Microlens array for stacked laser diode beam collimation

Qiling Deng, Chunlei Du, Changtao Wang, Chongxi Zhou, Xiaochun Dong, Yinghui Liu, Tao Zhou
(State Key Lab of Optical Technologies for Microfabrication, Institute of Optics and Electronics, Chinese Academy of Sciences, Chengdu 610209, China
Tel: 028-85100889, Fax:028-85100210, E-mail: dengqiling@hotmail.com

Abstract
To collimate effectively the beam emitted from the stacked laser diode in which the lasing surfaces of the diode bars are not located in a plane, a new type of fast-axis collimator, refractive cylindrical microlens array with tunable focal lengths, is presented in this paper. Each lens of the array has the same diameter of 300 μm but different focal lengths, ranged from 430 μm to 540 μm. By means of the mask moving lithography and replication technology, the microlens array was successfully fabricated. The measured fast-axis divergence of the stacked laser diode beam after the collimator was 25 mrad, about half of the one (40 mrad) for the microlens array with common focal lengths of 400 μm.

Key words: microlens array, laser diode stack, laser beam collimation

1. INTRODUCTION
With the increased requirement of laser power and brightness, stacked laser diodes have become important devices for many applications such as pumping solid-state laser and material processing. Usually 5~20 bars of laser diode are mounted on a common heat sink to reach the output power of several hundred to several thousand watts. Unfortunately, this process often delivers great assembling errors, such as the irregular and slight tilt, deviation and variant space between bars, which make the collimation of laser diode beams difficult. The general method to solve this problem is using individual optical cylinders for each bar, as the engineers did in Decade Optical Systems, Inc. But laborious and complicated work is needed to precisely position each lens with a six-axis mount. [1] In our recent research, it is found that the deviation of the lasing surfaces of bars plays the most harmful role in affecting the collimator, which makes it possible to use one arrayed lens element for stacked laser diode beam collimating in the fast axis. A new method presented in this paper shows that the non-uniform refractive microlens array, in which each lens has different focal lengths, proved effective to decrease the beam divergence of about 25 mrad.

The principle of this method was given in Section 2, and the manufacturing for the microlens array with tunable focal lengths was described in Section 3. The experiment for the laser diode stack beam collimation in fast axis was presented in Section 4. Some discussions were also given in the conclusion.

2. PRINCIPLES OF COLLIMATORS FOR STACKED LASER DIODE
The commonly used collimators for astigmatic laser beams like laser diode is two optical cylinders for fast axis and slow axis separately. For arrayed laser diodes, the micro lens array has been developed to facilitate assembling, for example a laser diode bar in which many laser diodes emitters are arranged accurately and periodically in a line [2]. It
seems plausible to employ two-dimensional microlens array for the collimation of stacked laser diode bars. However, present industrial packaging technology can not promise precise assembling diode stacks. Multiple errors might be existed: each bar in a stack can have more or less “smile” than another, bars can be tilted differently in elevation and azimuth and assembly and machining tolerances can produce variations in pitch from bar to bar. This fact makes the collimation via a single optical arrayed element very difficult.

The common method is described as follows [1]: Individual lenses are positioned using a six-axis mount to precisely position each lens, and fast-curing UV epoxy is used to set each lens in place on a set of insulative rails on either end of the diode bar to be collimated. This way offers the possibility of good lensing for each bar, but needs laborious and complicated assembling work and inevitably increases the cost. However, the arrayed lenses in a single element are still more competitive in some special cases, where the exact collimation of each bar is not necessary for required divergence and the tilt between bars is avoidable.

In our research, a stacked laser diode is used for pumping solid laser, in which five bars, with the total power of 300w at 808nm, are stacked together with the space of 400μm, and the emitting area of each bar is about 100μm×1μm. The divergence of the emitted beam is 40° and 10° in the fast and slow axis, respectively. To facilitate the following shaping optics, the divergence in the fast axis of the laser diode beam has to be decreased to the level of 1°. By using a microscope, the emitting surface of the laser diode bars was inspected carefully for any possible assembling errors. The front view of the stack, as shown in Fig.1, shows the uniform spacing and pitch size and imperceptible tilt in elevation between each bar. The micrograph (Fig.2) viewed from one side of the stack indicates obviously that there are great position deviations from each other.

So an array of five cylinders with common apertures of 300μm and space of 400μm but different focal lengths corresponding to the measured position deviation of each bar would work well for the beam collimation of the total stack. The collimation schematic is shown in Fig. 3. The parameters of the microlens array are given in Table. 1.
Table 1 Microlens array with different focal lengths and sag depths
(* The focal lengths and sag depths is calculated with the formulas of parabola lens [3])

<table>
<thead>
<tr>
<th></th>
<th>Lens 1</th>
<th>Lens 2</th>
<th>Lens 3</th>
<th>Lens 4</th>
<th>Lens 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position deviation μm of the correspondent bar</td>
<td>100</td>
<td>50</td>
<td>0</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Focal length μm *</td>
<td>436</td>
<td>478</td>
<td>536</td>
<td>478</td>
<td>436</td>
</tr>
<tr>
<td>Sag depth μm *</td>
<td>57</td>
<td>52</td>
<td>47</td>
<td>52</td>
<td>57</td>
</tr>
</tbody>
</table>

3. MANUFACTURE OF THE MICROLENS ARRAY

Moving lithography technology [3,4] is employed to fabricate the microlens array for the stacked laser diode beam collimation. The main principle of the technology is to obtain the desired exposure distribution on photo resist by an binary mask mounted close to the resist and moving the mask along a direction. After developing, the latent profile of the micro structures will be shaped on the resist, and can be transferred with expected accuracy to the surface of UV-curing adhesives by replicating technology or glass like optical materials by dry etching.

Fig.4 gives the micrograph of the mask for producing the microlens array, in which each column of hat like patches represents a micro cylindrical lens. The SEM picture of the replicated lenses is shown in Fig.5. From the measured profiles of the microlens array by Alpha step 500, as shown in Fig.6, five cylinders with different focal lengths are successfully fabricated.
4. EXPERIMENT

To show the superiority of the arrayed lenses with tunable focal lengths, a microlens array with similar configuration parameters except uniform focal length of 400um is also fabricated and experimented separately as a comparison. The experimental system was established as shown in Fig. 7. By the help of a six-axis mount, precise adjustment was done to position the collimating lenses to obtain the satisfied result.

A beam spots of the diode laser beam collimated by the microlens array with tunable focal length and the one with common focal length, were taken at a distance of 125mm from the emitting surface, and shown in Figs.8(a), Figs.8(b), respectively. Obviously, the laser beams with the two type of lens array are both collimated, but the collimator with tunable focal length provides much smaller spot size, and moreover, higher efficiency, as can be seen from Figs.8b) that a considerable amount of energy is strayed away from the central spot and the defocusing of collimating lenses with common focal length is believed to account for this phenomena.

The collimated divergence is estimated by the following formula:

$$2\theta = \arctg \frac{d_2 - d_1}{l}$$

(1)
Where $d_1$ and $d_2$ are the spots size of the laser beams on two planes separated with the distance $l$. With the emitting area width of 1.6mm, the distance of 125mm and the measured spot sizes of 4.7mm and 6.6mm (FWHM) in Fig.8 a) and Fig.8 b), the calculated divergences are 25mrad and 40mard for the two collimators.

Fig.8 Spot of laser diode stack collimated by microlens a) with tunable focal length b) with the same focal length.

5. CONCLUSION

The collimation of stacked laser diode beams is usually regarded as a complicated work for the existence of multiple assembling errors accompanied in the production. The microlens array with tunable focal lengths presented in this paper is experimentally proved useful to decrease the divergence in the fast axis to about $1^\circ$. Although difficult it is to extend this method to all cases, we believe that this idea is helpful to solve the similar problem aroused in the beam shaping of arrayed lasers.

REFERENCES