High-Resolution Spectral Mapping of a Lensed High Power Laser Bar

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ABSTRACT

Alkali gas lasers based on rubidium vapor have an extremely narrow absorption band (<0.01 nm at STP) at 780 nm. Diode-pumped alkali lasers (DPALs) require high-power diode arrays having emission spectra which are closely matched to this absorption peak. There are several methods which can be used for narrowing and stabilizing the output spectrum of a diode laser bar including external locking via a volumetric holographic grating (VHG). While this approach offers several advantages over internal stabilization techniques, the effect of pointing error arising from bar smile can be detrimental to the locked performance of the lensed array. In order to investigate the effect of smile on wavelength locking, a system capable of mapping the emission spectrum of the lensed diode laser bar was developed. The approach utilizes an imaging system and spatial filter to couple light from individual emitters of the lensed array into a commercial optical spectrum analyzer. This approach offers a larger dynamic range than traditional spectral mapping techniques, with a resolved signal to noise ratio in excess of 60 dB. Results from the characterization of a VHG-locked 780 nm laser bar array will be presented.

Keywords: High-power laser bar, VHG locking, Smile Deformation

1. MOTIVATION

There exist a variety of laser media having narrow linewidth pump absorption bands. Because of this, diodes with high power and narrow spectrum output are desirable. Several methods can be used to narrow the output spectrum of a diode laser bar including external locking with a volumetric holographic grating (VHG). This approach offers several advantages over other techniques including penalty free locking, easy wavelength changes, and simpler fabrication techniques. However, pointing error as a result of laser bar smile can have detrimental effects on the locked performance of the laser. In order to better characterize the effect of smile on locking performance, a system capable of spatially resolving the spectrum of a lensed high power diode laser bar is necessary. The goal of this work was to develop such a system.

Despite recent advances in fabrication techniques such as coefficient of thermal expansion (CTE) - matched heatsinks and improved processing, the individual emitters along the width of high power diode laser bar arrays are not perfectly aligned in the growth direction. The difference in thermal expansion coefficients between the bar and bonding heat sink in the mounting process can contribute to small (<3µm, typically <1µm) variation in emitter height across the bar. This deformation is commonly referred to as laser bar smile and is measured in terms of smile size – the total difference in height between the highest and lowest emitters, as shown in Fig. 1.
This difference in position between emitters results in variation of the incidence angles of the emitters onto the VHG proportional to the change in height over the focal length of the fast axis collimating lens.

$$\Delta \theta \approx \frac{\Delta h}{f}$$  \hspace{1cm} \text{Eq.1}

If this change in angle ($\Delta \theta$) is greater than the acceptance angle of the VHG (typically around 5mrad), then those emitters will not lock. This effect is illustrated in Fig. 2.

\[ \text{Fig. 1 Laser smile deformation} \]

\[ \text{Fig. 2 (a) No smile – light is reflected directly back into the emitter (b) - Smile deformation – light reflects from the grating at an angle and is unable to couple back into the detector} \]

2. EXPERIMENT

An initial model of several emitters collimated in the slow axis was created in Code V. The beam divergence was approximated paraxially by setting up three field points at each emitter location with NA equal to the divergence of the emitters and separation equal to half the beam size. The model revealed that the individual emission spectra of each emitter in the locked diode could not be easily measured using a technique such as a scanning slit. This is because optics in the system such as the VHG obstruct the placement of a slit in the near field and in the far field all of the emitters have overlapped as shown in Fig. 3.
The solution was to use a long focal length lens (100mm) to re-image the separated emitters. This created a region far behind the focal point where the overlapped images of each emitter had not diverged into one another as depicted in Fig. 4. This point corresponds to the image of the plane directly behind (or in front of) the SAC lens. A slit with high power handling capabilities placed in this region allowed direct measurement of the output of individual emitters.

The laser used was a 774nm, 100W-rated microchannel-cooled 1-cm laser array ran at 20A. To cool the array, distilled water was pumped through the microchannels at 23°C, 4L/m continuously during operation. Mounted on the front of the laser were the fast and slow axes collimating lenses. Immediately after the collimating lenses a 25% reflective, a 780.1nm VHG was emplaced. The VHG was held in place by a vacuum lens holder fabricated out of aluminum and mounted on a free-rotating platform, which allowed easy alignment for VHG locking. The collimated beam was then passed through a 90% reflective beamsplitter which directed most of the power onto a high-power thermopile. See Figures 5 and 6. The rest of the beam passed through a 100 mm focal length lens, which created a region well beyond the focal plane where the emitter images were spatially separated. This can be seen in Fig. 7. A slit with high power handling capabilities was placed in this area to scan across the emitter images and collect their individual spectra into the optical spectrum analyzer (OSA) for analysis.
Fig. 5 Diagram of the system setup.

Fig. 6 Image of system setup
3. RESULTS

A slit was placed at the focal point of the lens where all of the emitters overlapped to compare the total laser output for both the locked and unlocked spectra, as can be seen in Fig. 8. The full width-half max (FWHM) of the locked spectrum was 0.09 ± .01nm with a peak at 780.15±.05nm, considerably smaller than the unlocked FWHM of 0.356±.02nm with a peak at 773.9±.02nm.

![Graph](image)

**Fig. 8** – Measured total emission spectrum of the laser before and after locking. Results are shown in both linear normalized scale (a) and in dbm (b).
A calculated total spectrum composed by overlapping the individual spectra measured from each emitter is compared to the total measured signal in Fig. 7. While the general shape is the same for both spectra, the calculated total signal appears to be scaled up. This can be attributed to the fact that the slit did not collect all of the power from each emitter. Since the laser was running near its threshold current, the relatively lower threshold value introduced by the VHG allowed the locked emitters to put out more power than the unlocked emitters. Because not all of this additional power was collected by the detector, the locked emitters had less weight on the calculated spectrum which skewed the data towards the spectra of the unlocked emitters.

![Fig. 9](image_url)

**Fig. 9** – Comparison of the total measured output spectrum to the calculated spectrum. Results are shown in both linear normalized scale (a) and in dbm (b).

Below in Fig. 10 is the resolved spectrum of the locked and unlocked laser diode evaluated at each emitter from a scan across the laser bar. The data from each emitter were collected into a 2D array and numbered from left to right so their positions on the figure correspond to their physical locations on the bar. Figure 10(a) shows the unlocked laser characteristics – a broad spectral range that varies from emitter to emitter by up to 0.5nm. Figure 10(b) is the best locked laser spectrum, which was determined by placing the slit at the lens focal plane where all of the emitters had overlapped and adjusting the VHG alignment to maximize output around 780.1nm and minimize output at all other wavelengths. The locked spectrum shows evidence of smile deformation in the outermost emitters, but the majority of the emitters are locked with virtually all of the output at 780.15nm with a variation in peak wavelength of less than 0.05nm between emitters.
The smile size of the bar was estimated by rotating the VHG until the outer emitters were locked. A scan across the bar in this position can be seen in Fig. 11. Using the focal length of the fast-axis collimating lens (~600µm) and the change in angle from the best locked position to the outer locked position (Δθ ~1.4 milliradians), the height difference between the middle and outer emitters, or smile size, was calculated to be 0.84µm using Eq.1.

Fig. 10 – Spectrum of laser before (a) and after locking (b). Results are shown on a normalized log scale.

Fig. 11 – Spectrum of laser with the outer emitters locked. Results are shown on a normalized log scale.
4. CONCLUSION

The goal of this work was to develop a method to resolve the spectrum of a high power laser bar to investigate the effects of laser bar smile on VHG locking. A setup was created using a long focal length lens and a spatial filter to separate emitters. The individual spectra of the emitters on a locked 100W diode bar were resolved using the proposed setup, which was shown to offer a much larger dynamic range (>45dB) than other techniques such as a charge-coupled device (CCD) or complementary metal oxide silicon (CMOS) cameras with signal to noise ratios around 20 and 30dB respectively.

REFERENCES


