High-power semiconductor lasers for applications requiring GHz linewidth source

Ivan Divliansky*[a], Vadim Smirnov[b], George Venus[a], Alex Gourevitch[a], Leonid Glebov[a]
[a]CREOL/The College of Optics and Photonics, University of Central Florida, Orlando FL 32816
[b]OptiGrate, 3267 Progress Drive, Orlando, FL 32826

ABSTRACT

In this paper we present the development of semiconductor laser systems with output powers reaching 100 W and linewidths down to 10 GHz. The combination of high power and narrow emission spectrum was achieved through external resonator configurations based on volume Bragg gratings. By using Bragg gratings with extremely narrow spectral selectivity we were able to narrower and lock emission spectra of diode lasers, with precise wavelength tuning achieved by thermal control of the volume grating. The thermal coefficient of our volume gratings was approximately 8 pm/K, which was low enough to guarantee stable frequency operating regime. We implemented successfully two such schemes for lasers generating at 780 nm and 1.55 μm as pumping sources for Rb vapor and Er-doped solid state lasers, correspondingly.

Keywords: high-power semiconductor laser, volume Bragg grating, GHz linewidth

1. DEVELOPMENT OF GHz LINEWIDTH HIGH-POWER LASER SOURCES

The last several years, high-power diode lasers are becoming a viable compact alternative of the standard solid-state lasers. To find even broader application several key issues need to be addressed, one of them being the narrowing of the laser emission to GHz linewidths. High-power combined with GHz wide emission spectra have enormous potential in areas of optically pumped alkali-vapor lasers (cesium, rubidium and potassium) and solid state (erbium, thulium) lasers, in Raman spectroscopy and atom cooling [1-3]. Different approaches have been implemented during the years to match the pumping sources emission characteristics to the absorption linewidths of the particular pumped medium. The most widely experimented with are Ti:sapphire, dye and single emitter diode lasers because of their narrow line emission spectra [4-7]. The recent advances in the development of high-quality volume Bragg gratings (VBG) recorded in photo-thermo-refractive (PTR) glass have presented another path for designing and fabricating compact high-power laser systems based upon external cavity locking of single-emitter semiconductor lasers or bars [8-10]. These VBGs have unique properties that make them capable of handling kW range powers and reducing, in the same time, the laser emission spectra down to several or tens of GHz. They also show diffraction efficiencies above 95%, thermal stability up to 400°C and laser damage threshold of 40 J/cm^2 for 8 ns pulses. Such characteristics make them extremely suitable for high-power laser design schemes.

The first system developed was operating at 780 nm and consisted of one diode bar (LaserTel Inc.) with 24 laser diodes (LDs), a fast axes collimator and a feedback element. Each individual LD had 2 mm cavity length and 150 μm aperture width. The laser bar was first collimated in the fast axes and then locked in an external resonator configuration through a volume Bragg grating manufactured by OptiGrate. The VBG used was 18 mm thick and had a diffraction efficiency of 70% for the resonant wavelength. Its spectral and angular selectivity were around 30 pm and 1° (FWHM), respectively. The free-running laser diode bar (LDB) had a maximum emission at approximately 780 nm and a spectral width of 5 nm (FWHM). The locking of the LDB through the VBG brought down the emission spectrum to less than 10 GHz width, which was measured by a Fabry-Perot interferometer. If compared to the free-running regime the spectrum was narrowed by 250 times with measured power loss from the VBG of around 10%.

High-Power Diode Laser Technology and Applications VII, edited by Mark S. Zediker,
Proc. of SPIE Vol. 7198, 71981N · © 2009 SPIE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.810058

In order to achieve high pumping efficiency of the Rb vapor, the laser emission spectrum was thermally tuned by heating the Bragg mirror. The thermal shift of Bragg wavelength was measured to be 8 pm/K which brought the total tunability region to 400 pm. This active thermal management allowed precise matching of the laser emission wavelength to the absorption line of the Rb vapor. The experiments demonstrated that the low pressure Rb cell absorbed 90% of the pumping radiation at 779.92 nm. In conclusion, a 30 W 10 GHz CW pumping laser system operating at 780 nm was successfully designed and fabricated. The system was coupled to an alkali-vapor laser medium (Rb) to serve as a pumping source and was able to achieve 90% absorption efficiency.

Similar approach was used as a foundation for the development of a resonant pumping source for Er-doped lasers. The achieved parameters for this new system were as follows:

- 100 W output power
- 20 GHz spectral width emission
- 400 pm wavelength tunability
- ± 5 pm stability over 8 hours
- fiber delivery system

Laser diode bars from Princeton Lightwave were chosen working in the range 1525 ÷ 1538 nm, with output power of 35 W each (at 100 A pumping current). Each LB was mounted on a microchannel block and was water cooled to 15°C at all times. To condition the output emission of each bar we used a commercially available optical system from LIMO. It consisted of several optical elements responsible for collimating and rearranging the emission of the individual laser diodes inside the bar. After the beam was collimated a VBG was aligned to lock the laser in an external resonator configuration and provided narrowing of the laser emission spectrum. Figure 1 shows a comparison of the spectra of free running LB at 100 A and the same one locked with a VBG at different currents.

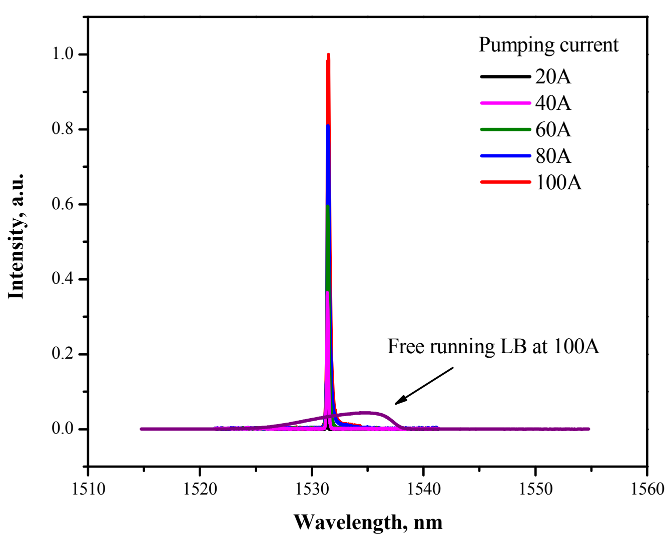


Fig. 1. Comparison of the emission spectra of free running and VBG locked LB.

The spectral widths of the VBGs used were 110-120 pm (~14 GHz) with spectral uniformity across the working aperture of approximately 30 to 50 pm. The locked LBs demonstrated minimum spectral widths of 160 pm (20 GHz) which is away from the level of 10GHz observed for the LD bars in the Rb-vapor pumping system. Such high linewidths were attributed to two reasons: first to the significantly wider emission spectrum of the LBs emitting in the range of 1.5 μm if compared to the ones used for generating 780 nm, and second to the anti-reflection coating on the output facet of the LBs which was not optimized for working in external cavity regime. The VBGs provided suppression of the side lobes on the order of 25 dB or better.

To optically pump a laser medium with high efficiency the pumping light frequency must be aligned with the absorption band and its width should be as close as possible to the band width. Both, the spectral width of the system developed and described here and the center of the emission were governed by the VBGs' internal properties. While the width for an already recorded VBG could not be changed, the center of the Bragg wavelength could be tuned with very high accuracy. To achieve such tuning each volume grating was heated from one side and its temperature was monitored simultaneously with a thermistor. Heating the glass plate in which a grating was recorded leads to its expansion and thus to a change in the grating's period. Using a feedback loop and active control made possible tuning and locking all the lasers with very high precision. The first experiments demonstrated very interesting behavior of the LD bars spectral widths upon heating of the VBGs (Figure 2). It was observed that increasing the temperature of the VBGs lead to wider output spectra. This was attributed to the asymmetric heating that the VBGs are subjected to when only one heater is used for tuning. The glass for the VBGs was thick enough to experience temperature gradient along which the volume grating's period was changing. This effect led to different parts of the beam and thus different lasers being locked at different wavelengths. The addition of second heater symmetrically opposite to the first one alleviated the width increase (Fig. 2 - symmetrical heating) and brought it in the range of 5-10 pm for 60°C degree change. Figure 3a demonstrates the stability of the spectral widths of all four LD bars upon heating of their corresponding VBGs to temperatures up to 90°C. As it was mentioned before if laser bars with narrower spectra are used a smaller than the measured 20-25 GHz linewidths could be achieved.

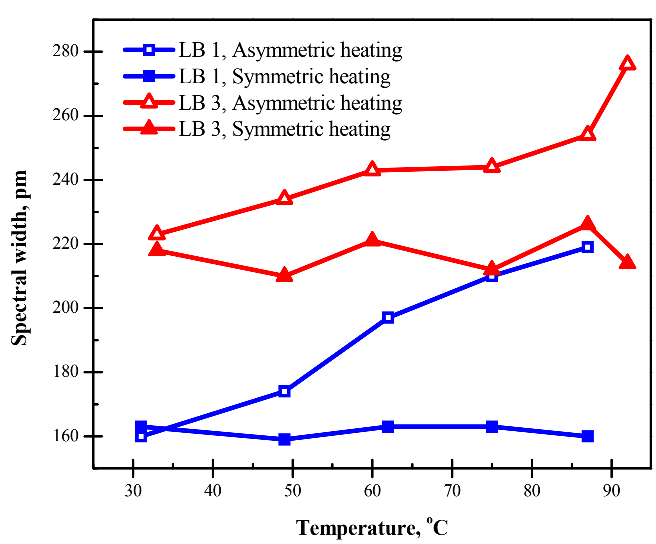
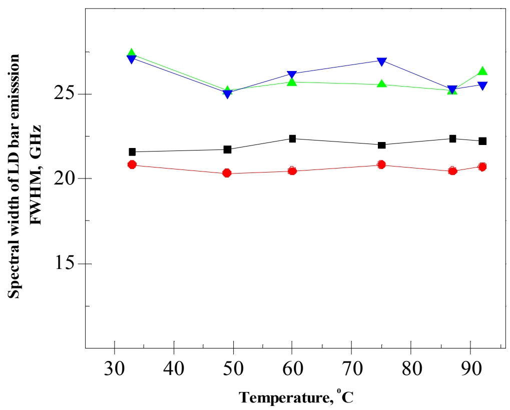


Fig. 2. Behavior of two LD bars' spectral widths upon heating of the locking VBGs.

Due to intrinsic absorption of the light propagating through the gratings their temperature achieved equilibrium at around 35°C with no external heating applied. Using this as a starting point for the tuning range it was possible to obtain a maximum of ≈ 100 GHz spectral shift (at 1552 nm) for the emission of each of the four LD bars (Figure 3b).



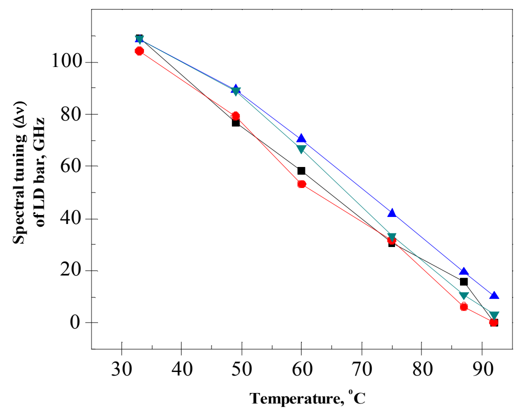


Fig. 3. a) Stability of the spectral widths upon heating of the VBGs, b) spectral tuning of the LD bars.

After individual calibration for ten different grating temperatures and their corresponding emission wavelengths the Lab View code written to manage the system was able to lock all lasers at any wavelength within the tuning range. Figure 4 demonstrates the common output after tuning request for 1532.3 nm. The wavelength center was reached with precision better than 10 pm which is lower that the spectrum analyzer resolution used for the measurements. The final spectral width was 204 pm at 100W total output power.

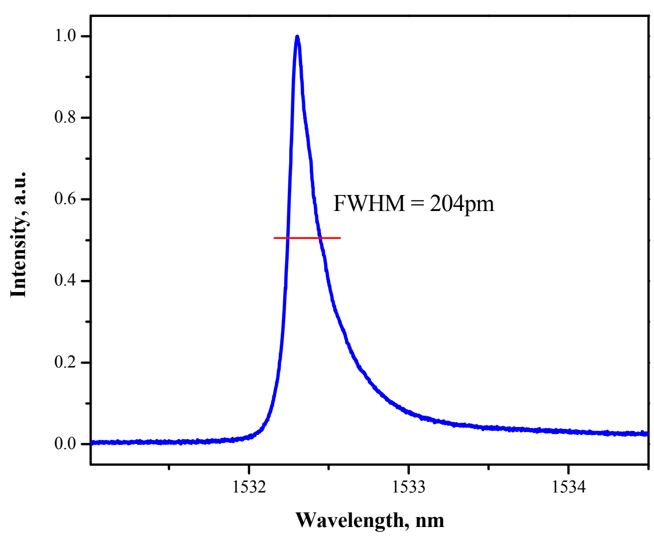


Fig. 4. Locking of all 4 LD bars at 1532.3 nm with 100 W common output power and linewidth of 204 pm.

Figure 5 presents the final module with all four lasers coupled to 1 mm optical fibers. The VBGs are the elements with black tops which are the heaters used to tune the Bragg wavelength. All four fibers were bundled together into single end to produce one high brightness and high power laser source.

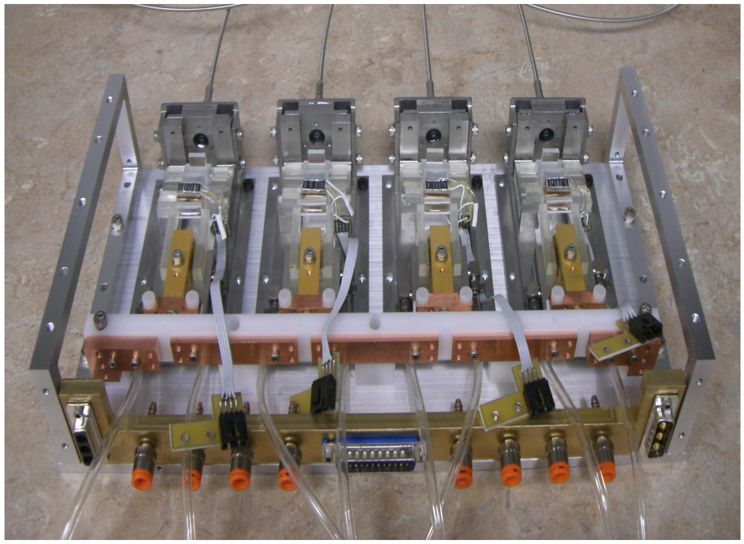


Fig. 5. Photo of the module consisting of four LBs with their emission coupled into 1 mm optical fibers.

In conclusion, this paper presents the development of two high-power laser systems operating at 780 and 1552 nm, with linewidths of 10 and 20 GHz correspondingly. The narrow linewidths were achieved by using volume Bragg gratings in external resonator configuration. Both systems used thermal tuning of the VBG to tune the wavelength with precision of approximately 10 pm and stability of few pm. Lasers with such narrow linewidths are ideal for pumping laser media with great efficiency.

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