# Narrow line width operation of a 980 nm gain guided tapered diode laser bar

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**Abstract:** We demonstrate two different schemes for the spectral narrowing of a 12 emitter 980 nm gain guided tapered diode laser bar. In the first scheme, a reflective grating has been used in a Littman Metcalf configuration and the wavelength of the laser emission could be narrowed down from more than 5.5 nm in the free running mode to 0.04 nm (FWHM) at an operating current of 30 A with an output power of 8 W. The spectrum was found to be tunable within a range of 16 nm. In the second scheme, a volume Bragg grating has been used to narrow the wavelength of the laser bar from over 5 nm to less than 0.2 nm with an output of 5 W at 20 A. To our knowledge, this is the first time spectral narrowing has been performed on a gain guided tapered diode laser bar. In the Littman Metcalf configuration, the spectral brightness has been increased by 86 times and in the volume Bragg grating cavity the spectral brightness has been improved over 18 times when compared to the free running operation. These schemes could be also extended for other wavelengths of interest in the future.

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**OCIS codes:** (140.2010) Diode laser arrays; (140.3425) Laser stabilization.

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## 1. Introduction

High power diode laser arrays are excellent light sources for pumping solid state lasers, alkali vapour lasers etc [1]. Tapered diode lasers bars can deliver watt level output powers with good beam qualities and power efficiencies [2, 3]. Their compact nature and long life time also facilitates them to be promising candidates for applications such as display, material processing etc. Typically, high power diode laser emissions have line widths of the order of a few nanometers which make them less useful in wavelength specific applications such as spin exchange optical pumping where a line width in the range 0.1 – 0.3 nm is required for efficient polarization of the noble gasses [4, 5]. There are several approaches which have been made in order to stabilize and narrow down the line width of the emission. A Littrow or Littman Metcalf configuration [6–8] employing a reflective wavelength selective element in an external cavity is the most common one among these. Recent advances in the volume Bragg grating (VBG) technology [9] have also helped in making the set ups more compact and less complicated. A volume Bragg grating is a very straight forward solution to stabilize and narrow the emission from a diode laser array. In 2006, Meng et al. [10] demonstrated 13.5 W of spectrally narrowed optical power with a line width of 14 pm. In 2008, Gourevitch et al. [11] displayed 30 W of output power with a narrow line width of 20 pm using a diode laser bar incorporated into an external cavity with a volume Bragg grating. In 2009, Liu et al. [12] reported 12.8 W of output power with a narrow line width of 70 pm from a V- shaped Talbot cavity.

The 'smile' observed on the laser bars also forms a big challenge in narrowing the wavelength [6]. Different groups have made efficient approaches towards solving this problem. Chann et al. [6] used a magnifying telescopic lens system in the external cavity to reduce the effective smile. Talbot et al. [8] showed that tilting the cylindrical lens in the cavity could compensate the large smile to a certain extend. 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; such phase plates are commercially available and also custom made. Even though numerous works have been reported on the spectral narrowing of broad area diode laser bars, not many have been reported on tapered diode laser bars. Recently, Paboeuf et al. [15] reported 1.7 W of optical power with a line width of 0.1 nm by the spectral stabilization and coherent combining of index guided tapered laser diodes using a volume Bragg grating external cavity. In this article, we report on the demonstration of two different methods employed for the line width reduction and spectral stabilization of a high power gain guided tapered laser bar. The first approach is using a Litmann Metcalf external cavity technique employing a reflective grating and the second approach is using an external cavity employing a volume Bragg grating. Both approaches led to efficient line width reduction of the laser bar emission. In the former case, 8 W of optical power has been achieved with the line width reduced from a free running 5.5 nm to 40 pm at 30 A of operating current. The laser output could be tuned over a range of 16 nm with no significant reduction in the power. In the latter case, an optical output of 5 W has been achieved at 20 A of operating current with the line width reduced from a free running 5 nm to 0.2 nm.

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## 2. Experimental setup

### *2.1 Tapered diode laser bar*

The tapered diode laser bar is based on a (GaAlInAs) (GaAs) laser structure with a large optical cavity grown by molecular beam epitaxy (MBE). The lateral structure consists of a ridge waveguide section with a length of 0.5 mm combined with a tapered section with a length of 2 mm. The taper angle amounts to 6°. The ridge-sided facet was covered with a highly-reflecting mirror coating of reflectivity, R > 97%, whereas the front facet was covered with an anti-reflection coating with a residual reflectivity of about 1%. The entire laser array has a width of 6 mm. The 2.5 mm long emitters are separated by a pitch of 500 µm and the tapered laser bar consists of 12 single emitters with 30% fill factor. The laser bar has been custom collimated on both axis and a phase plate based wave front corrector has been combined with the collimation optics. The phase mask is commercially available (*powerphotonic*, UK) [16] and is custom made to correct wave front errors on each of the 12 emitters on the bar. The antireflection coated collimation optics consists of a fast axis collimator (micro lens) of focal length 600 µm and a numerical aperture of 0.8 and an array of 12 individual cylindrical micro lenses with a focal length of approximately 1.38 mm for slow axis collimation and compensation for astigmatism. The individual slow axis collimating lenses has slightly different values for focal length depending on the variation in the astigmatism among the emitters. The wave front corrector helps eliminating the 'smile' on the laser bar. In the absence of the wave front correction optics, the bar had a smile of 2.4 µm peak-to-valley. After correction, this value reduced to below 0.6 µm. Figure 1 shows the near field images of the laser bar at 10 A of operating current before and after the wave front correction. At all currents, only 11 emitters out of 12 are emitting.

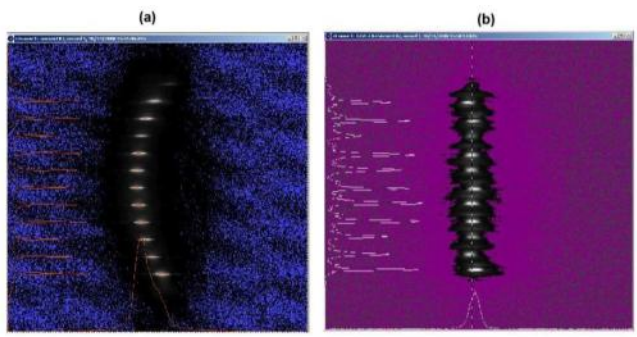


Fig. 1. Near field image of the laser bar at 10 A (a) Without wave front correction optics. (b) With wave front correction optics.

### *2.2 Littman Metcalf configuration for spectral narrowing*

Figure 2 shows a schematic of the experimental set up of the Littman Metcalf configuration for the spectral narrowing of the tapered diode laser bar. The external cavity consists of the 12 emitter tapered diode laser bar, collimation and beam correction optics ($L_1$), a half wave plate to adjust the direction of polarization between the grating and the tapered diode bar so as to optimize the diffraction efficiency, a beam expander which consists of a 15 mm focal length cylindrical lens ($L_2$) and a 100 mm focal length cylindrical lens ($L_3$), a reflective grating with 1200 lines/mm and 85% diffraction efficiency in the first order, a 40 mm slow axis focusing cylindrical lens $L_4$ and a 10% reflective output coupler. $L_4$ improves the feedback to the laser and increases the stability of the system. The beam expander system in turn forces the light beam to be incident on a greater area on the grating surface and thereby increases the spectral selectivity of the system. In addition to this, the beam expander would also minimize the effect of any residual smile from the laser bar [6, 13]. The spectrum of the laser is continuously monitored by sending the zero order beam from the grating to an optical spectrum analyzer (*Advantest Q8347* with 6 pm resolution). All the lenses are AR coated

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around the laser wavelength. For the spectral stabilization of the laser, the first order diffraction from the grating is fed back to the laser using the 10% reflective output coupler. The stabilized emission could be easily tuned by tilting the grating in the direction of the fast axis. This configuration allows the laser light to hit the grating twice before it is fed back to the laser and it in turn, enhances the spectral selectivity of the feedback system.

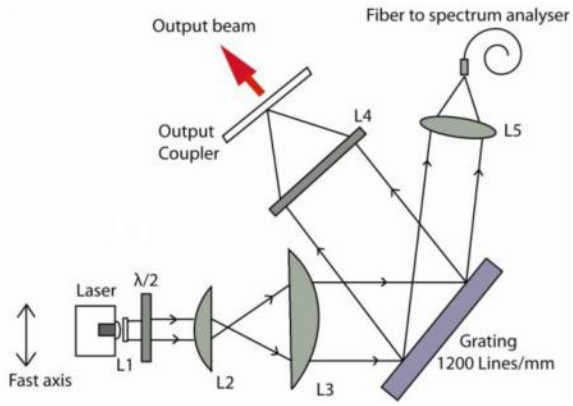


Fig. 2. Schematic diagram of the experimental setup of the Littman Metcalf configuration for spectral narrowing of the tapered diode laser bar.

Output couplers with different reflectivity (3- 15%) were used in this experiment with the best performance obtained with 10% reflectivity which is reported here. Considering 85% first order diffractive efficiency of the grating, 10% reflectivity of the output coupler, and the fact that the light is incident twice on the grating before being fed back into the laser, an effective feedback of approximately 7% could be assumed for the cavity. The temperature of the laser has been maintained at 20°C using a thermo-electric temperature controller. 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.

*2.3 Volume Bragg grating for spectral narrowing*

Figure 3 shows the experimental set up of the external cavity based on the volume Bragg grating for the spectral narrowing of the tapered diode laser bar. The cavity is considerably simpler and more compact compared to the first approach. It consists of the same 12 emitter laser bar, collimation and beam correction optics and a volume Bragg grating with a reflectivity of 25% at 981 nm and a bandwidth of 0.2 nm.

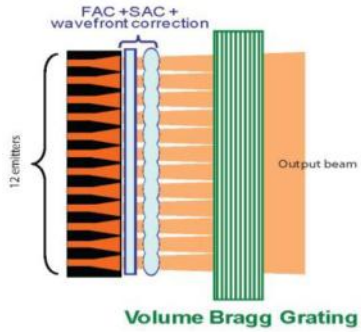


Fig. 3. The schematic diagram of the external cavity setup based on the volume Bragg grating.

The VBG is mounted on a mirror mount and placed very close to the wave front correction optics forming a compact cavity with a length < 10 mm. The wavelength locking is obtained by achieving the proper angle of incidence on the VBG by fine adjustment of the

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VBG along both the fast and the slow axis of the tapered diode laser bar. A part of the output beam is sent to the optical spectrum analyzer (resolution of 50 pm). The laser temperature has been maintained at 17°C by using a thermo-electric temperature controller.

## 3. Experimental results and comparison

Figure 4 shows the light current characteristics of the laser bar in the free running mode, with the Litmann Metcalf cavity and with the VBG cavity. The output power reaches 12.7 W at an operating current of 30 A in the free running mode. With the Littman Metcalf external cavity configuration, the setup generates 8 watts of optical power at 30 A and in the VBG external cavity, it generates 5 W at 20A.

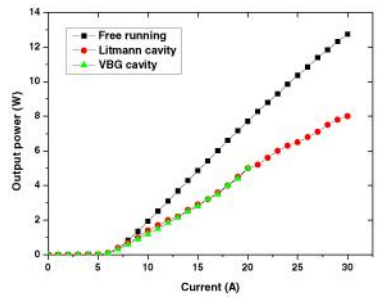


Fig. 4. The light current characteristics of the laser bar operated in the free running mode and in the external cavities.

In the free running mode at 30 A, the laser spectrum consisted of discrete peaks which was spread over 5.5 nm as shown in Fig. 5. Using the Littman Metcalf configuration, the line width of the laser emission could however be narrowed down to 40 pm at FWHM. This corresponds to an improvement in spectral brightness by a factor of 86.

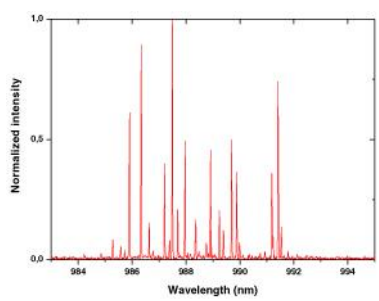


Fig. 5. The free running spectrum of the laser bar at I= 30A and the laser operating at 20°C.

Operation of the laser system without the beam expander was investigated as it provides a simpler and more compact setup. Spectral narrowing was also achieved in this case but the minimum line width obtained was 100 pm proving the superior performance of the laser system including the beam expander. The wavelength locked laser output could be tuned over a range of 16 nm without any considerable loss in the output power. 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 which broadened the output spectrum. This is in contrast to the results obtained on a similar laser bar used for spectral beam combining where a wavelength span of approximately 50 nm was possible [3]. This may be explained by less effective feedback in the present setup where the feedback aperture is the narrow fast axis aperture of the diode laser bar and indicates that an increased tuning range is not possible.

Figure 6 shows the spectral tuning of the laser. The line width of the output varies between 40 and 60 pm over the entire tuning range. All the measurements were taken at the FWHM of the peaks. The external cavity setup has an efficiency of approximately 63% when compared to the free running mode. It is partly limited by the diffraction efficiency of the

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grating. This is comparable to the results obtained using broad area bars [7]. It is the facet coating, diffraction in the grating and the output coupler that are mainly responsible for the losses in the cavity.

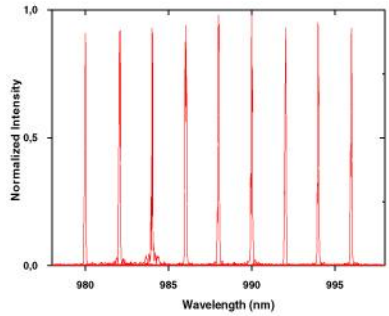


Fig. 6. The spectral tuning of the external cavity tapered diode laser bar at I= 30A and the laser operating at 20°C.

In the VBG configuration, the emission has been locked at a wavelength around 981 nm which corresponds to the Bragg wavelength of the VBG. The line width at the FWHM is measured to be 0.2 nm using an optical spectrum analyzer with a resolution limit of 50 pm whereas the free running line width at this current level exceeded 5 nm. This corresponds to an improvement in the spectral brightness by a factor of 18 over the free running laser bar. Above 20 A, the self lasing from the laser starts to dominate the output and a perfect locking using the VBG was not possible. The overall efficiency of the VBG cavity is approximately 65% compared to the free running mode. This is attributed to the reflectivity of the VBG and other internal losses. Figure 7 shows the stabilized normalized wavelength spectrum of the laser bar at a current of 20 A in a VBG cavity and at 30 A in a Litmann Metcalf cavity. The larger line width of the output beam from the VBG cavity in comparison to that of the Littman Metcalf cavity could be attributed to the limited bandwidth of the VBG and the lower resolution of the optical spectrum analyzer used for the measurement.

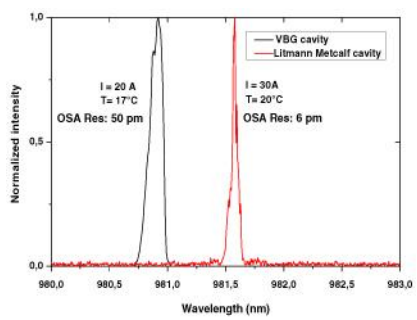


Fig. 7. Comparison of the spectrum from a Litmann Metcalf and a VBG cavity.

The VBG cavity has the advantage of being significantly more compact, robust and easy to align compared to the Littman-Metcalf cavity. However, the lack of tuning possibilities makes the Littman-Metcalf cavity more suitable in certain applications where tuning is required.

## 4. Conclusion

We have demonstrated two different approaches for the wavelength narrowing of a high power gain guided tapered diode laser bar, with a free-running line width > 5 nm. The first approach using a Littman Metcalf configuration yielded 8 W of output power at 30 A of operating current with a narrow spectral line width of 40 pm. Moreover, the output spectrum could be easily tuned over a range of 16 nm. The second approach using a VBG external

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cavity yielded an output power of 5 W at an operating current of 20 A. The line width of the emission has been narrowed to 0.2 nm. We achieved an improvement of the spectral brightness of the tapered diode laser bar of a factor of 86 in the Littman Metcalf cavity and a factor of 18 in the VBG cavity, compared to the free running mode of the laser bar. The first approach is suitable for demanding applications which require both very narrow line width and wavelength versatility, at the cost of a more complex setup than the second approach. To our knowledge, this is the first time wavelength narrowing has been performed on a gain guided tapered diode laser bar. The phase plate based wave front correction helps in eliminating the smile effects in the laser bar which plays a crucial role in limiting the line width of the stabilized output. This technique could be applied on broad area laser bars, diode laser stacks, etc. in the future which in turn could deliver even higher output powers with very good spectral quality for desired applications.

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