第 35 卷第 6 期
2016 年 12 月

红外与毫米波学报
J. Infrared Millim. Waves

Vol. 35, No. 6
December, 2016

文章编号: 1001 - 9014(2016)06 - 0652 - 04 DOI:10.11972/j.issn.1001 - 9014.2016.06.003

High efficiency beam shaping of GaSb based diode lasers

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Abstract: GaSb-based diode lasers with emitting wavelength of 1.8 ~ 4 μm have a wide range of applications due to advantages of compact in size, light in weight and electric drive. However, single emitter can not provide enough laser power for practical applications. Therefore, methods of beam combination which have been successfully applied to diode lasers in near-infrared band are needed to be transplanted to mid-infrared band. In every method of beam combination, high efficiency beam shaping is basic and principal. A method of high efficiency beam shaping using multiple single diode lasers was demonstrated. A continuous-wave optical power of 1.93 W at wavelength of 1.94 μm with efficiency of higher than 90% was achieved experimentally. This method of beam shaping can be utilized to build spectral or coherent beam combination.

Key words: mid infrared, diode laser, beam shaping, beam combination
PACS: 42.55.Px; 42.60.Jf

锑化镓基半导体激光器高效率光束整形

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摘要: 锑化镓基半导体激光器发光波长为 1.8 ~ 4 μm,因为具有体积小、重量轻和电流驱动等优势,应用范围很广. 但是单管激光器并不能提供满足实际应用的激光功率,因此需要将已经成功应用于近红外半导体激光器的光束合成方法移植到中红外波段. 在各种光束合成方法中,高效率的光束整形都是重要基础. 展示了一种采用多只单管半导体器件的高效率光束整形方法,并在实验中实现了 1.94 μm 波长 1.93 W 连续光功率输出,整形效率高于 90%. 这个光束整形方法可以用于构建更复杂的光谱或相干光束合成.

关 键 词: 中红外; 半导体激光器; 光束整形; 光束合成

中图分类号: TN216; TN365 **文献标识码:** A

Introduction

Mid-infrared laser sources are needed in many areas, such as industry, medical, environment, and defense. GaSb-based diode lasers can project light with wavelength of 1.8 ~ 4 μm directly and become potential candidate which will replace solid-state lasers due to the advantage of compact in size, light in weight, high wall-plug efficiency (WPE), and electric drive. Recently, distributed feedback structure has been fabricated in GaSb-based diode lasers to obtain single longitudinal mode emitting [1-4]. Several schemes to obtain single-special mode [5-7] and high performance [8-10] have also been researched. However, optical power from single diode laser is still not enough for some high-power applications in industry and defense. In order to exceed optical power limit of single diode laser, methods of beam shaping and combination are needed. Various methods of beam combination have been widely applied to diode lasers in near-infrared band. When they are transplanted to mid-infrared band, high efficiency beam shaping becomes very important due to expensive price per watt of optical power in mid-infrared band. In this paper, a scheme of high efficiency beam shaping using multiple single diode lasers is demonstrated.

Received date: 2016-02-24, **revised date:** 2016-09-30 **收稿日期:** 2016-02-24, **修回日期:** 2016-09-30
Foundation items: Supported by National Natural Science Foundation of China (61307032), and the Science Research Program of Jilin Province (20140520108JH)
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1 Unit beam shaping

The emitting cavity-surface of single diode laser is in size of microns which leads to strong diffraction. As a result, the original output beam of single diode laser generally has large divergence angle of 15° ~ 80°. Besides, the beam waists of vertical and lateral special modes are at different places along light emitting direction due to different size of the wave-guide in vertical and lateral direction, which is defined as astigmatism. Therefore, the original output beam of single diode laser should be shaped in order to be utilized further.

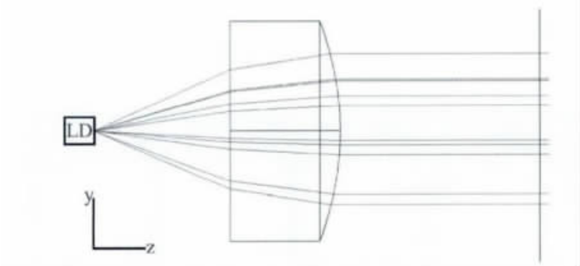

Fig. 1 The collimation design of single laser diode (LD)
图 1 单管激光二极管准直设计图

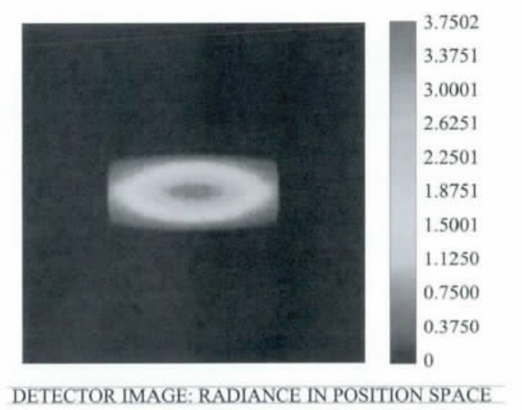

Fig. 2 The collimated beam spot in near field of single diode laser by simulation
图 2 单管二极管激光器近场准直光斑的模拟结果

Usually, one short-focal-length and one longer-focal-length cylindrical lenses are combined to collimate the Gaussian beam on fast and slow axes, respectively, which can obtain low divergence-angle beam eliminating the influence of astigmatism. However, using only one rounded non-spherical lens with high numerical aperture is also a simpler and effective method in many schemes. This kind of collimated lens can reduce spherical aberration significantly to obtain as low as possible collimated divergence angle. In the collimation design, a non-spherical lens with 4 mm focal length and NA of 0.6 is used. Short focal length will lead to large slow-axis collimated divergence angles. On the other hand, long focal length will lead to large size of the collimated beam spot which is harmful for arraying beams densely. Figure 1 shows the beam collimation in fast axis direction and Fig. 2 shows the profile of collimated beam spot in near field by ZEMAX simulation. The simulated beam size is 5.0 mm × 2.4 mm.

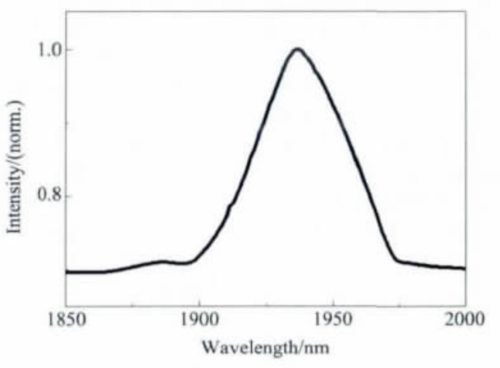

Fig. 3 Optical spectrum of the GaSb-based FP-LD
图 3 锑化镓基法布里-珀罗腔二极管激光器的光谱图

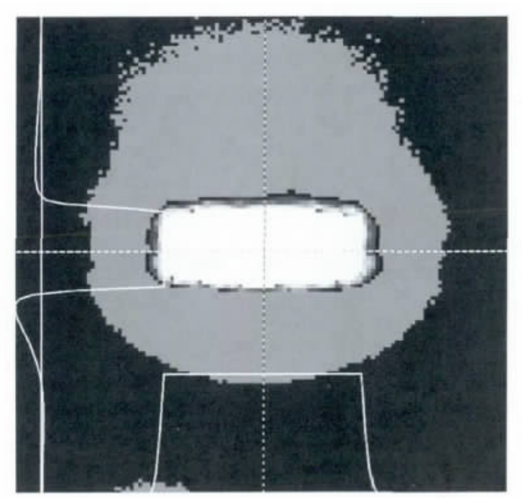

Fig. 4 The mid-infrared camera image of the collimated beam spot in near field from single diode laser
图 4 单管二极管激光器近场准直光斑的中红外相机图像

Based on the analysis above, an experiment to collimate a single diode emitter was investigated. A single 1.94 μm GaSb-based FP-LD with 150 μm waveguide and 40° fast axis divergence angle was used. Figure 3 shows the optical spectrum of the GaSb-based laser by a spectrometer with 1 nm resolution. A black diamond non-spherical lens with NA of 0.6 and 4 mm focal length was also used. The lens was adjusted finely in order to acquire the lowest divergence angle. Figure 4 shows mid-infrared camera image of the collimated beam spot in near field when the diode laser was working at drive current of 3 A and temperature of 20 °C. The beam size fits well with the simulation result in Fig. 2. The lateral and vertical collimated divergence angles were 5.2 mrad and 47.3 mrad, respectively, by size measurement of the focused beam spot using a 200 mm-focal-length plane convex lens.

2 System beam shaping

Generally, beam quality of vertical mode from a single diode laser is much better than beam quality of lateral mode, due to the common wide-stripe chip structure in high-power diode lasers which induces large amount of high-order lateral modes. If a group of parallel collimated beams are arrayed linearly and densely in vertical direction, the total beam quality will be more symmetrical. Traditionally, diode emitters should be positioned on steps with proper height difference so that all the collimated beams can be arrayed vertically. However, this mounting method will lead to non-uniform working temperature for each diode emitter. The working temperature of diode emitters on higher steps will be higher than that on lower steps which is harmful to maintain steady high-power output. If each diode emitter is rotated 90° along light emitting axis, all diode emitters can be positioned at the same height and all the collimated beams can be arrayed horizontally. The working temperature of all the diode emitters will also be uniform which is helpful for high-power output.

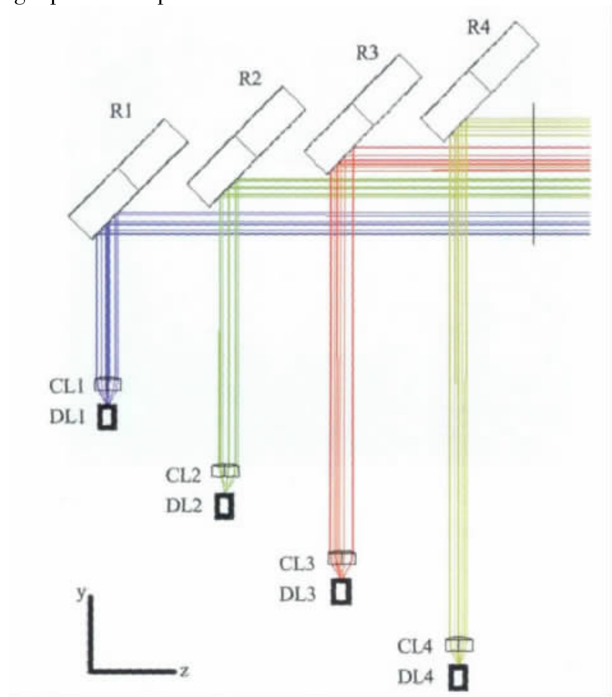

Fig. 5 The optical design of high-efficiency beam shaping

图 5 高效率光束整形的光学设计图

Based on the analysis above, the optical path of beam shaping was designed, as shown in Fig. 5. Four single diode lasers which are the same as in collimation experiment above (DL_1 ~ DL_4) were arranged at proper positions for equal optical path length. Each single diode laser was collimated by a non-spherical lens which is the same as in Fig. 1 (CL_1 ~ CL_4) and all collimated beams were arrayed linearly and densely in y direction by planar mirrors (R_1 ~ R_4). The total beam spot was simulated by ZEMAX, as shown in Fig. 6. The simulated beam size is 23.2 mm × 5.0 mm.

Based on the design above, an experiment was set up. Four single GaSb-based diode lasers with emitting wavelength of 1.94 μm and C-mount package were used. All the diode lasers were rotated 90° along light emitting axis and positioned on a heat spreader at the same height. The temperature of the heat spreader was controlled at 20 °C by thermal electrical coolers below. Each diode emitter was collimated by a rounded non-spherical lens made of black diamond and all the collimated beams were arrayed horizontally and densely by four gold planar mirrors. The mid-infrared camera image of the total beam spot is shown in Fig. 7 and the beam size fits well with the simulation result in Fig. 6. The lateral and vertical divergence angles are 6.5 mrad and 57.7 mrad, respectively. The optical power of each beam from single diode lasers and the total beam with beam shaping (BS) were also investigated, as shown in Fig. 8, while Fig. 9 shows the beam shaping efficiency calculated by the optical power data in Fig. 8. The maxi-

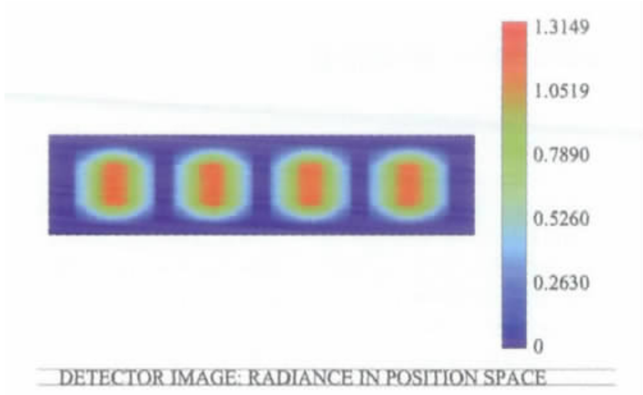

Fig. 6 The total beam spot in near field of the beam shaping system by simulation

图 6 光束整形系统近场总光斑的模拟结果

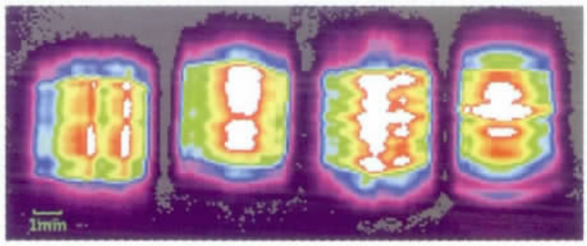

Fig. 7 The mid-infrared camera image of the total beam spot in near field

图 7 近场总光斑的中红外相机图像

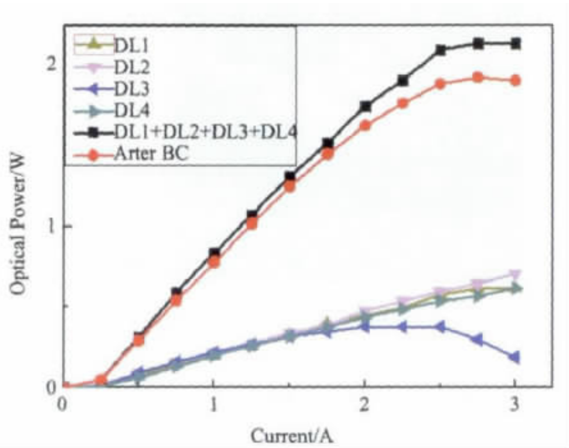

Fig. 8 The continuous-wave optical power versus driving current at 20℃

图 8 20℃连续波光功率随驱动电流变化图

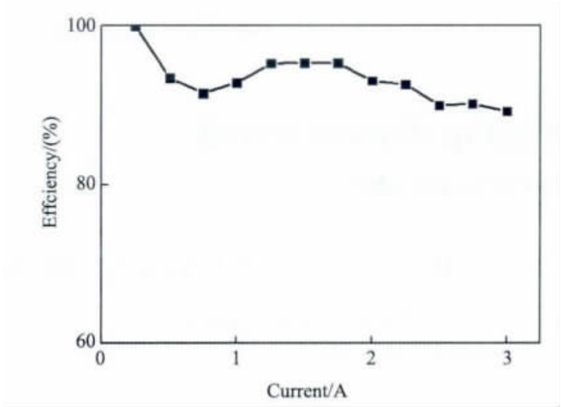

Fig. 9 The efficiency of beam shaping versus driving current
图 9 光束整形效率随驱动电流变化图

mal optical power of 1.93 W was achieved at drive current of 2.75 A. The beam shaping efficiency was higher than 90% in the range of working current.

3 Conclusion

In conclusion, a scheme of high-efficiency beam shaping using multiple single diode emitters is demonstrated in this paper. Each single diode emitter was rotated 90° along the light emitting axis and positioned at the same height which is helpful to maintain uniform working temperature and stable high-power output. All the beams were densely arrayed in horizontal direction after collimation by rounded non-spherical lenses. The beam profiles fit well with the simulation. Finally, continuous-wave optical power of 1.93 W at wavelength of 1.94 μm with efficiency of higher than 90% was achieved. This method of beam shaping can be applied to build spectral or coherent beam combination further.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (No. 61307032), and the Science Research Program of Jilin Province (20140520108JH).

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