

# Hollow-duct radiation delivery system investigation

M. Fibrich<sup>a</sup>, B. Rus, and D. Kramer

Institute of Physics AS CR, Na Slovance 2, 182 00 Prague 8

**Abstract.** Investigation of hollow-duct structure for high-power laser-diode-array radiation delivery into the end-pumped large-aperture gain media is reported. A ray tracing method has been used to evaluate the performance of the structure designed for maximum transmission efficiency and output beam profile homogeneity. Variable hollow-duct lengths as well as emanating angles of laser-diode-array have been taken into account.

## 1 Introduction

High-power solid-state lasers attract a great deal of attention, in the current period. It is connected mainly with the fast progress made in the development of high-power laser-diodes over the past several years [1–3]. These improvements of laser-diodes combined with cost reductions in the laser-diode-array fabrication have resulted in reduction of the price per average watt of diode radiation. So, the compact and efficient high-power laser-diode-array pump sources gradually replace the inefficient and cumbersome flash-lamp pump systems.

For optical pumping of the laser materials, two fundamental approaches including end and side pumping have to be considered. End pumping has the potential to yield high-efficiency and high-beam-quality laser systems [4], provided that a good overlapping between the laser-diode radiation and the intracavity laser-mode inside the active material is reached. This matching is difficult to achieve in the case of high-power laser systems as they require a large amount of diode-arrays as a pumping sources with considerable emitting area dimensions and beam divergences. The problem of beam homogeneity and transfer efficiency can be solved, e.g., by employing tapered geometric structures [5–7]. These passive and robust optical devices are able to effectively couple and concentrate the pump radiation from the broad laser-diode-array area into the relatively small (in cross-section) laser gain media. In addition, scalable diode end-pumping architecture can be easily reached by simple modifying the number of laser-diode stacks. The most common version of such devices is a lens [5] and a hollow duct [6]. In spite of the lens duct, the hollow duct does not need any AR coating and can be easily used for dual-end-pumped laser design because the laser-cavity-beam passes through the duct without interaction. On the contrary, the hollow duct suffers from internal reflection losses that can be avoided in the case of the lens duct. However, by proper coating of the hollow-duct reflective planar sides [8,9], these losses can be significantly reduced.

In this contribution, hollow-duct concentrator and homogenizer, intended for longitudinally end-pumped slab-active-medium laser architecture, has been investigated and optimized in terms of its length by preserving efficient transmission and beam profile uniformity. The effect of the pump-

laser-diode emitting angle has been taken into account, for the first time to our best knowledge. Optimization has been carried out in a simplified 2D-model developed in the computing environment Matlab and subsequently compared with 3D-model designed in the commercial ray-tracing software ZEMAX.

## 2 Problem analysis

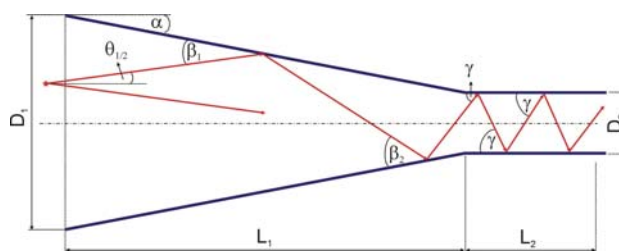
The transmission system investigated was formed by a tapered hollow-duct followed by a flat one, as illustrated in figure 1.

The first part is responsible for coupling of the pump radiation, spread over the relatively large area compared to the crystal dimensions, into the active medium; the second one is intended for homogenisation of the pump-radiation. If we look at the radiation-propagation through the duct like at a two-dimensional geometric task (for better understanding of the key aspects influencing the hollow-duct transmission properties; the sophisticated analytical 3D model can be found e.g. in [6]), it can be on the basis of Snell's law easily derived that angles  $\beta_1, \beta_2, \dots, \beta_i$  are given by

$$\beta_i = (2i - 1)\alpha + \theta_{1/2}, \quad (1)$$

where  $i = 1, 2, \dots$ , and  $\theta_{1/2}$  is the angle (with respect to the duct longitudinal-axis) under which the laser-diode-ray is emitted. Angle  $\alpha$  represents a slant of the tapered hollow-duct which can be expressed in terms of the input  $D_1$  and the output  $D_2$  dimensions, and the length  $L_1$  (see figure 1) as

$$\alpha = \arctan\left(\frac{D_1 - D_2}{L_1}\right). \quad (2)$$



**Fig. 1.** Schematic layout of ray propagation through the hollow-duct-system

<sup>a</sup> e-mail: martin.fibrich@eli-beams.eu





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