Bandwidth narrowing and dual wavelength emission of a 20 W laser diode array

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Abstract

We report on the performance of a commercial, non-AR coated diode laser bar, consisting of 20 emitters, which uses an external cavity to achieve 16 W of bandwidth-narrowed output and 2.9 W of dual wavelength emission. These are the highest output powers reported so far for this type of cavity and diode laser array.

Introduction

For numerous scientific and industrial applications it is of interest to have tunable, dual wavelength laser emission. Such applications include wavelength-division-multiplexing in optical communications systems, optical sensing of single (DIAL) or multiple species [1], optical switches and optical pumping of mm-wave lasers. For these diverse applications several types of broad emission bandwidth lasers have been employed such as Ti: Sapphire [2] and dye lasers [3]. Because of its high power output, low cost and small dimensions, the high-power diode laser array (HPDL) has become nowadays a common broadband laser source. Several injection locking schemes based on external cavities have been developed that permit tuning of one or more wavelength [4]. These schemes can be divided into master-injection lasers and self-seeded lasers [5]. The complex master-injection schemes [6] use external lasers whereas the simpler, self-seeded diode lasers use an external cavity to generate a selective feedback of the HPDL’s emission [5,7].

Nevertheless, the small photometric[1] and spectral brightness[2] of diode lasers hampers their use in most applications. Pumping of solid state lasers, production of hyperpolarized noble gas, lidar and teraherz generation, all these applications benefit to some extend if either type of brightness is increased. For example, in order to achieve efficient solid-state laser pumping in longitudinal pumping schemes, it is necessary to achieve mode matching of pump and intracavity beam that can only be achieved for high brightness pump beams. Also, the emission bandwidth should small enough to be efficiently absorbed by the absorption peak of the active media. Using a diffraction grating in an external cavity is an effective technique to narrow the emission spectra of commercial diode arrays [7]. An array consists of a large number of emitters, typically twenty to sixty, arranged in a line. Emission from these emitters is highly astigmatic having divergences angles of 40º and 10º degrees perpendicular and parallel to the line, respectively. The light from each individual emitter needs to be collimated and imaged upon the diffraction grating from which it is reflected back at an appropriate angle into the emitter. Intensity injected back into the diode is what matters and the higher the diode current the higher the re-injected intensity should be in order to force the diode’s oscillation at the desired frequency. Therefore, the imaged system has to re-inject the light with high efficiency. This task is further complicated by a small curvature of the emitter line, called diode “smile”, produced during the manufacturing process [8]. It is essential to compensate for this smile because narrowing can only be achieved if the emissions of the individual emitters overlap [9]. For this reason a telescope can be used in the re-imaging system which creates a magnified image of the emitters on the grating. This reduces the angular spread on the grating resulting from smile and from the emitters, which in turn increases the light intensity re-imaged onto the emitters and also increases the frequency selectivity of the grating, generating further frequency narrowing of the diode’s emission [7] at less re-injected power. Self-injection bandwidth narrowing is proportional to the number of emitters and it has been shown that with three emitters 0.07 nm can be achieved and with ~20 emitters, ~0.7 nm. We achieve bandwidth narrowing down to 0.65±0.11 nm using a commercial 20 W, 20 emitter diode-array.

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[1] Photometric brightness or radiance (L): the radiated power per unit solid angle per unit area normal to the direction defined by the solid angle Ω. $L=P/(\Omega A\cos\Theta)$

[2] Spectral brightness (L_f): the radiance per unit frequency interval: $L_f=L/\Delta f$. Some authors define the spectral brightness in W/THz.

Most of the dual-wavelength injection schemes are either low power [10] or not tunable [5]. Some of the simpler dual wavelength self injection schemes are composed of a grating and a dual wavelength selective device such as a highly reflective mirror and a couple of slits [11], an intra-cavity etalon with an appropriate FSR [12] or two external cavities [13,14]. In this letter we investigate an even simpler external cavity which permits high power, dual-mode output with tuning of the mode separation and wavelength. This laser could be used to pump YLF crystals co-doped with thulium and neodymium at the absorption peaks, which are 792 nm and 797 nm, respectively. This work demonstrates to our knowledge the highest dual mode spectral output so far reported.

Experimental Setup

We used a commercial diode array, without special AR coating on its facets, emitting nominally at 792 nm and consisting of 20 emitters (OPC A020) with a maximum of 20 W of output power. The factory mounted fiber lens had a diameter of 440 μm and a focal length of 340 μm. The diode array smile was measured [8] and calculated to 4 μm [Figure 1].

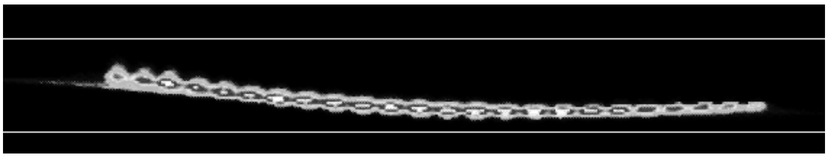

Figure 1: Photo of the diode smile registered with a CCD.

An afocal telescope (4x magnification) was used to focus the diode radiation onto the diffraction grating (2362 grooves per mm). The first order grating reflectivity was 85% and 14% for light polarized perpendicular and parallel to the grooves, respectively. A half wave plate was inserted at the location of the focus inside the telescope in order to control the power injected back into the diode by the grating (Figure 2). The resolution of the spectrometer used to analyze the diode spectra was 0.22 nm (Ocean Optics HR2000 Spectrometer with 5 μm slit).

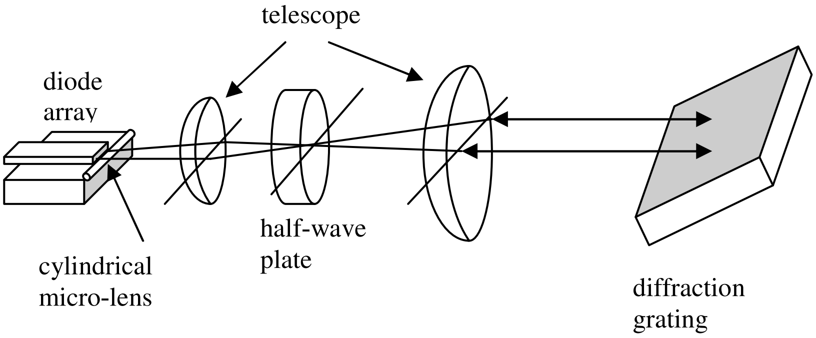

Figure 2: Diagram of the external-cavity diode-laser array.

Because the diode's curvature is also imaged onto the grating, the light from the emitters in the middle of the array is reflected from the grating at a slightly different angle than the light from the emitters at the end of the array, causing frequency broadening.

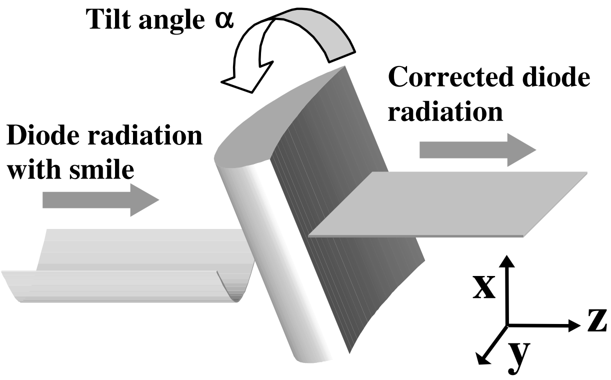

Figure 3 : Schematic of the working principle of the inclined cylindrical lens.

In order to correct for the diode smile, we changed the spherical lens closest to the diode to a cylindrical lens of the same focal length, which was slightly inclined at an angle such that the array image on the grating appeared closer to a straight line (Figure 3).

Results and Discussions

In free running operation we measured a bandwidth of 3.5±0.11 nm at 18 W of diode output power. With the half wave plate adjusted to 29% reflection the bandwidth was narrowed down to 0.65±0.11 nm (Figure 4). This corresponds to a spectral brightness increase of approximately 280% even when including the losses introduced by the diffraction grating.

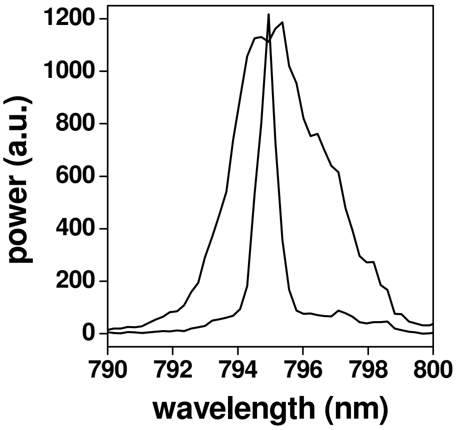

Figure 4: Original power spectra of the diode and high power (14 W), bandwidth-narrowed output.

In a second step, the grating was detuned from the diode's emission peak (790 nm at low power) by 4 nm. We then increased the diode's current gradually, maintaining the same amplitude of both emission peaks (790 nm and 794 nm) by adjusting the grating feedback with the half wave plate, until, even at the highest feedback (85%), the detuned peak (794 nm) became smaller than the other one that is at the diode's gain center. At this condition a total of 2.9 W of output power was obtained from both peaks (Figure 5).

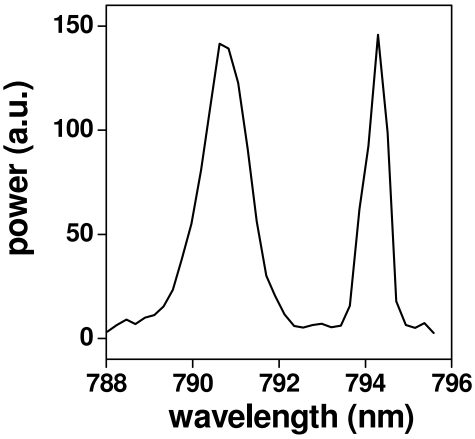

Figure 5: Dual wavelength output of 2.9 W.

The width of the peak at 790 nm was 1.3±0.11 nm and for the other peak we measured 0.75±0.11 nm. No diode degradation was observed during the experiment.

Conclusions

We have demonstrated spectral narrowing of a commercial diode laser array with 20 emitters to 0.65 nm and obtained a total output power of 16 W using a single grating external cavity. This is to our knowledge the highest output power and the narrowest spectra reported so far for this kind of cavity. We also achieved dual wavelength output of 2.9 W by detuning the grating from the diode's emission peak. This is the highest reported dual-wavelength output power for standard diode-arrays.

Acknowledgements

The authors thank the **Fundação de Amparo à Pesquisa do Estado de São Paulo** for grant 02/05535-5.

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