Continuous wave, 30 W laser-diode bar with 10 GHz linewidth for Rb laser pumping

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Received January 22, 2008; accepted February 12, 2008;
posted March 5, 2008 (Doc. ID 91858); published March 28, 2008

A laser-diode bar incorporated into an external cavity with a volume Bragg mirror produced 30 W of cw output power within a 20 pm (10 GHz) spectral linewidth (FWHM) centered at 780 nm. The device output power exceeded 90% of that for the free-running laser-diode bar. The emission wavelength was tuned over a 400 pm range without broadening laser spectrum width. Absorption of 90% of the laser radiation by a 25 mm vapor cell containing Rb that has been pressure broadened with 300 torr of ethane was demonstrated.

OCIS codes: 140.2010, 140.5960, 140.5560.

Diode lasers with gigahertz-wide emission spectra have a great potential for applications in Raman spectroscopy, atom cooling, and in the emerging field of optical pumped alkali vapor (cesium, rubidium, and potassium) lasers. Efficient operation of lower-pressure (<1 atm) alkali-vapor lasers requires pump sources with a bandwidth that matches the pressure-broadened absorption band (~ 10 GHz) of the alkali vapor. Several approaches to match the pump-source linewidth to the absorption feature of the alkali have been attempted. Owing to their narrow linewidths, Ti:sapphire [1,2], dye [3], and narrow-banded single-emitter diode lasers have previously been used to pump Rb and Cs alkali lasers. A distributed-feedback laser diode (LD) emitting 1 W within 0.1 nm spectral linewidth was demonstrated in[4]. Single LDs and laser-diode bars (LDBs) integrated into wavelength-selective external cavities with surface diffraction gratings have shown narrowing of linewidths down to tens of gigahertz at power levels of tens of watts [5–10]. Conversely, the alkali-vapor lasers have been optically pumped by LD arrays with linewidths exceeding several nanometers (a few terahertz) by using high-pressure buffer gases [11–13] to broaden the alkali absorption transition.

Recent technological progress with volume Bragg gratings (VBG) recorded in photothermorefractive glass has opened new opportunities for the design and fabrication of compact external-cavity semiconductor laser systems suitable for optical pumping of solid-state, fiber, and gas lasers [14–16]. Spectral narrowing down to the subnanometer range for LDs, LDBs, and stacks integrated in VBG external cavities has been shown [17–20]. Recently, a LDB with a volume Bragg external cavity has demonstrated an output power of 13.5 W within a 7 GHz spectral width in cw operation for pumping of a 3.2-GHz-wide oxygen molecule transition [20]. However, the laser system had only 0.5 W/A slope efficiency and required a drive current of 45 A to achieve 13 W output power. Such low efficiency could be a result of 2 nm wavelength mismatch between positions of a free-running laser spectrum and a grating-resonant Bragg wavelength.

In this Letter, we report on the development of a volume Bragg laser (VOBLA) operating at 780 nm with 30 W cw output power. The VOBLA output power is 90% of the free-running LDB power. The VOBLA emission-spectrum width was on the order of 10 GHz (FWHM), the spectral contrast was about 40 dB, and the laser radiation absorption by a low-pressure Rb cell at 780 nm was 90%.

The VOBLA consisted of an off-the-shelf passively cooled LDB, a fast-axis collimator, and a reflective volume Bragg mirror used as a wavelength-selective output coupler. The LDB was fabricated by LaserTel Inc. and consisted of 24 LDs with 2 mm cavity length and 150 μm aperture width. The LDs were equally distributed across the 1-cm-wide LDB. The laser bar facets were high-reflection-/anti-reflection-coated with reflection coefficients of 95% and 0.5%, respectively. The 18-mm-thick Bragg mirror was designed and fabricated at OptiGrate. This mirror had a diffraction efficiency of 70% at resonant wavelength. The spectral and the angular selectivity of the mirror were around 30 pm and 1° (FWHM), respectively. The resonant Bragg wavelength at normal incidence (retroreflection) was 779.7 nm. The fluctuation of diffraction efficiency was less than 5% across the full aperture. The Bragg mirror and a fast axis collimator had antireflection coatings to prevent parasitic reflections. The LDB and the Bragg mirror were mounted on thermoelectrically cooled copper heat sinks with a temperature stability of ±0.1 K.

The free-running LDB and VOBLA were studied in cw operation. To evaluate the overall laser-emission spectra, the output radiation was collected into an integrating sphere and coupled into an optical-

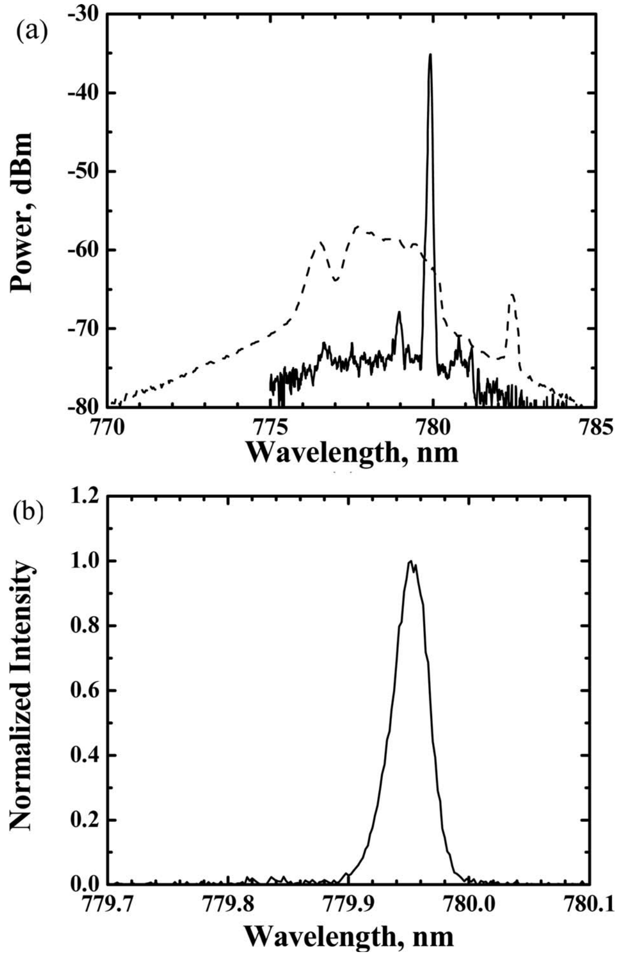

Fig. 1. (a) Emission spectra of free-running (dashed curve) and volume Bragg (solid curve) diode lasers in semi-log scale. (b) Emission spectrum of a VOBLA in linear scale.

spectrum analyzer (OSA) (ANDO AQ6317B) using a single-mode fiber. The spectral resolution of the experimental setup was 15 GHz (30 pm). Precise measurement of the VOBLA mode structure and spectral width was performed using a Fabry–Perot interferometer with 15 GHz free spectrum range (FSR) and 0.8 GHz spectral resolution.

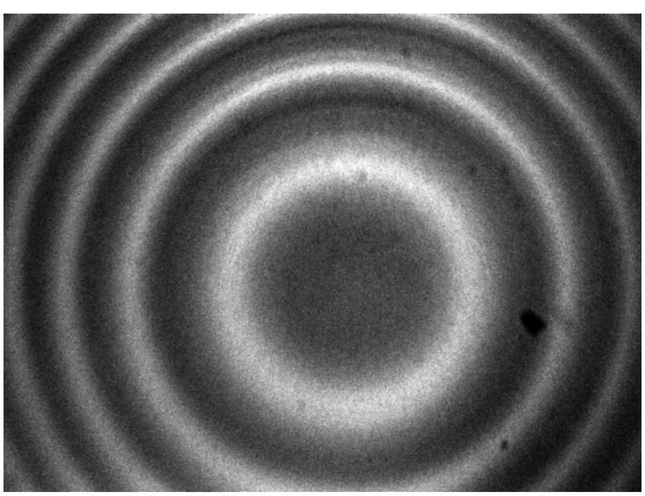

Fig. 2. Emission spectrum of the VOBLA measured using a Fabry–Perot interferometer with a 15 GHz FSR.

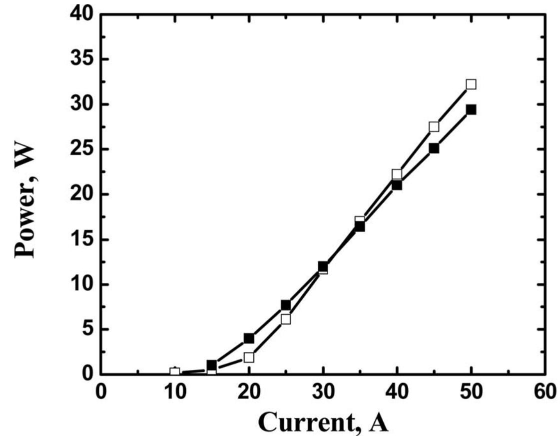

Fig. 3. cw output power of a free-running (empty square) and a volume Bragg (filled square) LDBs versus driving current.

Figure 1(a) shows the emission spectra of the free-running (dashed curve) and volume Bragg (solid curve) LDBs measured at 20 W cw output power. The emission spectrum of the free-running LDB had a maximum around 780 nm and a spectral width of 5 nm (FWHM) at room temperature. After integration of the LDB into the external Bragg resonator, the laser emission spectrum had been narrowed down to less than 15 GHz (30 pm) (FWHM), which was the spectral resolution of the OSA; see Fig. 1(b). The spectral contrast (side-mode suppression ratio) of the VOBLA emission spectrum was approximately 40 dB. The precise value of the VOBLA spectral linewidth was determined using a Fabry–Perot interferometer with 15 GHz FSR. Figure 2 shows the mode structure of the VOBLA producing 20 W cw power. The spacing between the next-order modes in the circular Fabry–Perot fringe pattern equal to the free spectral range (15 GHz) of the Fabry–Perot interferometer. The spectral modes of individual lasers in the laser bar were overlapped, producing a VOBLA spectrum with a linewidth of less than 10 GHz (FWHM). The spectral linewidth of individual LDs implemented into the similar external Bragg resonator achieved 14 pm (7 GHz) [19]. In the LDB, the emission spectra of individual LDs were slightly different owing to spatial fluctuations of resonant Bragg wavelength across the aperture. The VOBLA spatial mode distribution measured at 20 W cw output power showed multi mode operation, with a far-field divergence of around 8° FWHM along the slow axis direction.

Compared with the free-running LDB, the spectral width of the VOBLA was narrowed by 250 times with only a 10% output power decrease at maximum drive current (Fig. 3). The decrease in current threshold and the drop in slope efficiency resulted from higher reflection from the external Bragg mirror as compared to the free-running LDB.

Optical pumping of rubidium vapor media requires tuning of pump laser emission to precisely overlap with Rb absorption bands. The VOBLA emission spectrum was thermally tuned over 400 pm spectral range by heating the Bragg mirror, which had a ther-

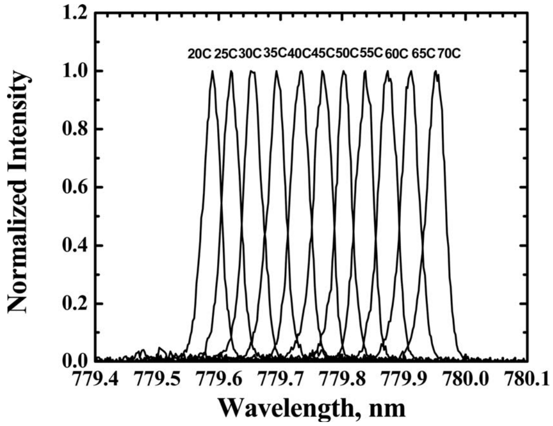

Fig. 4. Emission spectra of a volume Bragg diode laser at different grating temperatures.

mal shift of 8 pm/K (Fig. 4). The thermal shift of the wavelength does not increase the width of the laser spectrum. The absorption of the pump light by Rb atoms was measured in the 25-mm-thick alkali cell at 420 K. The cell contained excess Rb with a vapor phase number density of 7.2×10^{13} at/cc at 420 K mixed with C_2H_6 buffer gas (300 Torr at 298 K). This resulted in an absorption transition on the order of 8 GHz (FWHM). The Rb cell absorbed 90% of VOBLA radiation at wavelength of 779.92 nm.

In summary, a diode laser bar with a volume Bragg output coupler emitting at 780 nm produced up to 30 W cw output power with a slope efficiency of 0.8 W/A. The laser had a spectral width (FWHM) of 10 GHz (20 pm) and a tunability of over 400 pm. The output power of the volume Bragg laser exceeded 90% of the output power of the free-running LDB. The low-pressure Rb cell absorbed 90% of the laser emission.

The authors are grateful to L. Glebova, I. Ciapurina, I. Popkova, E. Rotari, A. Balam, and J. Lumeau for reflecting Bragg grating fabrication and certification. The work was funded in part by Air Force Research Laboratory (contract FA9451-07-C-0199).

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