Stigmatic focussing of astigmatic beams emitted by tapered laser diodes

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The tapered laser diode is a favourite for high power monomodal emission. Unfortunately, it shows a strong astigmatism in the mm-range. The inclusion of the optical path within a planar waveguide into the free space optical light path function allows the geometrical construction of optical surfaces which provide stigmatic imaging as generalization of Descartes ovaloides.

1 Introduction

A tapered laser (Fig. 1) is an example of an extremely astigmatic laser source. It consists of a ridge waveguide RW and a tapered range T, designed for the „free space propagation" of a Gaussian beam in a planar waveguide. The transition range P_0 between RW and T is the geometric-optical source point of radiation to be stigmatically imaged.

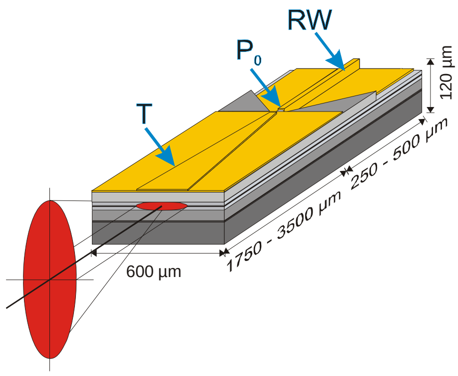

Fig. 1 *Tapered laser with point source P_0*

At present, the monomodal cw-power of the taper lasers achieves 8 W [1],[2]. For example, they are used for second harmonic generation [3],[4]. Here is shown how a corresponding focussing lens can be constructed from eikonal considerations.

2 Eikonal function for a single surface

The stigmatic imaging of the source point P_0 into the image point P_B via a single refracting surface S_2 is shown in Fig. 2.

The transition of the light from the laser into the free space is characterized by refraction of the rays within the plane of the waveguide of the laser. Then, the construction procedure of Descartes ovaloides [6] can be generalized by taking into account the optical path length (eikonal) in the planar waveguide from P_0 to P_B:

$$\delta(\overline{P_0 P_1 P_2 P_B}) = 0$$

In the case of a refractive index $n_0 = 1$ in the planar waveguide, an equation of the sixth degree for surface S_2 results. This corresponds to the neglect of the spherical aberration of the "thick" slab between P_0 and S_1.

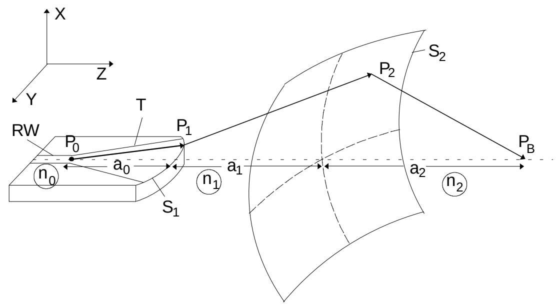

Fig. 2 *Single surface imaging*

Curved facets S_1 of the laser can be included in the correction process, but they are connected with difficulties in technology. The method applies also to concave mirrors and corrected concave gratings which lends oneself to astigmatism correction

3 Mathematical formulation

3.1 A single unknown surface (Fig. 2):

The following values are given: x_2, y_2 (transversal coordinates of the point P_2), a_0, a_1, a_2 (axial distances), n_0, n_1, n_2 (refractive indexes). The two unknown values y_1 (lateral facet coordinate of the point P_1) and $z_2(x_2,y_2)$ (sag of the surface S_2) are determined by the two equations

(1) refraction at S_1 in the plane of the waveguide

(2) optical path length $P_0P_1P_2P_B$ = optical path length along the axis

3.2 A first given surface S_2 and a second wanted surface S_3 afterwards:

The parameters x_3, y_3, a_0, a_1, a_2, a_3, n_0, n_1, n_2, n_3 and $z_2(x_2,y_2)$ are known and the four unknown parameters y1, $z_3(x_3,y_3)$, x_2, y_2 (ray piercing points at surface S_2) are determined by the four equations:

(1) refraction at S_1 in the plane of the waveguide

(2) optical path length $P_0P_1P_2P_3P_B$ = axial path

(3)+(4) general vectorial ray refraction at surface S_2 contains x_2 and y_2 which corresponds to two independent equations of two vector components of the direction vectors.

3.3 N surfaces: Every added known surface generates two additional equations for the ray piercing point coordinates at this surface with help of the vectorial ray tracing at this surface.

4 Inclusion of a diffractive structure

If the surface S_2 in Fig. 2 is given, then the difference

$$\Delta = \left\{ path\,length\ \overline{P_0P_1P_2P_B} \right\} - \left\{ axial\ path\,length \right\}$$

is unequal to zero. That positions on the surface $z_2(x_2,y_2)$, where Δ is equal to an integer multiple of the wavelength of light, get a grating line [5].

5 Example: Plano-convex lens

A simple example is a plano convex lens (Fig. 3).

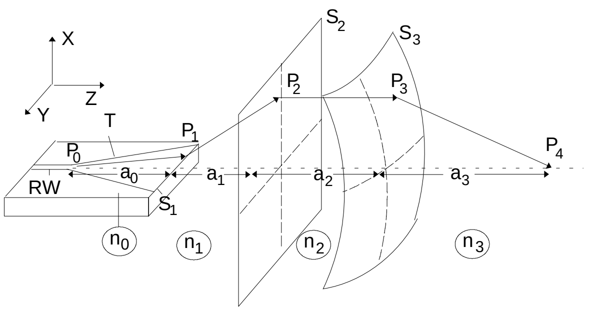

Fig. 3 Plano-convex lens

The parameters are: a_0 = astigmatism = 3 mm in GaAs (n_0 = 3.5), a_1 = 4mm, n_1 = 1, a_2 = 1mm, n_2 = 2, a_3 = 5 mm, n_3 = 1. The deviation of a toroidal surface which is paraxial fitted to the calculated surface S_3 is shown in Fig. 4.

6 Descartes ovaloides for negative refractive index

The geometrical constructions also work for negative refractive indices, as shown for the ovaloids in Fig. 5, related to Fig. 2 for a_0 = 0. The sags of the usual ovaloides are seen for positive indices. The sags for negative indices show very weak curvatures.

7 Conclusions

The inclusion of optical path length in waveguides allows the construction of optical surfaces for stigmatic imaging of astigmatic sources within planar waveguides [5] as generalization of Descartes ovaloides [6]. Negative indices are included.

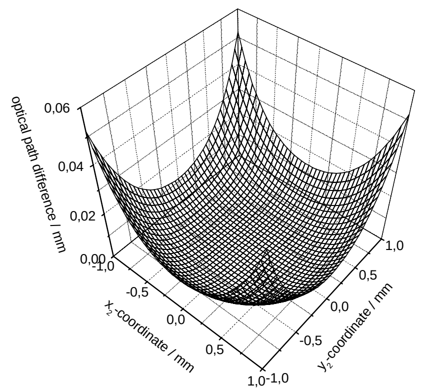

Fig. 4 *Optical path difference between the constructed surface and an approximated toroidal surface*

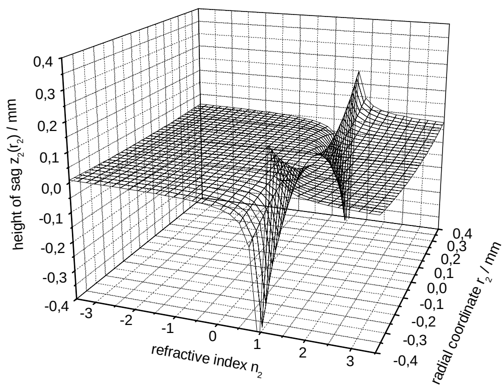

Fig. 5 *Ovaloides for negative refractive indices n_2. Partially, the singularity at $n_2 = 1$ is suppressed by graphical sampling.*

References

[1] K. Paschke, B. Sumpf,F. Dittmar, G. Erbert, R. Staske, H. Wenzel, G. Tränkle, „Near-diffraction limited 980 nm tapered diode lasers with an output power of 7.7 W", IEEE J. Sel. Topics Quantum Electronics, **11**:1223-1227 (2005)

[2] M.T.Kelemen, J. Weber, G. Kaufel, R. Moritz, M. Mikulla, G. Weimann, „8 W high-efficiency high-brightness tapered diode lasers at 976 nm", Proc. SPIE **6104**:123-13 (2006)

[3] R. Güther, „Optimization of SHG for high-brightness semiconductor laser diode radiation with large aberrations",*http://www.dgao-proceedings.de/download/106/106_p44.pdf* (2005)

[4] M. Maiwald, S. Schwertfeger, R. Güther, B. Sumpf, K. Paschke, C. Dzionk, G. Erbert, G. Tränkle „600 mW optical output power at 488 nm by use of a high-power hybrid laser diode system and a periodically poled MgO: $LiNbO_3$ bulk crystal", Opt. Lett, **31**, 802-804 (2006)

[5] R. Güther, G. Erbert, Patent (2006)

[6] R. Descartes, „La Dioptrique", ch. 8, Leyden (1637)