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Spectral narrowing of a 980 nm tapered diode laser bar

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ABSTRACT

High power diode laser bars are interesting in many applications such as solid state laser pumping, material processing, laser trapping, laser cooling and second harmonic generation. Often, the free running laser bars emit a broad spectrum of the order of several nanometres which limit their scope in wavelength specific applications and hence, it is vital to stabilize the emission spectrum of these devices. In our experiment, we describe the wavelength narrowing of a 12 element 980 nm tapered diode laser bar using a simple Littman configuration. The tapered laser bar which suffered from a big smile has been "smile corrected" using individual phase masks for each emitter. The external cavity consists of the laser bar, both fast and slow axis micro collimators, smile correcting phase mask, 6.5× beam expanding lens combination, a 1200 lines/mm reflecting grating with 85% efficiency in the first order, a slow axis focusing cylindrical lens of 40 mm focal length and an output coupler which is 10% reflective. In the free running mode, the laser emission spectrum was 5.5 nm wide at an operating current of 30A. The output power was measured to be in excess of 12W. Under the external cavity operation, the wavelength spread of the laser could be limited to 0.04 nm with an output power in excess of 8 W at an operating current of 30A. The spectrum was found to be tuneable in a range of 16 nm.

Keywords: Diode lasers, external cavity laser, wavelength stabilization.

1. INTRODUCTION

High power diode lasers are excellent sources for many applications. They are capable of delivering high output powers with very good power conversion efficiencies[1] and reliability[2]. Advances in the power scaling of diode lasers have facilitated the usage of diode lasers in many applications which were formerly depending on solid state or gas laser counterparts. Tapered diode lasers bars[3] can deliver tens of watts of output powers with good beam quality from the individual emitters, which makes them interesting compared to broad area diode laser bars. However, for certain applications such as spin exchange optical pumping[4], alkali vapour laser pumping[5], nonlinear frequency conversions etc., it requires very narrow line width emissions[6,7]. High power laser diodes in general emits with a broader line width in the range of a few nanometres which makes them unsuitable for these applications. However, various schemes for the line width reduction and wavelength stabilization of these lasers have been demonstrated by different research groups. A Littman Metcalf external cavity, Littrow cavity or a volume Bragg grating (VBG) cavity could be the most straightforward choices for the line width reduction of a diode laser. While the first two employs a reflective diffraction grating, the latter uses a volume Bragg grating for that purpose. Advances in the VBG technology has led to very compact wavelength stabilized diode laser systems. In 2006, Meng et al.[8] demonstrated 13.5 W of spectrally narrowed optical power with a line width of 0.014 nm. In 2008, Gourevitch et al.[9] displayed 30 W of output power with a narrow line width of 0.02 nm using a diode laser bar incorporated into an external cavity with a volume Bragg grating. In 2009, Liu et al.[10] reported 12.8 W of output power with a narrow line width of 0.07 pm from a V- shaped Talbot cavity. Even though a Littman Metcalf cavity involves a larger number of optical elements compared to a VBG cavity, the inherent double pass nature of the cavity enhances the spectral selectivity of the cavity which could result in narrow line width emissions.

The 'smile' found on most laser bars and arrays is an important factor that limits the line width in an external cavity configuration. A smile could be defined as the curvature observed on the linear laser array caused by the

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manufacturing process. But several successful approaches have been made over the years in order to compensate the effects of the smile on the laser bars. Smile compensating techniques has been incorporated into Littman Metcalf and Littrow cavities. Talbot et al.[11] showed that tilting the cylindrical lens in the cavity could compensate the large smile to a certain extend. Chann et al.[12] used a magnifying telescopic lens system in the external cavity to reduce the effective smile. Gopinath et al.[13] used a large magnification telescope by combining a GRIN lens and long focal length cylindrical lens. Monjardin et al.[14] employed a micro machined phase mask to correct the optical path difference in the fast-axis direction, which corrects the smile effect and residual lens aberrations. These phase plate based smile compensation is a very effective and compact solution which are commercially available and also custom made these days. In this report, the smile observed on the tapered diode laser bar has been compensated using a similar technique. The smile compensated tapered diode laser bar in a Littman Metcalf external cavity yielded 8 W of optical output power with a narrow line width of 0.04 nm at an operating current of 30 A. An improvement of the spectral brightness by a factor of 86 has been noted compared to the free running laser bar.

2. TAPERED DIODE LASER BAR

The 980 nm gain guided tapered diode laser bar consists of 12 emitters. The structure consists of a ridge wave section with a length of 0.5 mm combined with a tapered section with a length of 2 mm. The tapered angle amounts to 6°. The front facet has been anti-reflection coated with a residual reflectivity of 1% whereas the rear facet has been provided with a high reflective coating with a residual reflectivity of R > 97%. The laser has been collimated along both the fast and slow axis using cylindrical lenses. The fast axis collimation is done using a single cylindrical micro lens with a numerical aperture of 0.8 and 600 µm focal length. Along the slow axis, each emitter is collimated using individual cylindrical micro lenses with a focal length of approximately 1.38 mm. The focal length varies slightly taking into account the fact that the astigmatism varies slightly between emitters. The smile observed on the laser bar amounts to 2.4 µm peak-to-valley. A phase plate based wave front corrector (*powerphotonic*, UK)[15] has been used to compensate the smile and after correction, this value reduced to below 0.6 µm. At all currents, only 11 out of 12 emitters were found to be lasing.

3. EXPERIMENTAL SETUP

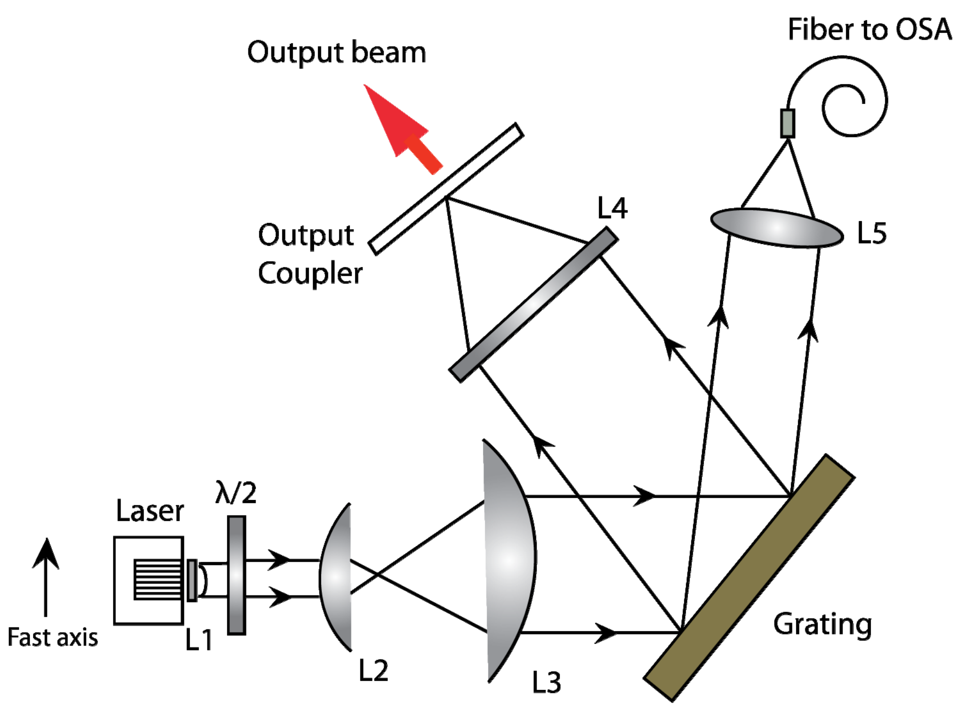

Fig. 1. Experimental setup of the Littman Metcalf external cavity.

The Littman Metcalf cavity used in this experiment consists of the tapered diode laser bar, a combination of the collimation and wave front correction optics as described in section 2, a half wave plate to adjust the polarization of the beam and maximize the diffraction efficiency along the first order, a telescopic system for the magnification of the laser beam in the fast axis (L_1 = 15 mm and L_2 = 100 mm in focal length), a reflective diffraction grating with 1200 lines/mm and 85% diffractive efficiency in the first order, a 40 mm cylindrical slow axis focusing lens L_4 and a 10% reflective output coupler that feeds the diffracted light back into the laser. The slow axis focusing lens L_4 improves the tolerance of the positioning of the output coupler and hence the feedback. Figure 1 shows the schematic diagram of the experimental setup. The overall distance from the laser to the grating is approximately 26 cm and the beam is incident on the grating at an angle of approximately 60° with respect to the grating normal. The laser has been maintained at a constant temperature of 20°C using a thermo-electric temperature controller.

Smile observed on laser bars could be a limiting factor in narrowing the line width. Using a large focal length lens to increase the magnification factor would reduce the resultant line width of emission. This is due to the reduction in the effective angles due to smile and due to the reduction of the angular spread of the emission at the grating. Moreover, the smile compensation used in this setup proves to be vital for the line width reduction of the tapered diode laser bar. The effective feed back in this system amounts to approximately 7%. The laser line width was measured by coupling the zero order beam from the grating to an optical spectrum analyzer (Advantest *Q8347*, resolution 6 pm). The spectrum of the output beam could be tuned by tilting the diffraction grating along the fast axis direction.

4. EXPERIMENTAL RESULTS

4.1 Output power

The output beam has been characterized in terms of output power and the wavelength spectrum. Figure 2 shows the comparison of the light current characteristics of the tapered diode laser bar in the free running mode and the Littman Metcalf cavity mode. In the free running mode, the laser produced 12.7 W at 30 A of operating current and in the external cavity mode, it produced 8 W at the same current level.

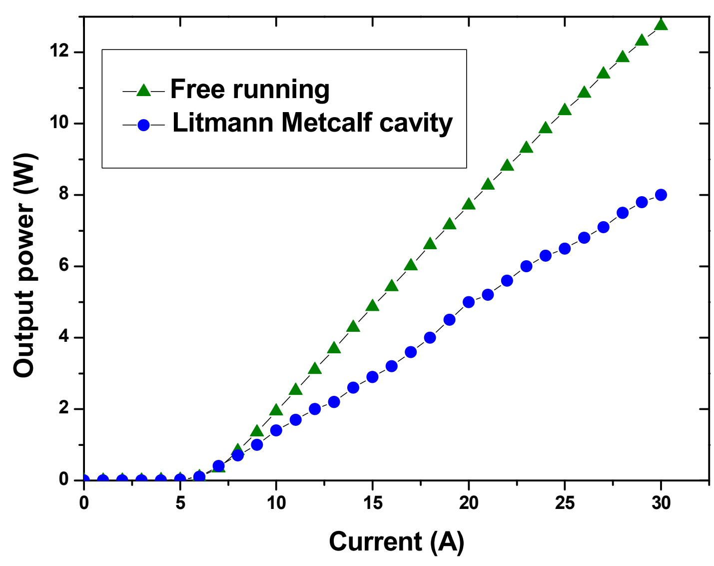

Fig. 2. Comparison of the light current characteristics of the tapered diode laser bar.

4.2 Wavelength spectrum

The line width of the free running emission from the tapered diode laser bar amounts to 5.5 nm at 30 A of operating current. In the external cavity mode, it could be narrowed down to 0.04 nm at the same operating current levels. The measurements were taken at FWHM level. The external cavity laser was also operated without the beam expander lens system. In that case the line width could not be narrowed below 0.1 nm at 30 A. Figure 3 shows the free running output wavelength spectra of the laser bar.

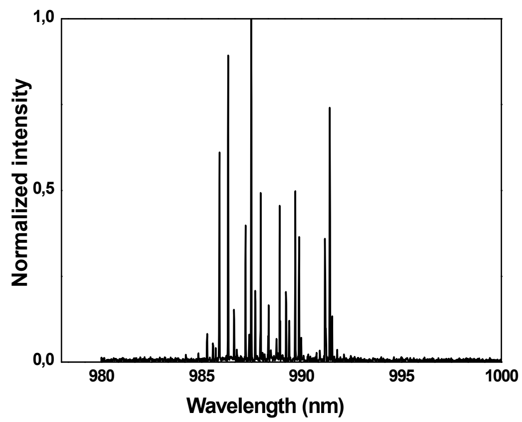

Fig. 3. Wavelength spectrum of the laser beam in the free running mode at I = 30 A and T =20°C.

Efforts were also made to optimize the magnification factor, M of the lens combination. Cavities with $M = 2.5$, 4 and 6.6 were tested with the latter giving the best performance. Beyond that level of magnification, the line width starts increasing. The strength of feedback is also an important factor that determines an efficient wavelength locking. Output couplers with different values for reflectivity (3- 15%) were tested with the 10% one giving the best results. Above 10%, even though the spectral locking was good enough; the output power levels dropped below 8 W due to the increase in the cavity losses. Below 10% reflectivity, the system could not provide enough feedback to maintain the locking of the emitters. Figure 4 shows the line width narrowed wavelength spectrum of the output beam.

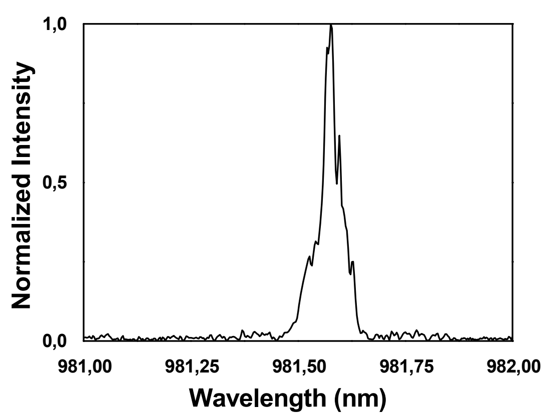

Fig. 4. Wavelength spectrum of the laser beam in the Littman Metcalf external cavity mode at I = 30 A and T = 20°C.

The output beam could be tuned in a range of 16 nm maintaining the output power level not less than 95% of the maximum output. Figure 5 shows the tuning of the wavelength spectrum of the output beam. Outside this range, the feedback from the external cavity was not strong enough for the operation of the laser in the locked mode. Hence, side peaks started to appear due to the free running contribution from the laser which broadened the output spectrum. Within the tuning range, the line width of the emission varied between 0.04 to 0.06 nm.

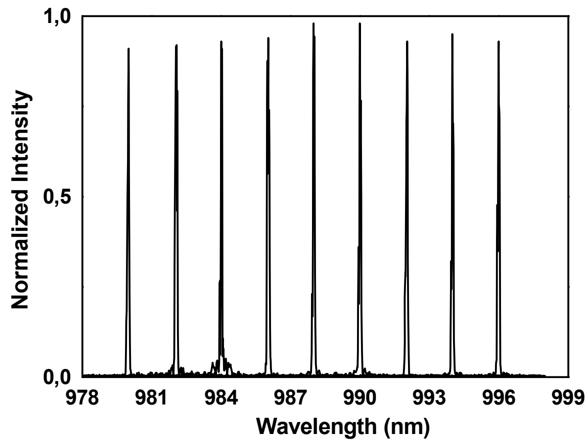

Fig. 5. Wavelength tuning of the tapered diode laser bar at I= 30 A and T= 20°C.

5. DISCUSSION AND CONCLUSUION

In this paper, we have reported efficient line width reduction of the emission from a 980 nm gain guided tapered diode laser bar in a Littman Metcalf cavity. Comparing the Littman Metcalf cavity with a VBG cavity, we have several advantages such as; the output beam could be tuned in terms of wavelength while a VBG cavity is always rigid in terms of the output wavelength and the increased wavelength selectivity of the double pass configuration which is also quite desirable. Moreover, reflective diffraction gratings are comparatively cheaper than VBGs. In short, 8 W of wavelength stabilized optical output power with a spectral line width of 0.04 nm has been demonstrated and high spectral brightness could be obtained from this system which was 86 times better compared to the free running diode laser. These systems could also be extended to other wavelengths of interest that may facilitate other applications. In the future, it could lead to simple and compact laser systems with high output power and narrow emission line width suitable for wavelength specific applications.

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