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External Cavity Design for Laser Diode Bar Based on Calculation of Combined Array Mode

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Abstract: In this paper, the concept of "combined array mode" for laser diode bar is proposed, and the far-field profile of "combined array mode" is calculated. The far-field of each combined array mode exhibits a two-lobe profile with different angular position. On the basis of the characteristic of far-field profile of combined array mode, an off-axis external cavity feedback laser diode bar is designed. By employing the setup, the far-field profile of laser diode bar is narrowed by 4.3 times compared with the free-running laser diode bar. The output power of external cavity feedback laser diode bar is about 1.82 W at the drive current of 16 A, or 79% of the radiated power of the free-running state. The theory of combined array mode cannot only be applied to design the external cavity feedback laser diode bar but also can be designed the external cavity feedback laser diode stack.

Key words: Laser diode bar; Combined array mode; Far-field profile; External cavity
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0 Introduction

Because of their compactness, long life times, low cost and excellent electro-optical conversion efficiency, high-power laser diode bars are interesting optical sources for many applications such as material processing, solid state and fiber lasers pumping and so on[1-4]. However, one of main disadvantages of high power laser diode bar is poor beam quality, which limits their applications. In the fast axis, the beam of laser diode bar displays excellent quality, however in the slow axis direction the beam quality is very poor. The poor beam quality of diode bar is a consequence of the high divergence along the slow axis caused by the broad emitter area. Various approaches have been employed to improve beam quality of laser diode bar along slow axis[5-6]. Off-axis external cavity feedback is one of effective approaches to improve beam quality of laser diode bar[1,5]. The design of external cavity configuration depends on the spatial modes characteristic and far field profile of laser diode bar along slow axis direction. Many researchers have calculated the far-field profile of single-emitter laser diode[7-8]. However, the calculation of far-field profile for laser diode bar has not been reported to now. In this paper, we calculated the far-field profile of laser diode bar. According to the calculation result of the far-field profile and spatial mode characteristic, an off-axis external cavity was designed to improve the beam quality of laser diode bar in slow axis.

1 Theory and calculation of combined array mode

In Ref. [7], JEAN-MARC proposed an analytical model for calculating the eigenmode of broad-area laser diode. The eigenmode is also called as "array mode" with the following expression

$$\varphi_m(x)=\psi_m(x)-\frac{4x_0^2\mu_0k_0^2}{\pi^2}\left[\frac{\Delta g(\beta_c+i)}{8N(N-m)k_0}\psi_{2N-m}(x)+\frac{\Delta T(\mathrm{d}n/\mathrm{d}T)}{8(1+m)}\psi_{m+2}(x)+\frac{\Delta T(\mathrm{d}n/\mathrm{d}T)}{8(1-m)}\psi_{m-2}(x)\right] \quad (1)$$

Here, the x axis is taken along the slow axis. According to the result, we will derive the expression and analyze the characteristic of mode for laser diode bar. In general, high-power laser diode bar is made up of 19 or 49 emitters. The m-th order array mode of the v-th emitter in a bar should be the following

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$$\varphi_\nu(x)=\psi_m(x)-\frac{4x_0^2\mu_0k_0^2}{\pi^2}\left[\frac{\Delta g(\beta_c+i)}{8N(N-m)k_0}\psi_{2N-m}(x)+\frac{\Delta T(\mathrm{d}n/\mathrm{d}T}{8(1+m)}\psi_{m+2}(x)+\frac{\Delta T(\mathrm{d}n/\mathrm{d}T)}{8(1-m)}\psi_{m-2}(x)\right]\times \mathrm{rect}\left[\frac{x-(x_1+(\nu-1)W)}{x_0/2}\right] \quad (2)$$

where W is the separation between emitters, x_0 is the dimension of one emitter along slow axis direction and x_1 is the center position of the first emitter in a bar. $\mathrm{rect}\left[\frac{x-(x_1+(\nu-1)W)}{x_0/2}\right]$ is a rectangular function that can be defined as following

$$\mathrm{rect}\left[\frac{x-(x_1+(\nu-1)W)}{x_0/2}\right]=\begin{cases}1 & \text{for } |x-(x_1+(\nu-1)W)|<x_0/2\\ 0 & \text{others}\end{cases} \quad (3)$$

The incoherent addition of all the m-th order array modes from different emitter can be calculated as following:

$$E_m=\sum_{\nu=1}^{Q}\varphi_{\nu m} \quad (4)$$

where Q is the total number of emitters of a laser diode bar. E_m can be called as "combined array mode". The far-field profile of the combined array mode can be obtained easily by making the Fourier Transform for the combined array mode. Fig. 1 shows that the far-field profile of the 12-th order combined array mode. As seen clearly that the far-field profile has two lobes. The far-field profile of laser diode bar is a result of the incoherent addition of all combined array mode.

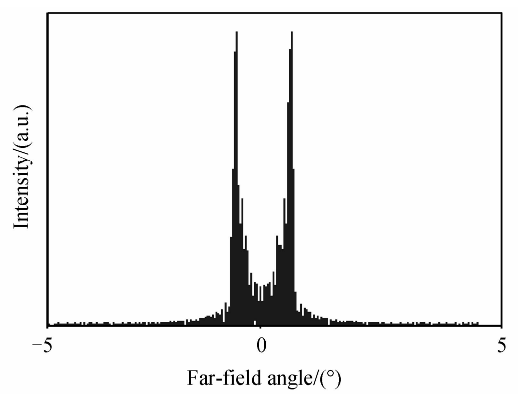

Fig. 1 The far-field profile of the 12-th order combined array mode

While calculating the far-field profile of laser diode bar, all the emitters are assumed the same and the separations between emitters are the same. We also assumed that the bar has no simile. Fig. 2 shows that the calculated far-field profiles of laser diode bar. It can be shown clearly that the far-field profile of laser diode bar is not two-lobe structure. Each combined array mode has a two-lobe profile in the far field with different angular position, so the overlap of far-field profile of all combined array mode can not produce the two-lobe profile[8].

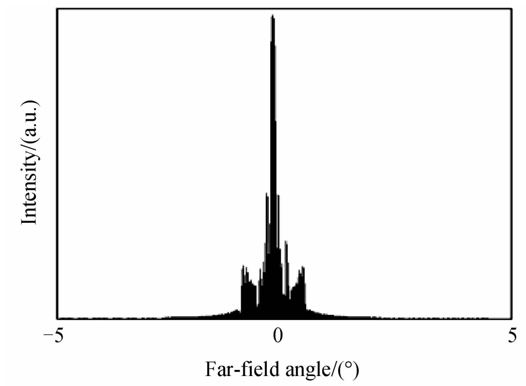

Fig. 2 The far-field profile of laser diode bar

2 Experimental results

The real far-field pattern and intensity profile of laser diode bar were measured as Fig. 3(a) and (b) respectively by experiment. There are some differences in the far-field profile of laser diode bar between the theory calculation and the real measurement. This is because that we did not consider the difference between emitters, the smile effect and so on, while calculating the far-field profile of laser diode bar.

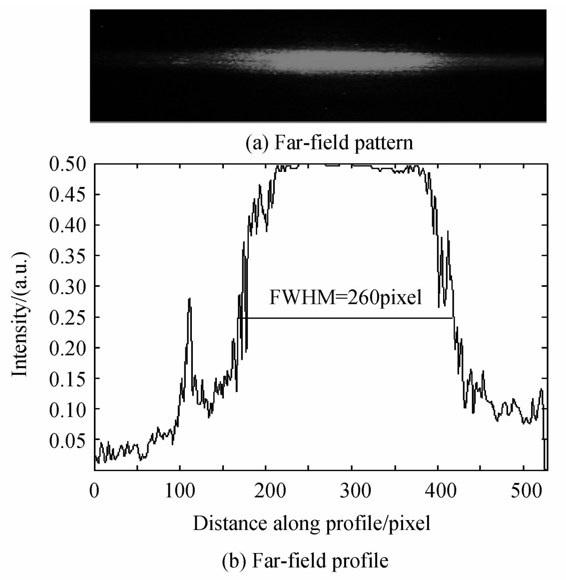

Fig. 3 Measured far-field pattern and profile

On the basis of the two-lobe, far-field profile of combined array mode, an off-axis external cavity setup can be designed to improve beam quality of laser diode bar in slow axis (x axis). The experiment setup is shown in Fig. 4. In this setup, a laser diode bar made up of 49 emitters was used. The dimension of each emitter is 1 by 80 μm with a separation of 200 μm between emitters. The center wavelength of laser diode bar is 808 nm and the length of laser diode bar along slow axis direction is 1 cm. Laser diode bar has an antireflection coating with the reflectivity of about 5%, whereas the back facet has a high-reflection coating. The setup is split into two branches. One branch is feedback branch and the other is output branch. The lens L_1, lens L_3 and high-reflective mirror M consist of feedback branch. And the output branch is made up of the lens L_1 and lens L_2.

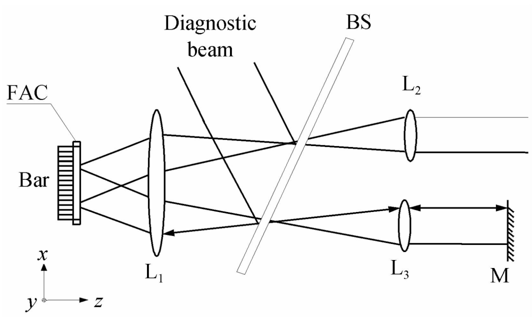

Fig. 4 Experiment setup

For the different combined array modes, the two-lobe profiles in the far field correspond to different angular positions. So, we can choose a single lobe of one of the combined array modes to feedback laser diode bar by tilting the high-reflection mirror M. Thus the other lobe of this combined array mode is amplified and taken as output beam. According to the mode competition theory, all the other combined array modes are suppressed effectively[9-11]. By this, the laser diode bar will oscillate in a narrow mode range. As a result, the beam quality is improved drastically.

A beam splitter is inserted into near the focal plane of lens L_1 to reflected a beam as diagnostic beam. In the path of diagnostic beam, we can insert a lens which can image the far-field pattern into CCD. Fig. 5 (a) and (b) is the far-filed pattern and intensity profile of external cavity feedback laser diode bar respectively at the drive current of 16 A. As seen clearly, the far-field profile with external feedback is a two-lobe profile. The width (FWHM) of one lobe of output laser is about 60 pixels in CCD. When we removed the high-reflection mirror M, the far-field pattern of free-running laser diode bar can be obtained as Fig. 3. However, the width (FWHM) of far-field of free-running laser diode bar is 260 pixels, which are about 4.3 times of that of external cavity feedback laser diode bar. Therefore, the divergence of external cavity laser diode bar has a reduction of 4.3 times. The output facet of laser diode bar is regarded as near field. The beam width (in slow axis) of near field is 10 mm. In this paper, the beam parameter product (BPP) is used to evaluated the beam quality of output laser. Compared with the free-running laser diode bar, the divergence of the external cavity laser diode bar has a reduction of 4.3 times. However, the free-running and external cavity feedback laser diode bar has the same beam width in near field. So the BPP of external cavity laser diode bar is reduced by 4.3 times. The beam quality of external cavity feedback laser diode bar improves by 4.3 times than that of free-funning laser diode bar. The output laser is taken from one branch. The output power of external cavity feedback laser diode measured 1.82 W at the drive current of 16 A or 79% of the radiated power of the free-running state.

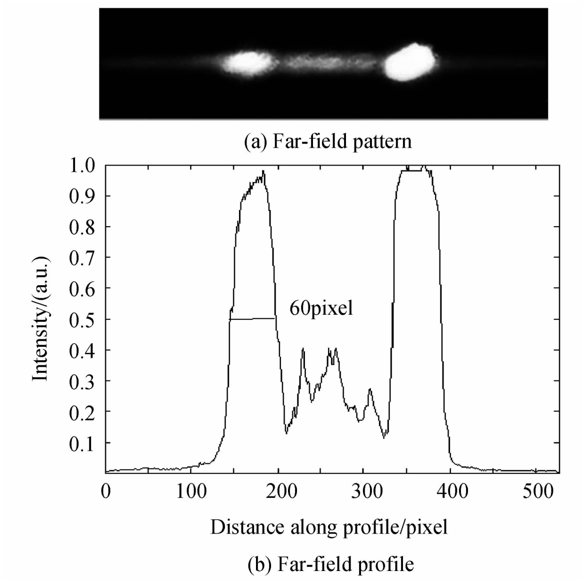

Fig. 5 Measured far-field pattern and profile with external cavity

3 Conclusion

In conclusion, we calculated the far-field pattern of free-running and external cavity feedback laser diode bar. On the basis of the characteristic of far-field profile of combined array mode, we design an off-axis external cavity setup. By employing the setup, a two-lobe, far-field profile was obtained. The width (FWHM) of one lobe of output laser is about 60 pixels in CCD which is narrowed 4.3 times than that of far-field profile of the free-running laser diode bar. The output power of external cavity feedback laser diode measured 1.82 W at the drive current of 16 A or 79% of the radiated power of the free-running state.

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基于组合模理论设计的激光二极管阵列外腔

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摘 要:针对激光二极管阵列提出了“组合模”概念,计算了组合模的远场分布.每个组合模在远场的空间分布呈双瓣结构.基于激光二极管阵列组合模的远场分布特征,设计了离轴外腔反馈的激光二极管阵列.运用此装置所获得激光二极管阵列的远场分布有了明显变化.与自由运转的激光二极管阵列相比,离轴外腔反馈的激光二极管阵列远场宽度减少了 4.3 倍.在抽运电流为 16 A 时,测得输出激光的功率 1.82 W,这相当于相同电流下自由运转激光器输出功率的 79%.组合模理论不仅可以用来指导设计一维离轴外腔反馈激光二极管阵列,而且也可以用于设计二维离轴外腔反馈激光二极管阵列.二维离轴外腔反馈激光二极管阵列可以产生高功率,高光束质量输出的激光.

关键词:二极管阵列;组合模;远场分布;外腔