Fabrication of asymmetric laser beam shaping elements

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The intensity distribution of conventional edge emitting semiconductor lasers is an asymmetric Gaussian beam. To use this light source in optical systems, typically a circularization is required, if light loss at the lens is to be avoided. In this paper, we present a new optical element, which generates a circular and homogeneous beam with only one component.

1 Introduction

Beam shaping is used to transform a given intensity distribution into a different, desired intensity distribution. Applications of beam shaping are typically in the area of efficient focussing and in high power laser operations, where the Gaussian beam shape leads to an inefficient usage of the available laser power due to loss at the focusing lens.

In high power applications, beam shaping is used to maximise the power transfer into the focus. In other applications, the aim is to minimise the spot diameter. In order to achieve a diffraction limited focal spot size, the amplitude in the plane of the focusing lens has to be approximately constant. Conventionally this requirement is satisfied by using only the inner fraction of the Gaussian beam profile, causing significant loss. By beam shaping, this loss can be removed, leading to a minimum focal spot size. At the same time, the efficiency can be increased to almost 100 %.

The conversion of a Gaussian intensity distribution into a uniform profile is well established for the case of one-dimensional or rotationally symmetric distributions [2]. The intensity distribution of conventional edge emitting semiconductor lasers, however, is an asymmetric Gaussian beam. In order to convert this light into a circular and homogeneous distribution by beam shaping, there is no existing theory.

2 Beam shaping of nonsymmetric sources

In the application described here, our goal is to transform a non-symmetric Gaussian beam from a semiconductor laser with directional intensity

$$I\left(s_x, s_y\right) = I_0 \cdot e^{-2s_\perp^2\left(\left(\frac{\cos\varphi}{\sigma_x}\right)^2 + \left(\frac{\sin\varphi}{\sigma_y}\right)^2\right)} \qquad (1)$$

into a rotationally symmetric, homogeneous soft flat top distribution. A soft flat-top of the form [1]:

$$I(r) = \left(1 + r^N\right)^{-\frac{2}{N}-1} \qquad (2)$$

is preferred to a constant flat-top because the final component is less insensitive to fabrication errors or misalignment. For the design, the underlying principle is the law of power conservation, which, expressed in the directional s-space is

$$I_1\left(\vec{s}_1\right) d\Omega_1 = I_2\left(\vec{s}_2\right) d\Omega_2 \qquad (3)$$

The design method [3] consists of three steps. The first is to develop a mapping for the rotationally symmetric case, transforming the Gaussian distribution into the soft flat-top according to eq. 2. For this distribution, a fully analytic solution exists:

$$s_{2\perp}\left(s_{1\perp}\right) = \frac{\left(\left(1 - e^{-2s_{1\perp}^2 A(\varphi)}\right)^{-N/2} - 1\right)^{-\frac{1}{N}}}{\sqrt{2\alpha A(\varphi)}} \qquad (4)$$

The second step is a linear transformation of the mapping, which reflects the asymmetric shape of the laser.

$$\vec{s}_2\left(\vec{s}_1\right) = \frac{s_{2\perp}\left(s_{1\perp}\right)}{s_{1\perp}} \begin{pmatrix} s_{1x} \\ s_{1y}\,\dfrac{\sigma_x}{\sigma_y} \end{pmatrix} \qquad (5)$$

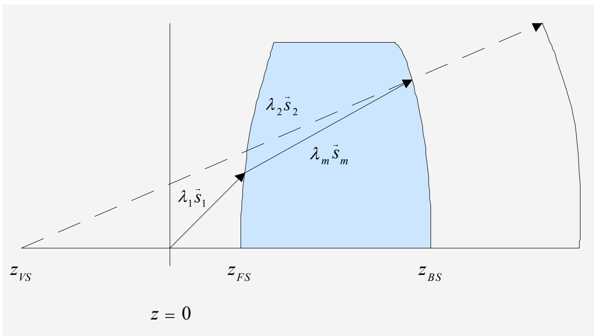

Fig. 1 *Beam shaping in directional space - geometry of the optical element.*

In the third step, the calculation of the front- and back surface, is based on the vectorial law of refraction and the constant path-length condition:

$$\lambda_1 + n\lambda_m - \lambda_2 = z_{FS} + n\left(z_{BS} - z_{FS}\right) - \left(z_{BS} - z_{VS}\right) \quad (6)$$

The quantities and the geometry are explained in fig. 1. The asymmetric laser source is located at z=0, and the total optical path length refers to a virtual point source, located at z_{VS}. We assume, that the direction vector behind the back surface is given. By solving the geometrical lengths $\lambda_1, \lambda_m, \lambda_2$, the direction vectors inside the element and consequently the surface normals can be computed. From these, the height distribution follows according to:

$$\frac{\partial h}{\partial x, y} = -\frac{N_{x,y}}{N_z} \quad (7)$$

Fig. 2 shows the x- and y-view of the ray path through the system. The component was designed to generate a divergent spherical wave at the element output.

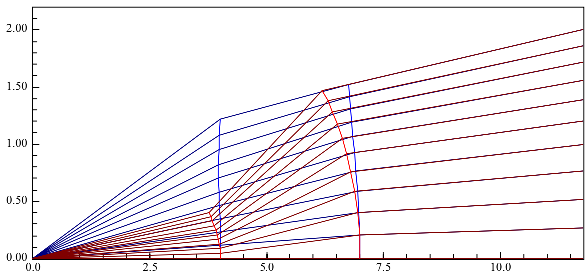

Fig. 2 *Computed ray path through the element for the fast axis (blue) and for the slow axis (red).*

3 Fabricaton of the optical element

For injection molding, metal mold inserts were fabricated at Ingeneric GmbH by ultra precision milling with a fly-cutting tool in nickel-silver.

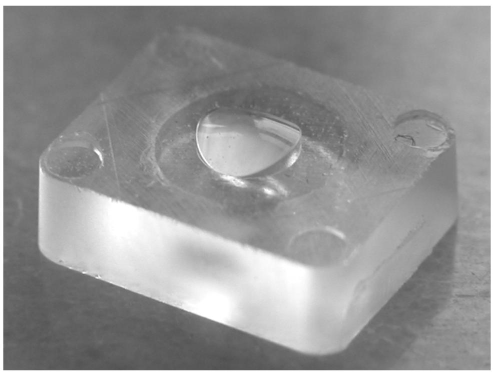

Fig. 3 *Final beam shaping component, fabricated by mold injection*

The surface of the mold inserts had optical quality and showed no measurable grooves. We used ZEONEX E480 as the injection material for the optical component.

The final component is depicted in fig. 3, showing the back surface at the top. A first test of the component, using a blue semiconductor laser with a FWHM of 22° in x-direction and 8° in y-direction is shown in fig. 4. Although, there are still small alignment errors between the front- and the back surface, the element shows the desired operation. The alignment between the laser and the element turned out to be much less critical than initially assumed.

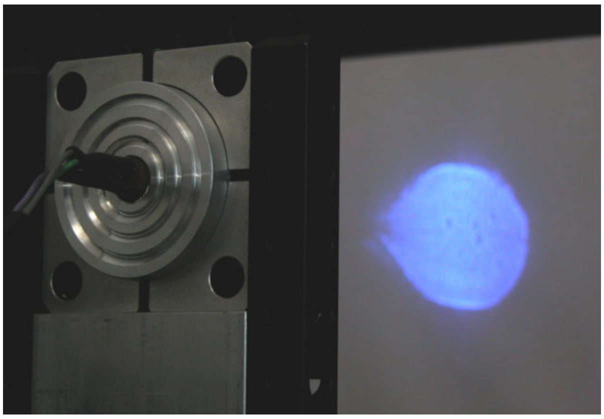

Fig. 4 *Demonstration of the optical performance using a blue laser diode.*

4 Conlusion

We have designed and fabricated a new optical element, which converts the asymmetric beam of edge emitting semiconductor lasers into a circular and homogeneous beam with only one component. Thus, the alignment between laser and optical component becomes very simple. For mass production, a mold insert was realized by ultra-precision milling.

References

[1] K.-H. Brenner, "Beam shapes with a soft flat-top", Annual Report, Chair of Optoelectronics, University of Mannheim (2002/2003), p.17.

[2] P.W. Rhodes and D.L. Shealy, “Refractive optical systems for irradiance redistribution of collimated radiation: their design and analysis”, Appl. Opt. **19**: 3545-3553, (1980)

[3] K.-H. Brenner, "Element zur kombinierten Symmetrisierung und Homogenisierung eines Strahlenbündels", German Patent, Filing No. 10121747.1 (2001)