Study on the beam shaping of high-power laser diode bars

Wei Huang (黄 伟), Xiaodong Zeng (曾晓东), and Yuying An (安毓英)

School of Technical Physics, Xidian University, Xi'an 710071

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Based on the Collins form, the intensity distribution of the resulting beam is derived when Gaussian beams of a high-power laser diode bar pass through a paraxial optical system. Then flattop beam profiles are obtained by a concave cylindrical lens, and the propagation properties are discussed in detail, such as the peak-intensity axis inclined at an angle γ_i. In addition, an expression to calculate beam angular width is presented.

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In many applications, such as laser material processing, laser projection printing, optical gauging, laser radar, and laser fusion, flattop beam profiles are required. However, Gaussian irradiance beams do not provide flattop irradiance distributions. Therefore, efficient shaping of Gaussian irradiance beams into a flattop irradiance beam is of great significance. So far, a considerable number of techniques have been suggested and used in attempts to get flattop irradiance distributions[1−7]. Lee suggested a method of using a phase filter to flatten Gaussian beams[1]. Han *et al.* proposed a method of flattening Gaussian beams by a focal system[2]. Dew and Parsons used an absorbing lens[3], and Pu *et al.* described a method of obtaining a flattop beam in which aberrated lenses are used[5]. However, the main drawback of these methods is that they require a complicated configuration.

In this paper, the intensity distribution of the resulting beam is derived when the beam of a high-power laser diode bar passes through a paraxial optical system, then a novel optical system for a laser array instead of a single laser is proposed to achieve ideal flattop beam with a great divergence angle, finally the propagation properties are studied.

Assume that the irradiance distribution of each emitter for a laser diode bar in slow axis is Gaussian function. These individual Gaussian beams are positioned at the $z = 0$ plane, whose waist width is ω_0 and the separate distance is x_d. Then the field distribution of the Gaussian beam is

$$E_{0i}(x,0) = \exp\left[-\frac{(x-a_i)^2}{\omega_0^2}\right],$$
$$a_i = mx_d,\ \ m \in \left[-\frac{N-1}{2}, \frac{N-1}{2}\right], \qquad (1)$$

where N is the number of laser diode emitters.

The propagation of the Gaussian beam described by Eq. (1) passing through a paraxial $ABCD$ optical system obeys the well-known Collins formula,

$$E_i(x,z) = \frac{i}{\lambda B}\int E_{0i}(x,0) \times \exp\left[-\frac{ik}{2B}(Ax_0^2 - 2x_0x + Dx^2)\right] \mathrm{d}x_0. \qquad (2)$$

Substituting Eq. (1) into Eq. (2), the result can be written as

$$E_i(x,z) = \frac{1}{A + B/q_0} \times \exp\left[-\frac{k}{2q_1(z)}(x - a_iA)^2 - ika_iCx + ika_i^2\frac{AC}{2}\right], \qquad (3)$$

where k is the wave number, q_0 and q_1 are the initial and final parameters at $z = 0$ and z planes, respectively, and defined as $q_0 = \frac{\pi\omega_0^2}{i\lambda}$ and $q_1 = \frac{Aq_0+B}{Cq_0+D}$.

For the case of the incoherent combination, the irradiance distribution of the resulting beam can be given by

$$I_i(x,z) = \sum_i E_i(x,z)E_i^*(x,z) = \frac{\omega_0^2}{\omega_x^2}\sum_i \exp\left(-\frac{2(x - Aa_x)^2}{\omega_x^2}\right), \qquad (4)$$

where $\omega_x = \omega_0\sqrt{A^2 - B^2/q_0^2}$.

It is obvious that the Gaussian beam maintains its transverse profile in the Gaussian manner after passing through a paraxial optical system.

The laser diode bar used in the experiment is consisting of 19 emitters, and the separation between two neighboring emitters is 500 μm, the wavelength of the laser diode bar is 808 nm and the output power is 20 W. For the sake of simplification, we assume that the waist radius and the power of each emitter are the same. These assumptions are reasonable for most laser diode bars. For compressing the high divergence of the laser beam, a microcylindrical lens is used for fast-axis collimation.

Substituting the matrix elements into Eq. (4), the intensity of the resulting beam is given as

$$I(x,z) = \frac{\omega_0^2}{\omega_x^2}\sum_{i=1}^{19}\exp\left\{-\frac{2[x - a_i(1-(z-d)/f)]^2}{\omega_x^2}\right\}, \qquad (5)$$

where $\omega_x^2 = 4\left[\frac{z-d(z-d)/f}{k\omega_0}\right]^2 + \left(1 - \frac{z-d}{f}\right)^2\omega_0^2$, d and z are the distances from the laser diode bar to the concave cylindrical lens and to the output plane, respectively.

A numerical example of the propagation for the laser diode bar described above is shown in Fig. 2 with the

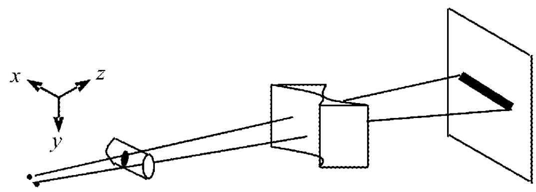

Fig. 1. Schematic view of the optical system composed of a concave cylindrical lens.

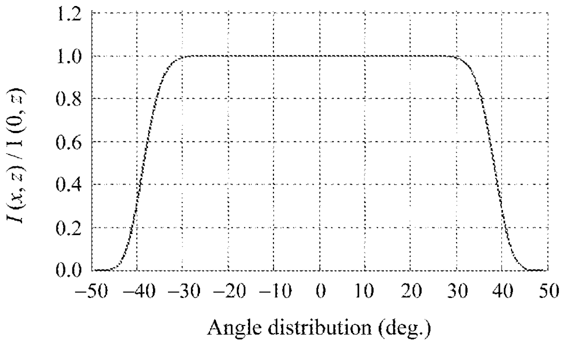

Fig. 2. Relative intensity distribution of the resulting beam.

parameters of $d = 20$ mm and $f = -6$ mm. It can be seen that the angular width of the flattop beam is as large as 60° in slow axis.

Equation (5) provides a complete description of the properties of the resulting beam as follows.

In the far-field region, the output Gaussian beam of each emitter has the same divergence angle in the x-z plane, expressed as

$$\begin{aligned}\theta_x &= 2\lim_{z\to\infty}\arctan\left(\frac{\omega_x}{z}\right)\\ &= 2\arctan\left[\frac{1}{f^2}\omega_0^2+\frac{4(1-d/f)^2}{(k\omega_0)^2}\right]^{1/2}\\ &\approx 2\arctan\left[\frac{2(1-d/f)}{k\omega_0}\right].\end{aligned} \quad (6)$$

The peak intensity of each output Gaussian beam lies on a straight line that passes through the focus of the concave cylindrical lens at an angle

$$\begin{aligned}\gamma_i &= \arctan\left[\frac{a_i(1-(z-d)/f)}{z-d-f}\right]\\ &= \arctan\left(-\frac{a_i}{f}\right).\end{aligned} \quad (7)$$

We call this line the peak-intensity axis. When these angles are small, the difference between two neighboring peak-intensity axes can be given by $\Delta\gamma \approx -x_d/f$.

The flattop beam spot size in the x direction is approximate to

$$\begin{aligned}L &= (N-1)\Delta x\\ &= -\frac{(N-1)x_d}{f}(z-d-f),\end{aligned} \quad (8)$$

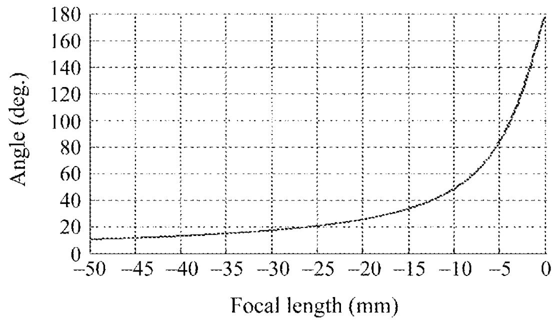

Fig. 3. The relationship between the focal length and beam angular width.

where Δx denotes the distance of two neighboring peak intensity at the output plane, and N is the number of emitters. Then the angular width of the resulting beam can be expressed as

$$\begin{aligned}\Delta\delta &= 2\arctan\left[\frac{L}{2(z-d-f)}\right]\\ &= 2\arctan\left[-\frac{(N-1)x_d}{2f}\right].\end{aligned} \quad (9)$$

It can be seen that the beam angular width depends on the focal length of a concave lens. However, the parameter d can affect the irradiance distribution of the resulting beam. Figure 3 shows the relationship between the focal length and the beam angular width.

In summary, flattop beam profiles can be easily achieved by a concave cylindrical lens. The larger the focal length of the concave cylindrical lens, the less the beam angular width. It is expected that this new method may provide a useful and effective technique for beam shaping in laser applications.

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W. Huang's e-mail address is zwenyi@sohu.com.

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