Compact self-aligned external cavity lasers using volume gratings

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ABSTRACT

We experimentally demonstrate a compact self-aligned external cavity 25W high power laser diode bar at 976 nm tunable over 0.5 nm with a bandwidth of 0.25 nm. The external cavity is based on double diffraction from a glass reflective volume holographic grating (VHG). The wavelength tuning is performed by rotation of the VHG. Passive alignment and fine wavelength tuning of the proposed external cavity are attractive new features over the state-of-the-art active alignment method and fixed wavelength limitation currently used in wavelength stabilized high power laser diode bars.

Keywords: High power laser diodes, external cavity, tunable, volume holographic gratings, self-aligned, passive alignment.

1. INTRODUCTION

High power laser diode bars have a broad multimode spectrum of several nanometers consisting of the superposition of the spectrum of each broad area emitter in the bar. With external feedback from a single reflective VHG, the broad spectrum of a laser diode bar is wavelength narrowed to a bandwidth equal to the bandwidth of the VHG [1,2,3], which is typically of the order of a couple of tenth of nanometers. However, to achieve optimal feedback in the cavity, the VHG must be actively aligned by rotating the VHG around the fast axis direction (Fig. 1.). Once the optimal angle is reached, the VHG is fixed (bonded) and must remain within a few milli-radian from its initial position for the life of the product. Although such tight tolerance can be maintained in production, it would be preferable to relax the angular requirement. The wavelength locked laser has a center wavelength fixed by the Bragg wavelength of the VHG. Although the center wavelength of the wavelength locked laser can be changed by varying the temperature of the VHG, this method adds complexity and cost. It would be preferable to have wavelength tunability by means other than thermal.

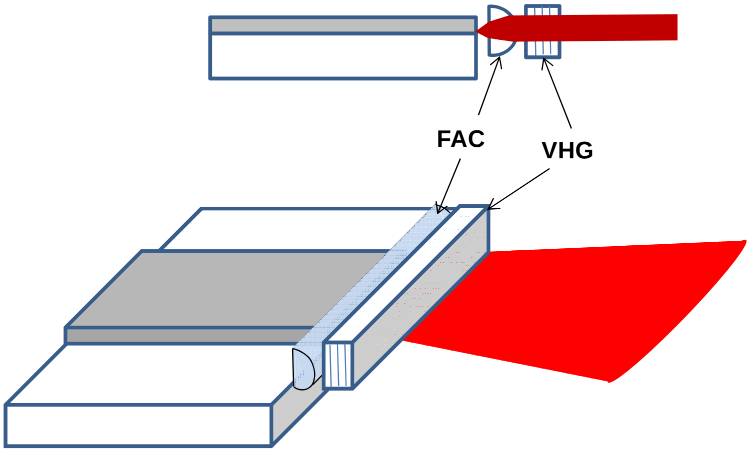

Fig. 1. State-of-the-Art wavelength locking of a laser diode array with fast axis collimation lens (FAC) and reflective volume holographic grating (VHG).

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In this work, we report on a passive alignment method of the VHG and wavelength tuning by angular rotation of the VHG.

2. EXTERNAL CAVITY ARCHITECTURE

The external cavity architecture, illustrated in fig. 2., is applicable to single broad area laser diode or an array of broad area laser diodes. This architecture is an extension of the cavity proposed by the authors for single frequency tunable lasers [4].

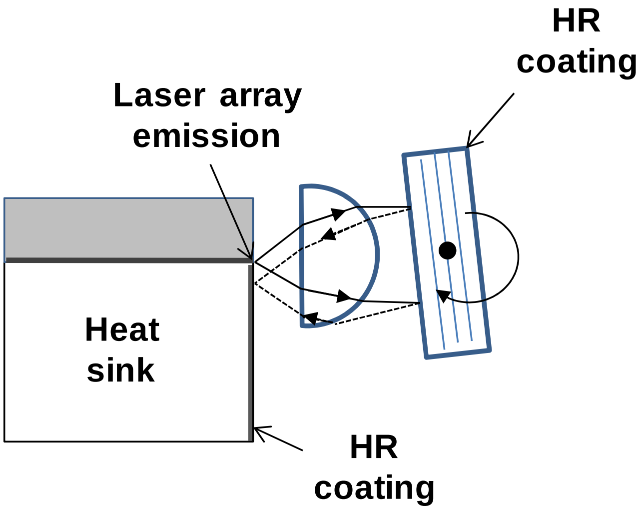


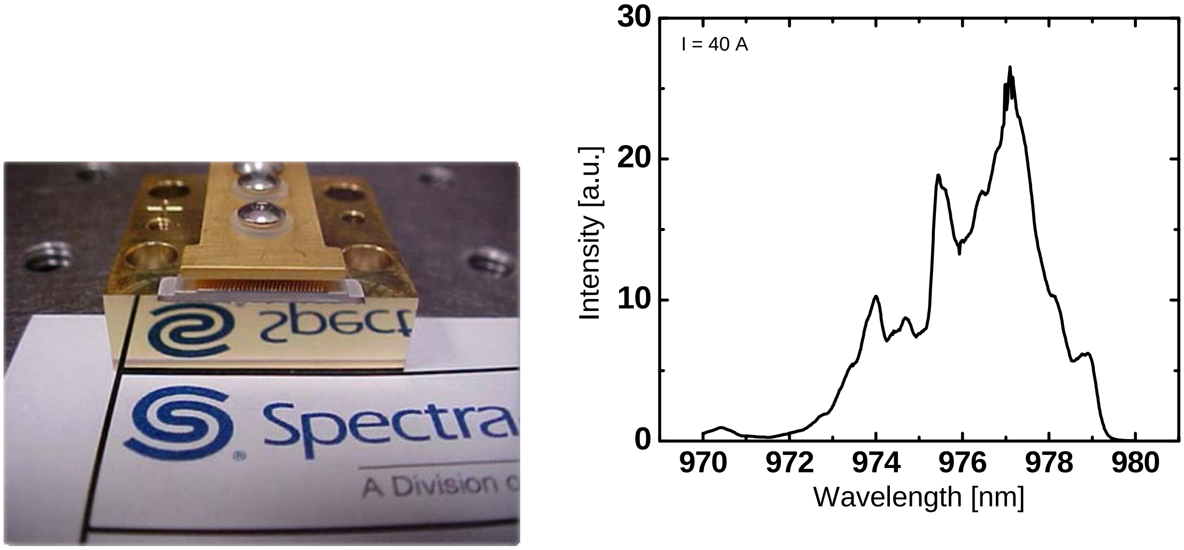
Fig. 2. Self-aligned external cavity architecture for a single broad area laser and laser diode array.

The FAC lens collimates the light in the fast axis direction. The VHG is positioned after the FAC lens and at an angle such that the diffracted light from the VHG impinges on the heat-sink below the laser diode array. The facet of the heat sink is a smooth surface, coated with a high reflective coating (for example gold coating). Upon specular reflection from the heat sink, the light is re-collimated by the FAC lens. The laser emission surface is assumed to be flush with the heatsink facet, so that the re-collimated light is well collimated. The VHG re-diffracts the re-collimated light, which by construction goes back in the laser diode array ("double diffraction architecture").
Upon rotation of the VHG around a direction perpendicular to the page (see fig. 2), the wavelength of the diffracted beam changes, which in turn changes the emission wavelength of the laser diode bar.

This architecture has the additional advantage that wavelength locking is independent of the smile of a laser diode array because the variation in pointing angle, after the FAC, is transformed in a variation of the center locked wavelength. This is in contrast with the state-f-the-art direct feedback (fig. 1), where a laser diode array with a smile larger than approximately 1 μm, collimated by a diffraction limited FAC lens, generates a partially locked spectrum.

3. EXPERIMENTAL RESULTS

The demonstration of the self-aligned tunable external cavity was carried out with a high power laser diode array from Spectra Physics (a division of Newport Corporation). The laser diode array has 19 emitters of width 100 um, 4% front facet AR coating and output 25 W of optical power at 40 A. Fig. 3 (a) shows a picture of the laser diode bar with the shiny reflecting gold coated surface. There was no overspray of Indium visible on the gold coated surface below the laser bar. The reflectivity of the gold surface is approximately 95% at 976 nm.



(a) (b)

Fig. 3. (a) Picture of the high power laser diode array used in the experiment showing the shiny reflected gold coated surface below the laser diode bar. (b) spectrum of the solitary laser diode bar after a fast axis lens (not shown in the picture)

The laser diode bar was lensed with an aspherical lens (FAC lens) of 900 μm focal length. Fig. 3(b) shows the spectra of the laser diode bar after the FAC lens at 40 A. The laser diode bar is conductively cooled with a water coolant temperature of 15^{o}C. A 13 x 1.75 mm x 1.5 mm volume holographic grating with 40% efficiency is used for the “double diffraction” external cavity. The VHG was mounted on a one-axis rotation stage to change the angle of the diffracted beam according to fig. 2.

When the diode was turned off, the VHG was positioned in front of the FAC. The 13mm long facet VHG was approximately parallel to the length of the FAC lens and the angle of the normal of the VHG was approximately a few degrees from the optical axis. When the diode was turned on, the laser diode array was wavelength locked thus confirming the self-alignment feature. Fig. 4 shows the result.

The VHG was incrementally rotated from 0.8 degree (from normal to the optical axis) to 3 degrees. The spectrum of the laser diode bar was narrowed to a FWHM of 0.27 nm +/- 0.01 nm for all angles. The center wavelength of the locked spectrum varied as the VHG was rotated. A total of 0.5 nm tuning was achieved corresponding to an angular range of 2.2 degrees. At higher angles, close to 3 degrees, the locked spectrum exhibited small side lobes. At smaller angles, the side lobes are not visible.

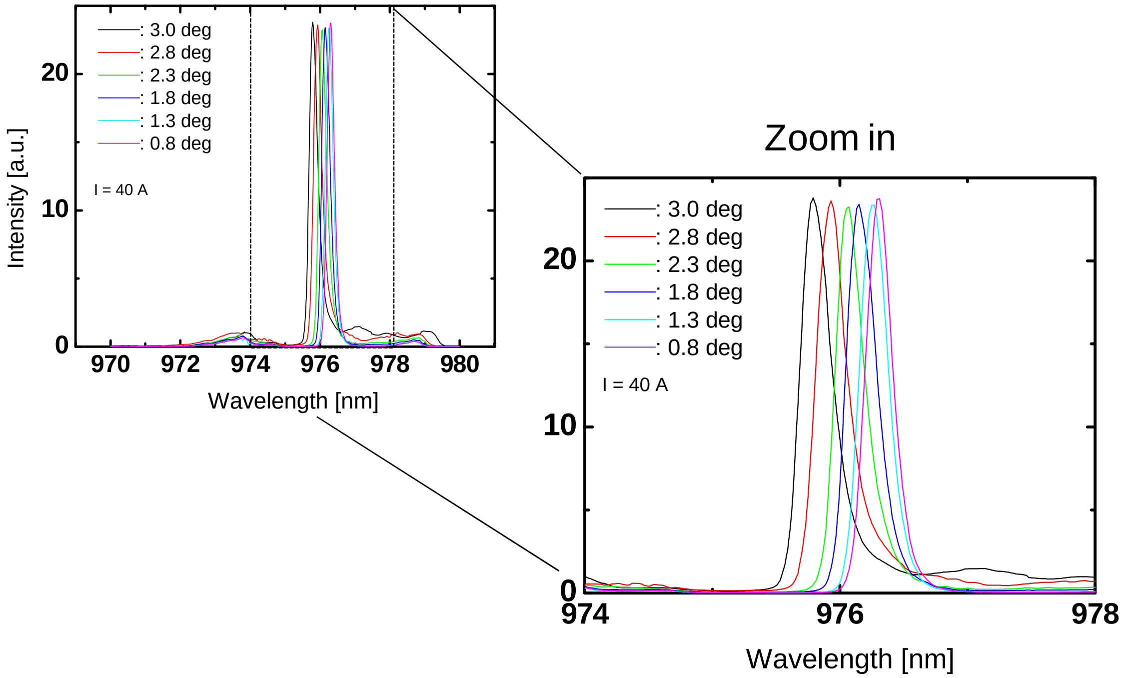


Fig. 4. Experimental results with a high power laser diode array and the the self-aligned external cavity architecture. The graphs show wavelength locking, bandwidth narrowing and a center wavelength tunable over 0.5 nm.

Fig. 5 is a plot of the optical power as a function of VHG angle (i.e wavelength). The solitary laser diode bar emits 25 W of optical power (no VHG). Upon applying feedback, the lowest optical power loss occur at large angles. At 3 degrees, the optical power loss was 2%, increasing to 12% at 0.3 degrees. The reasons for higher loss at smaller angles and lower loss at larger angles are currently not well understood and need further measurements.

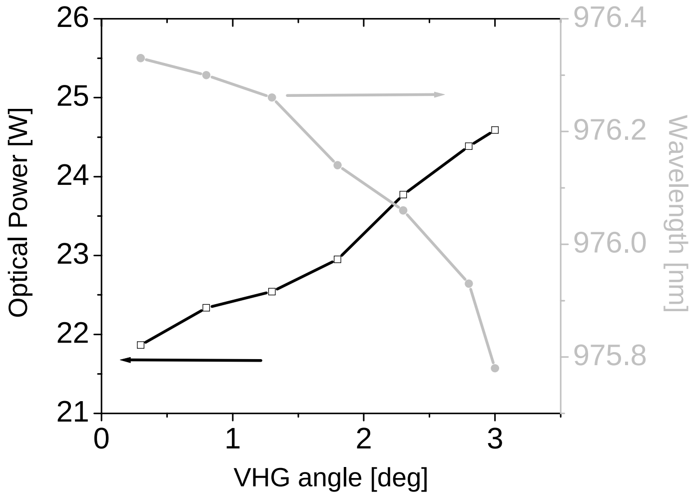


Fig. 5. Graph showing the center wavelength of the laser diode bar and optical power as a function of VHG angle (zero degree is normal incidence to the VHG).

However, the following analysis provides an insight into the loss mechanism of the architecture. The VHG has a FWHM angular acceptance of 1.7 degrees. In the slow axis direction the beam is freely diffracting with a FWHM divergence of 7 degrees. Upon the first diffraction, only the power within the angular acceptance of the VHG is diffracted. Therefore the effective efficiency of the first diffraction is 40% x 1.7 / 7 = 9.7%, which means that 90.3% of the optical power is transmitted through the VHG (minus ~1% loss of the VHG, which is the sum of the AR coating loss and scattering loss). However this transmitted power figure should increase because part of the power from the first diffraction goes back into the laser cavity. We then expect that the maximum loss is of the order of 10%, which explains the 12% measured.

Upon reflection from the gold coated surface, 95% is reflected, i.e 9.2%. Upon the second diffraction, the beam is diffracted with 40% efficiency i.e 3.7% of the original power contributes to the optical feedback and 5.5% of the original power is transferred in the secondary beam (the undiffracted beam after the second diffraction).

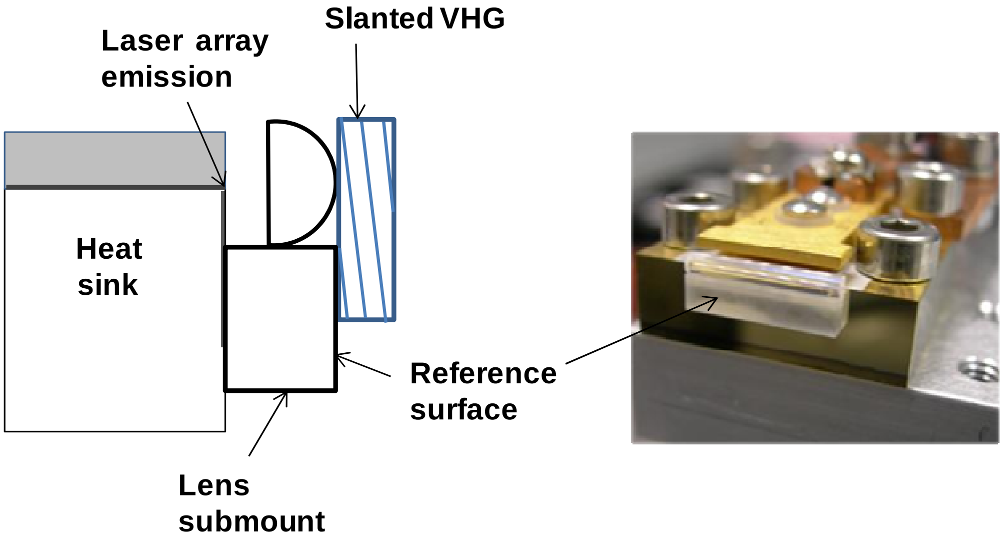


Figure 6. Packaging. Mounting a slanted VHG against the surface of the FAC submount provides a packaging method that ensures passive alignment.

Figure 6 illustrates a method to passively align a VHG to generate a wavelength locked laser diode bar. The method uses the surface of the FAC submount as the reference bonding surface for the VHG. The VHG slant angle (angle between the normal of the grating vector and VHG's surface normal) provides the necessary diffraction angle for the cavity.

4. CONCLUSIONS

We have presented and experimentally demonstrated a self-aligned external cavity based on double diffraction from a VHG applied to a high power 25W laser diode array at 976 nm. The simple and compact external cavity is wavelength tunable over 0.5 nm by rotating the VHG. This passive alignment method removes the tight angular tolerance that was required to align the VHG in previous external architecture and provides fine tuning of the center wavelength. This method can either be used in fixed wavelength application to reduce packaging cost and increase reliability or in applications requiring accurate center wavelength such as the production of hyperpolarized gases for pulmonary imaging [5] or for Alkali lasers [6].

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