Beam combining of a high-power laser diode bar on a temperature gradient heat sink

Xiang Wu (吴 翔)[1], Zi Ye (叶 子)[1], Zukang Lu (陆祖康)[1],

Yoshihiro Takiguchi (瀧口义浩)[2], You Wang (王 攸)[2], and Hirofumi Kan (管博文)[2]

[1]*State Key Lab of Modern Optical Instrumentation, Optical Department of Zhejiang University, Hangzhou 310027*

[2]*Central Research Laboratory, Hamamatsu Photonics K. K., Harakuchi 5000,*

Hamakita-City, Shizuoka-Pref., 434-8601 Japan

A new wavelength beam combining technique for a high-power laser diode bar by using a temperature gradient heat sink has been proposed. The thermal controlling principle of the temperature heat sink has been discussed. It has been proved by experiment that the linear temperature distribution, which generates linear wavelength spread of the output beams from a LD bar, can be obtained by introducing a temperature gradient heat sink and the output beams can be focused into a relative small spot by using the Czerny-Turner beam shaping system.

OCIS codes: 140.0140, 140.2010, 140.3300.

High-power laser diode (LD) bars emitting at near infrared wavelength (790 − 980 nm) are required for pumping solid-state lasers, material processing, and numerous medical applications[1−3]. Due to the large beam divergence and the bad beam quality, many beam combining techniques for laser diodes have been proposed[4−10]. However, the incoherent beam combining techniques, such as using fibers, micro-optics[4], and two-mirror beam shapers[5], can only symmetrize the beam quality of the output without increasing brightness. The coherent approaches based on phase-locked techniques[6−9] have the difficulty that the relative phases of the emitters of the LD bars must be controlled with the accuracy of much less than a wavelength.

Based on the wavelength multiplexing principle, V. Daneu *et al.* in Lincoln Laboratory, MIT realized the equalization of the beam quality factors and high power density of output beams from an 11-elements, linear laser diode array with broad stripes[10]. However, a very stable external cavity that is not suitable for the industrial applications is still necessary in this method. Therefore, we carry out a simple method on the basis of the wavelength multiplexing technique to focus the output beams from a LD bar into a relatively small spot.

In order to take advantage of the wavelength multiplexing technique, a light source with wide spectrum spread is essential. A LD bar emitting at only one wavelength cannot be used as such a light source. Therefore, a new kind of heat sink, which is so-called "temperature gradient heat sink", is proposed to generate linear wavelength spread of the output beams from a LD bar. By using the temperature gradient heat sink, the wavelength of output beam from each emitter of a LD bar can be controlled. we will discuss the thermal controlling principle of the temperature gradient heat sink in detail. Suppose that GaAs multiple quantum wells are used as the high-power laser diode structure, the band gap energy $E'_g(T)$ of the quantized laser diode active layer at temperature T is given by

$$E'_g(T) = E_g(T) + \Delta E, \qquad (1)$$

where $E_g(T)$ is the bulk band gap energy of GaAs and ΔE=0.113 eV, which is the quantized energy due to the quantum confinement of the AlGaAs/GaAs/AlGaAs well structure. ΔE is less sensitive than $E_g(T)$ for temperature change. Therefore, rough wavelength change can be estimated from the band gap energy $E_g(T)$, which is given by

$$E_g(T) = E_g(0) - \frac{aT^2}{T + b}, \qquad (2)$$

where $E_g(0)$=1.519 eV, $a = 5.405 \times 10^{-4}$, and $b = 204$ for GaAs. The relation of wavelength λ and the temperature T can be expressed as

$$\lambda = \frac{hc}{E'_g(T)}, \qquad (3)$$

where h is the Plank constant and c is the velocity of light. To achieve linear wavelength spread $\lambda(x)$ of the output beams of a LD bar, the temperature distribution $T(x)$ have to be generated.

By using Eqs. (1)−(3), the temperature distribution $T(x)$ can be estimated. Figure 1 shows the temperature distribution $T(x)$ for $\lambda(0) = 808$ nm when the size of the laser diode bar is 10 mm and the wavelength dispersion is 1.0 nm/emitter. In this case, the wavelength of the output beams from the laser diode bar changes from 808 to 818 nm and the corresponding temperature change is from 300 to 340 K. It has been shown that the approximate linear temperature distribution can generate the linear wavelength spread. As shown in Fig. 2, the linear temperature distribution can be obtained by introducing a temperature gradient heat sink with the combination of a heater and a cooler. Theoretical analysis and preliminary experiments indicate that the shape of the heat sink will affect the temperature distribution. We will report the design and material of the temperature heat sink in details in further papers.

The schematic configuration of Czerny-Turner beam shaping system for the outputs from a GaAs/AlGaAs multiple quantum well (MQW) LD bar operating at

nominal 808-nm wavelength is shown in Fig. 3. The output beams are collimated in the plane perpendicular to the bar with an antireflection-coated cylindrical lens. The concave mirror M_1 is used to transform the position distribution of the emitters on the LD bar into an incidence angle distribution on the Al-coated grating with 1800/mm at least. Because of the linear wavelength spread of the output beams, the grating diffracts the beams with different angles into a same direction and the concave mirror M_2 focuses the beams into a small spot.

The parameters of the system are chosen as the following. The length of the laser diode bar is 10 mm. $f_1 = 78$ mm and $f_2=78$ mm are the focal lengths of the concave mirrors M_1 and M_2, respectively. The grating is ruled with 1800/mm. The chosen period is so high that the grating has only zero- and first-order diffraction in order to eliminate efficiency losses to higher diffraction orders. The estimated spot size at the focal point of M_2 is 1.1×1 mm^2.
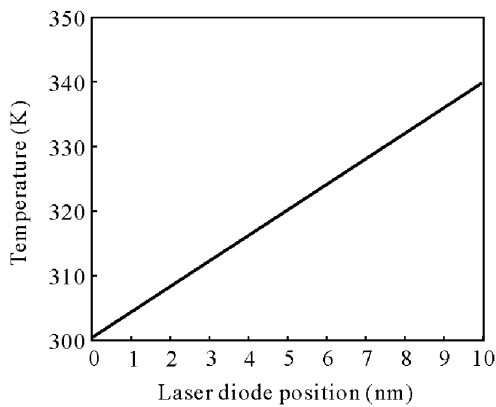

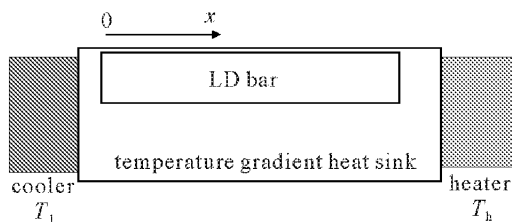Fig. 1. Temperature distribution on a LD bar having linear wavelength spread.

Fig. 2. Schematic configuration of the temperature gradient heat sink.
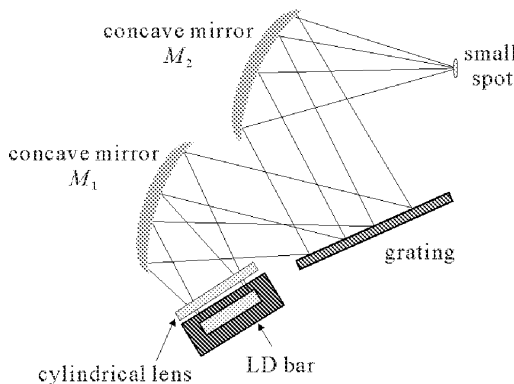

Fig. 3. The Czerny-Turner beam combining system.

In order to verify the feasibility of the Czerny-Turner beam shaping system, the preliminary experiment as illustrated in Fig. 4 has been carried out. An emitter of a GaAs/AlGaAs MQW LD bar is chosen to simulate a LD bar with linear wavelength spread. The output wavelength can be changed by controlling the temperature of the water through the water-cooling heat sink packaged under the LD bar. To simulate each emitter of the LD bar with linear wavelength spread, the emitter should be shifted to different positions with the corresponding wavelength dispersion. A CCD camera is placed at the focal point of the concave mirror M_2 to detect the position of the focused spot. When the emission wavelength changes, the emitter should be shifted to keep the focused spot at the same position. Figure 5 shows the emission wavelength as a function of the LD temperature. It has been shown by experiment that the linear temperature distribution can generate the linear wavelength spread and the wavelength spread is 7 nm when temperature changes from 0 to 40 °C. The experimental thermal wavelength dispersion is 0.175 nm/°C. According to Eqs. (1) − (3), the corresponding theoretical one is 0.25 nm/°C. It should be noted that only the influence of temperature on wavelength change was taken into account in our theoretical analysis. Therefore, the thermal properties of the actual devices should be studied in detail in the further study.

Figure 6 shows the relation between emission wavelength and the shift distance d. According to

$$\sin \alpha + \sin \beta = mG\lambda, \quad (m = 0, \pm 1, \pm 2 \cdots), \qquad (4)$$
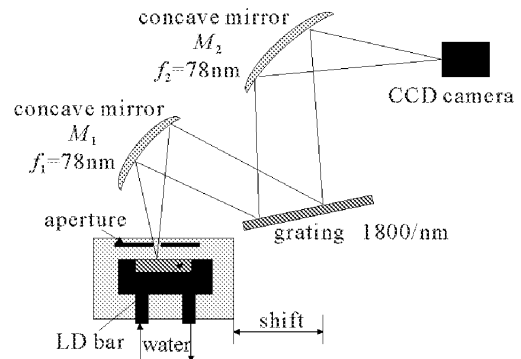

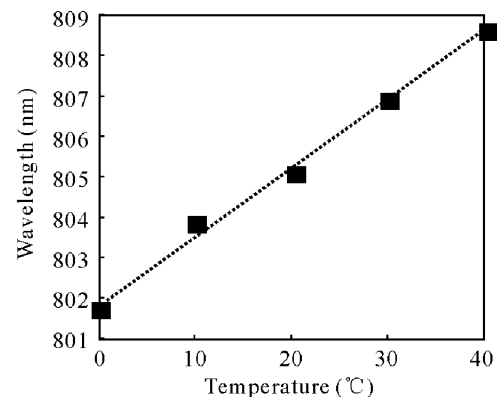Fig. 4. Schematic configuration of the experimental set up.

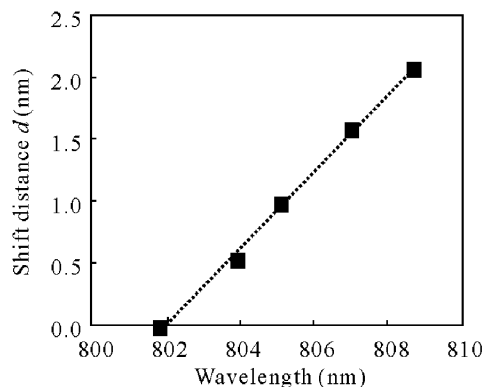Fig. 5. The emission wavelength as a function of the LD temperature.

Fig. 6. The relation between wavelength and shift distance d.

where α is the incidence angle, β is the diffraction angle, G=1800/mm is the groove frequency, and m is the diffraction order and only the first order ($m = 1$) is considered in this case, the shift distance d can be evaluated by

$$d \approx \frac{f_1 \Delta \lambda G}{\cos \alpha_0}, \tag{5}$$

where f_1=78 mm is the focal length of concave mirror M_1, $\Delta \lambda$ is the wavelength spread, and $\alpha_0 = 58.5°$ is the initial incidence angle. It is shown by experiment that the shift distance d is 2.05 mm when the corresponding wavelength spread $\Delta \lambda$ is 7 nm. The theoretical result is found in agreement with the experimental value.

In summary, the new beam combining technique for a high-power LD bar by using temperature gradient heat sink has been proposed. It is shown that the output beams of a LD bar can be focused into a relative small spot by this simple technique. In the further work, the thermal properties of the actual LD bar devices and the structure of the temperature heat sink will be studied.

References

1. D. L. Cunningham and R. D. Jacobs, Proc. SPIE **2382**, 72 (1995).
2. M. Pessa, J. Nappi, P. Savolainen, A. Ovtchinnikov, M. Toivonen, R. Murison, and H. Asonen, Proc. SPIE **2682**, 161 (1996).
3. P. Albers, H. J. Heimbeck, and E. Langenbach, Proc. SPIE **1780**, 533 (1993).
4. W. Chen, C. S. Roychoudrhuri, and C. M. Banas, Opt. Eng. **33**, 3662 (1994).
5. W. A. Clarkson and D. C. Hanna, Opt. Lett. **21**, 375 (1996).
6. P. Ehbets, H. P. Herzig, R. Dändliker, P. Regnault, and I. Kjelberg, J. Mod. Opt. **40**, 637 (1993).
7. L. J. Mawst and D. Botez, Proc. SPIE **2397**, 526 (1995).
8. D. Mehuys, W. G. Streifer, R. G. Waarts, and D. F. Welch, Opt. Lett. **16**, 823 (1991).
9. R. H. Rediker, K. A. Rauschenbach, and R. P. Schloss, IEEE J. Quantum Electron. **27**, 1582 (1991).
10. V. Daneu, A. Sanchez, T. Y. Fan, H. K. Choi, G. W. Turner, and C. C. Cook, Opt. Lett. **25**, 405 (2000).