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Diode pumping of a solid-state laser rod by a two-dimensional CPC–elliptical cavity with intervening optics

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Abstract

The pump radiation from a large area two-dimensional diode stack is concentrated into a cylindrical intervening optics by a first-stage 2D-CPC concentrator. The compressed radiation from the intervening optics is then efficiently coupled into a laser rod by a second-stage 2D-elliptical pump cavity. Depending on the width of the pump source, optimized rod mounting position is found through a non-sequential ray-tracing analysis. By comparing with the performance of a 2D-CPC–CPC cavity, significant improvements in both absorption efficiency and absorption distribution are achieved by a 2D-CPC–EL cavity. This asymmetric pumping scheme constitutes also an effective alternative to conventional symmetric pumping approaches.

Keywords: Lasers; Diode-pumped; Pumping

1. Introduction

In the past years the research and studies of highly efficient, high beam quality and long-time operation of solid-state lasers pumped by diode lasers instead of discharge lamps have been maintained by the performance improvements of semi-conductor diode-lasers arrays. High efficiency can be obtained because there is a good spectral match between the emission spectrum of the pump beam and the absorption spectrum of the laser medium. The most efficient laser systems have end-pumping configurations. The reason for the increased efficiency of the end-pumping is that the pump power is absorbed over a small centred region within the laser rod leading to a much higher inversion density than in side-pumping, where a sizable amount of the pump power is absorbed near the surface, not in the centre, of the gain medium. The highest inversion density in a region the same size or smaller than the fundamental mode is the deciding factor for low threshold and high optical efficiency [1,2]. For cylindrical gain media, the end-pumping and close-coupled side-pumping geometries approach the ideal TEM_{00} mode-matched absorption distribution, but they have total pump-power limitations. Side-pumping is a simpler configuration for power scaling as it gives uniform absorption along the axis of the laser rod and spreads the absorbed power over a large area, thus reducing the thermal loading. The pump radiation from the diode stacks can be compressed by either compound parabolic concentrators or by wedge lenses into the diffusive cavity chamber surrounding the laser rod. The rod absorbs the pump light and converts it into infrared laser light [3–6]. However these methods do not allow for flexibility in shaping the pump beam distribution inside the medium, leading to nearly homogeneous output profiles. To tailor the pump distribution within the medium, the micro-lensed diode stacks [7,8] are required since the concentration ratio is limited by the divergence of the pump beams. The typical transfer efficiency of a commercial micro-lens is about 85%, which has been one of the reasons for low wall-plug efficiency. Inserting optics, such as optical fibres, between the diode laser and the pump cavity increases the laser head complexity.

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However, the pump-beam distribution can peak at the centre of the medium [9], resulting in an improved match of the pump distribution with the resonator mode. For low-average-power applications, in which thermal lensing is moderate, the overlap of the laser mode with an excitation peaked at the centre of the rod can be advantageous.

The most suitable pump cavity is the one that efficiently concentrates the radiation from many diode lasers into solid-state gain medium when the diodes are not densely packed and are placed over a large entry aperture [10]. By sparsely packing the diodes, we can reduce thermal loading problems in the array and therefore wavelength-emission problems. A possible candidate for a pump cavity that can efficiently transfer radiation from an extended, sparsely packed, two-dimensional diode array (ESDA) to the gain medium is a non-imaging concentrator [11]. Although the non-imaging pump cavity provides a large amount of pump power, it does not give a Gaussian absorption profile. What we believe to be a novel pumping scheme is reported in this paper. Symmetric multi-side-pumping arrangements for high-average-power applications are firstly discussed, providing excellent examples for the proposed asymmetric 2D-CPC–EL pumping scheme. Having nearly the same effectiveness as conventional symmetric schemes, the 2D-CPC–EL proposal constitutes an alternative approach in dealing with the radiation-coupling problem from a large area two-dimensional micro-lens-free diode stack into a cylindrical laser medium. Non-sequential ray-tracing is performed to analyze both the absorption efficiencies and the absorption distributions within the Nd:YAG laser rods of different diameters. By comparing with the performances of the 2D-CPC–CPC cavity, the superiority of the 2D-CPC–EL cavity with intervening optics is confirmed, leading to a much stronger pump radiation concentration within the small centred region of the rod. This scheme can provide better matching between the lasing mode volume and the pump volume generated due to the focusing properties of both the truncated elliptical pump cavity and the cylindrical intervening optics.

2. High-average-power symmetrical multi-side-pumping arrangement

For low-average-power applications such as laser oscillators, an excellent efficiency of pump absorption (>80% overall), a good pump symmetry around the rod and the required peak on-axis to enhance low order modes are three important features of a modern diode-pumped solid-state laser with symmetric pumping arrangement. A limited number of horizontal or vertical diode arrays can provide sufficient pump power for the efficient production of high quality laser beam.

For high-average-power applications such as laser amplifiers, a huge amount of pump power can be obtained from either a large area diode stack in rectangular arrangement or from many narrow vertical diode stacks in several-folded pump cavity segments. Fig. 1 shows the schematic drawing of a symmetric pump cavity composed of 16 narrow vertical diode stacks, distributed uniformly around cylindrical surface with 80 mm perimeter and 100 mm height. The laser rod of 6.35 mm diameter and 115 mm length is water-cooled within the flow tube of 11 mm external diameter.

In Fig. 1, each diode laser emitter in each of the 16 vertical diode stacks has an elliptical Gaussian emission with FWHM 12° divergence in the slow-axis direction and FWHM 40° in the fast-axis direction. The fast-axis of the diode stacks are arranged parallel to the laser rod axis. Therefore the pump beams are incident upon the laser medium in P polarization, which increases the transmittance at the rod surface and leads to high pump efficiency. In the fast-axis direction, the pump radiations reach the rod either directly or by the reflections from two end plates (not shown in Fig. 1). The fast-axis divergence of 40° also assures to filling more uniformly the rod along the optical axis while the 12° slow axis divergence enables an easy direct light coupling from the diode stack to the laser rod through the flow tube with cooling water. For easy comparison, 1000 W is considered as the total power from the pump source in each case of this paper.

The peak absorption at 808 nm is nearly 10 per cm for a Nd:YAG laser medium with 1.0% doping. To reach sufficient absorption of pump power, one has to control the emitted wavelength of the diode stacks. For low-average-power applications, tuning to the peak absorption can however cause side-lobes at the input surface of the rod [6]. At high-average-power, the laser rod of lower absorption coefficient (0.6% doping, for example) is usually used to achieve a uniform absorption distribution. The absorption coefficient of 4 per cm is therefore assumed as a representative average value. The laser rod of 6.35 mm diameter is water-cooled within the anti-reflection-coated flow tube of 11 mm external and 9 mm internal diameters. The side-surface of the laser rod is modelled as uncoated. Actual ray propagation within the crystal rod is three-dimensional. However, the number of rays that propagate

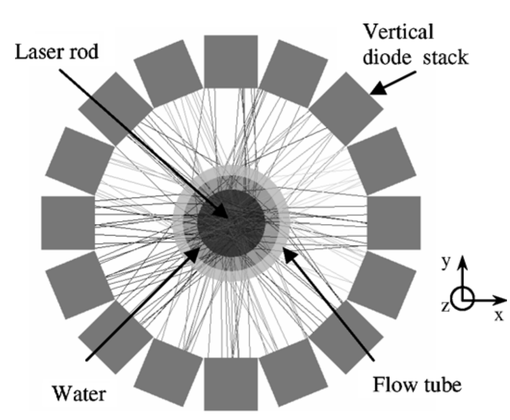

Fig. 1. Sixteen-side-puming arrangement for high-average-power applications.