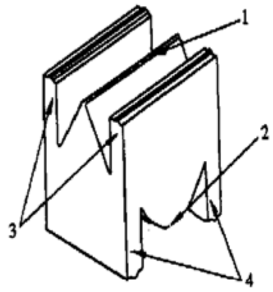

FIG. 2 Active Areas (1, 2) and Positioning Areas (3, 4) of a Double-Curved Lens

Figure 3 shows the schematic diagram of the coupling system. The distance between the high power LD and the double-curved lens is 0.05mm, and that between the lens and the fiber is 0.35mm.

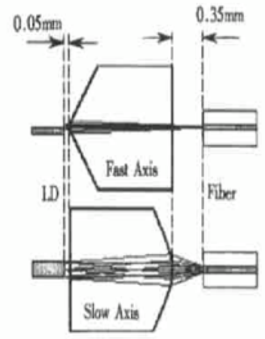

FIG. 3 Schematic Diagram of the Coupling System

3 Results

The coupling efficiency of optical fiber depends upon the divergence of a laser diode, specific fiber and fiber-end finish[9]. In this work, the beam divergence angle (FWHM) of the laser source (width: 100μm, depth: 1μm, operating wavelength:

808nm) is 32.4° in fast axis′ direction and 3.9° in slow axis′ direction, respectively. The fiber used here is step-index, low OH content with a flat end (core diameter: 50μm, cladding diameter: 125μm, NA: 0.22, length: 1m).

Figure 4 shows the comparison of *P-I* properties between the fiber coupling output and LD output. The coupling efficiency is 70%. Because it couples the 100μm source into 50μm fiber, the fiber output of a high power LD with high brightness and high power density can be achieved. The power density is up to $3.6\times10^4 W/cm^2$.

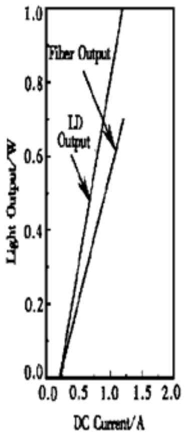

FIG. 4 Comparison of *P-I* Properties Between Fiber Coupling Output and LD Output

4 Conclusions

In conclusion, a high power LD-multimode optical fiber coupling scheme is proposed, by using a double-curved lens with two cross cylindrical lenses structured on both sides of the glass substrate. The fiber output of a high power LD with high brightness and high power density is achieved. The power density is up to $3.6\times10^4 W/cm^2$ and the coupling efficiency is 70%.

References

[1] C. Q. Wang, Y. T. Chow, L. Reekie, W. A. Gambling, H. J. Zhang, L. Zhu and X. L. Meng, A Comparative Study of the Laser Performance of Diode-Laser-Pumped Nd: $GdVO_4$ and Nd: YVO_4 Crystals, Appl. Phys. B, 2000, **70**: 769—772.

[2] T. Kasamatsu, T. Sumiyoshi and H. Sekita, Laser-Diode-Pumped Yb: YAG Laser as a New Pump Source and its Application to an Er^{3+}, Yb^{3+} -Codoped High-Output-Power Fiber, Appl. Phys. B, 1999, **69**: 491—495.

[3] S. Taccheo, P. Laporta, S. Longhi, O. Svelto and C. Svelto, Diode-Pumped Bulk Erbium-Ytterbium Lasers, Appl. Phys. B, 1996, **63**: 425—436.

[4] Sergey B. Sevastianov, Sergey M. Vatnik and Alexander P. Mayorov, Shaping of the End of a Multimode Optical Fiber for Efficient Coupling Light from a Laser Diode, Appl. Opt., 1999, **38**: 77—85.

[5] Gyeong-il Kweon, In-shik Park and Jong-in Shim, Laser-to Fiber Optical Coupling Scheme with a Long Working Distance by Use of Thermally Overexpanded Fiber, Appl. Opt., 1998, **37**: 4789—4796.

[6] Friedhelm Dorsch, Petra Hennig and Michael Nickel, High-Brightness Fibre-Coupled Diode Laser Module, SPIE, 1998, **3285**: 192—198.

[7] Kenji Kawano and Osamu Mitomi, Coupling Characteristics of Laser Diode to Multimode Fiber Using Separate Lens Methods, Appl. Opt., 1986, **25**: 136—141.

[8] Joan M. Stagaman and Duncan T. Moore, Laser Diode to Fiber Coupling Using Anamorphic Gradient-Index Lenses, Appl. Opt., 1984, **23**: 1730—1734.

[9] Murphy J. Landry, Jeffrey W. Rupert and Anthony Mittas, Coupling of High Power Laser Diode Optical Power, Appl. Opt., 1991, **30**: 2514—2526.

大功率激光二极管高亮度、高功率密度光纤耦合

王晓薇　肖建伟　王仲明　马骁宇　刘宗顺　方高瞻　张敬明　冯小明

(中国科学院半导体研究所 国家光电子工程中心，北京　100083)

摘要：将条宽为 100μm，有源区厚度为 1μm 的大功率激光二极管 (LD) 的输出光束高效地耦合到芯径是 50μm 的多模光纤中，得到了高亮度、高功率密度的光纤输出．功率密度高达 $3.6\times10^4 W/cm^2$，耦合效率为 70%．LD 输出光束的发散角较大并且存在较大的像散，因此耦合系统中需要结构复杂、性能可靠的微透镜．采用在一个玻璃衬底上，具有两个不同曲率半径的双曲面透镜实现 LD 与多模光纤的耦合．

关键词：大功率激光二极管；双曲面透镜；光纤耦合；高亮度；高功率密度

EEACC：4320J

中图分类号：TN248.4　　**文献标识码**：A　　**文章编号**：0253-4177(2001)09-1112-04

王晓薇　女，1973 年出生，博士研究生，主要从事大功率半导体激光器列阵及其与光纤耦合的研究．

肖建伟　男，1954 年出生，研究员，主要从事半导体量子阱激光器和大功率半导体激光器列阵的研究．

王仲明　男，1944 年出生，研究员，主要从事半导体激光器与单模和多模光纤耦合的研究．

2001-03-29 收到，2001-04-27 定稿　