Wavelength Stabilization of HPDL Array – Fast-Axis Collimation Optic with integrated VHG

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ABSTRACT

Volume holographic gratings (VHG) provide the capability of narrowing and stabilizing the wavelength of semiconductor lasers by forming an external cavity laser (ECL). The standard configuration of these ECL's is to use a collimating lens followed by the VHG to provide feedback to the resonator and lock the wavelength. In this configuration both elements have to be carefully aligned with tolerances in the sub-µm and mrad range. The present paper presents a fast-axis collimation lens (FAC) with integrated VHG for locking a laser diode bar. Besides the advantage of having only a single element, the integrated element is also less sensitive to alignment tolerances with respect to the locking due to the large divergence angle of the uncollimated array compared to a collimated array. Using a standard AR coated array with 19 emitters an output power of 67.4 W was achieved. The spectral bandwidth was within 1 nm over the whole power range. Due to high stability requirements in this application, glass was chosen as the VHG material. Though the refractive index is low compared to standard FAC lenses, the design and manufacturing process of the lens still guarantees a diffraction limited collimated beam.

Keywords: Wavelength stabilization, VHG, FAC, diode laser, holographic grating, spectral brightness

INTRODUCTION

Wavelength narrowing and stabilization of diode lasers is advantageous for many applications where either the natural linewidth of a diode laser is too broad or the movement of the center wavelength during changing operation conditions has to be avoided. Typical applications are pumping of solid-state-lasers, where the center wavelength shifts due to changing cooling conditions or driving current, or the Dense-Wavelength-Multiplexing of diode lasers with closely spaced wavelengths (e.g. several nm or less) using wavelength combiners with steep edges. Applications like Raman-scattering, medical treatment or military applications also require stable and narrow spectral emission characteristics. Furthermore, diode lasers with high spectral brightness can be used for frequency conversion. Stabilization of the wavelength also helps to increase the yield during manufacturing of diode lasers because a larger area from a wafer can be used.

The most common technique for stabilizing the spectrum and collimating the output radiation is to use a collimation lens (e.g. FAC) and a volume-holographic-grating (VHG) that provides feedback only for a certain wavelength range[1-3]. This configuration forms an external cavity using two discrete elements (Fig. 1). FAC lenses are commercially available with a broad range of geometries and focal lengths (EFL)[4], and due to flexible manufacturing processes VHG's can be optimized for any type of laser and application[5]. However, the configuration consisting of two discrete elements requires that both have to be carefully aligned individually in the sub-µm and mrad regime, which is challenging especially for high-power diode laser arrays or two-dimensional stacks. In the latter case a single slightly misaligned FAC leads to a non-locking condition when using a large area VHG.
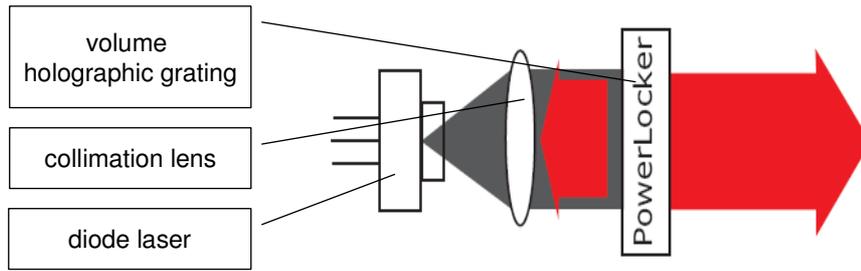
Fig. 1   Typical configuration of diode laser, FAC and VHG for narrowing and stabilizing the wavelength.

The optical element presented in this paper combines the two functions of stabilizing and collimating the output power of diode lasers[6]. For this purpose a VHG element is equipped with an acylindrical surface so that the grating is positioned within the uncollimated part of the beam and the acylindrical surface collimates the spectrally locked output (Fig. 2). We call this element the "VHG-FAC".
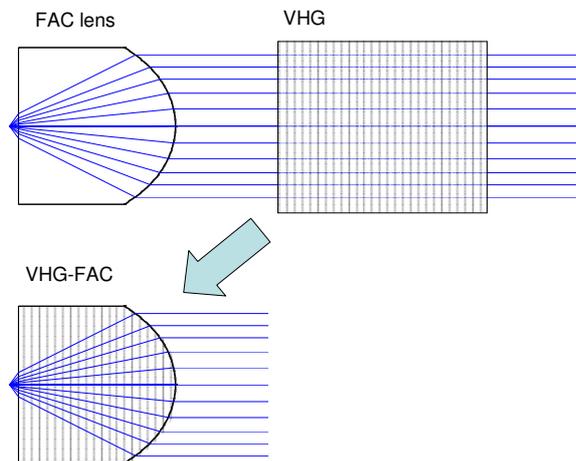

Fig. 2   VHG-FAC: Combined element with VHG and acylindrical surface for collimation of the diode laser output.

In addition to the advantage of having only one optical element to handle, the VHG-FAC is also insensitive to misalignment with respect to the wavelength locking functionality. The most critical degree of freedom for the VHG in a standard two-piece configuration is the rotation around an axis parallel to the slow-axis of the diode laser, which is called "rolling". Due to the angular selectivity of volume holographic gratings as shown in Fig. 3, for the VHG-FAC only a small part of the beam that satisfies the Bragg matching condition, on the order of 0.1°, is diffracted into the laser diode cavity. (Fig. 3). The angular divergence of the diode is very large, hence on rolling the lens, another part of the beam will be Bragg matched and provide the required feedback.
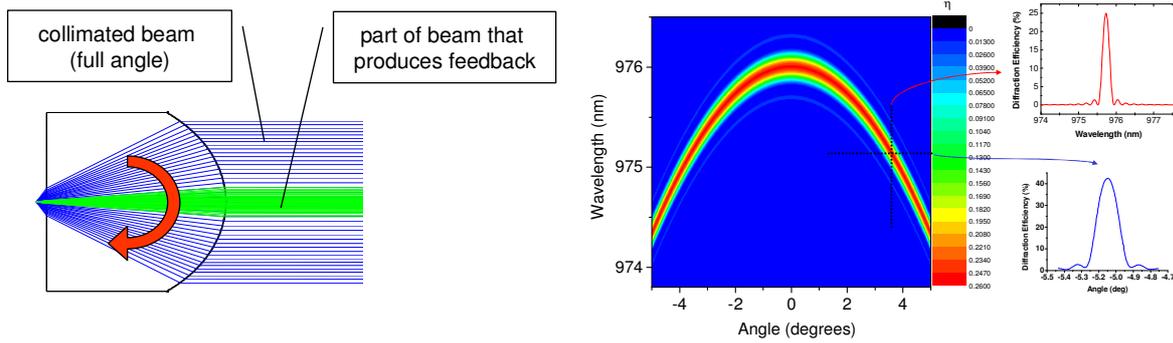
Fig. 3   Left: VHG-FAC is insensitive to rolling around the axis parallel to the slow-axis of the laser diode. Only the portion of the beam highlighted Bragg-matches the grating and produces feedback into the laser diode. Right: Diagram shows the angular and the spectral efficiency of a VHG.

Additionally, the VHG-FAC is insensitive to laser diode "smile" because the grating structure does not change in the direction parallel to the fast-axis of the laser diode. In the case of a two-piece assembly, radiation from an emitter positioned above the optical axis is not coupled back into the cavity[7]. Fig. 4 shows the situation for an emitter positioned "off-axis" in the standard two-piece configuration, as in the case of a laser diode with excessive "smile".
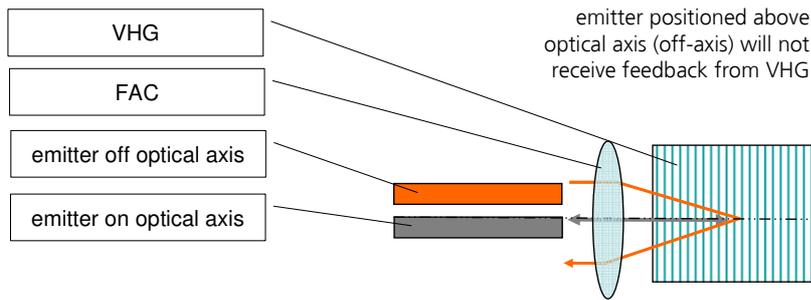

Fig. 4   Feedback situation for the two-piece configuration of FAC and VHG in the case of an array with "smile". The emitter above the optical axis will receive less feedback.

EXPERIMENTAL RESULTS

Experiments were carried out using a diode laser array with a fill-factor of 30% (19 emitters, 150 µm emitter width, 500 µm pitch) and a fast-axis divergence angle of 65° (95% power content). The array was passively cooled and mounted on a CS-mount. The VHG-FAC had a focal length of f=900 µm. Fig. 5 shows the power vs. current characteristics for three configurations. Configuration 1 consists of the diode laser array and a standard FAC lens (EFL=900µm) without a holographic grating. Though the facet is AR-coated an output power of 33 W is obtained. Using the "VHG-FAC" (configuration 2) lens and the two-piece configuration of FAC and separated VHG (configuration 3) a slightly higher output power of 35 W is measured. The VHG used in configuration 3 has a peak efficiency of 22.5%.
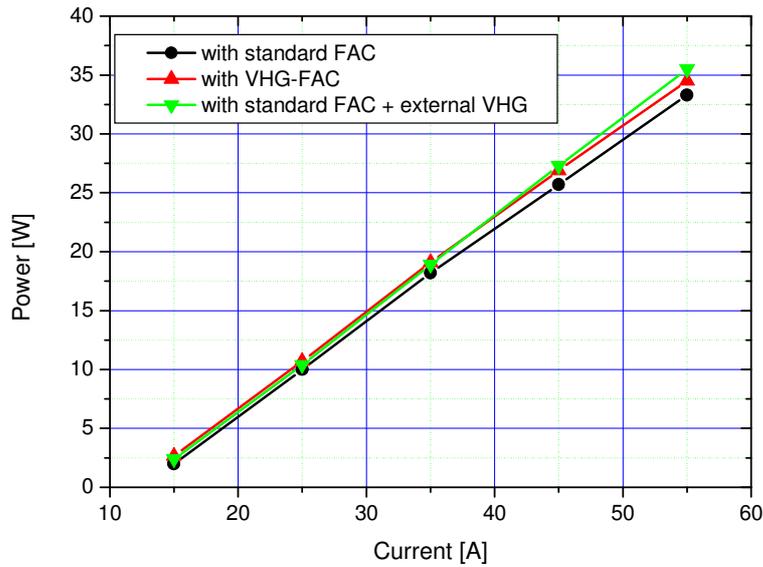
Fig. 5   P-I curve of different collimation scenarios. Comparison of standard FAC, standard FAC + external VHG and VHG-FAC shows same output power for both stabilized cases.

Fig. 6 shows the corresponding spectra at different driving currents. The free-running spectrum of the diode laser is broader than typically measured with standard arrays due to the AR coating of the diode laser chip. Using the VHG-FAC the spectrum is narrowed below 0.5 nm and stabilized over the whole power range.
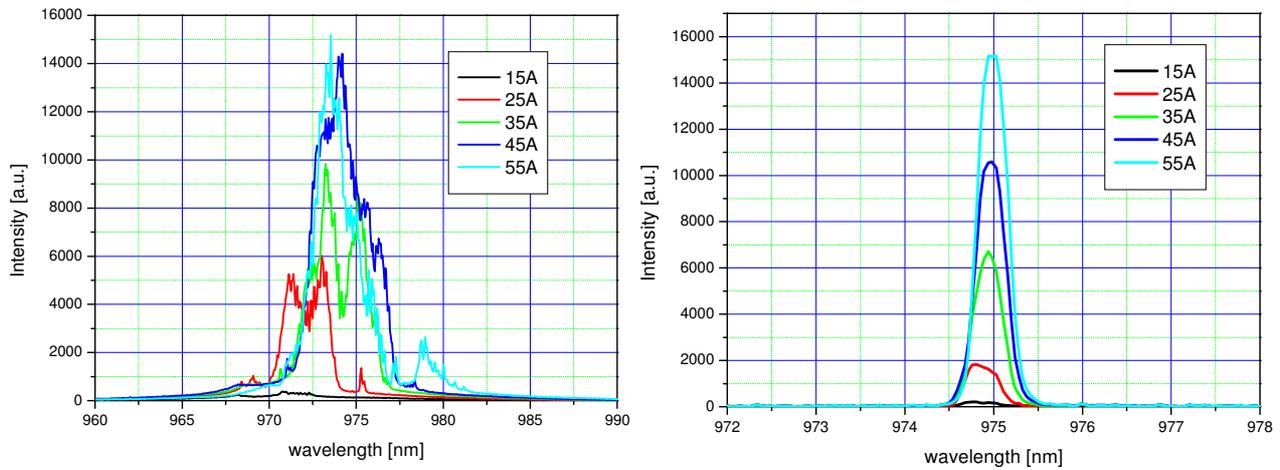

Fig. 6   Spectrum of diode laser array for various driving currents. Left diagram shows the "free-running" array collimated using a standard FAC lens. Diagram on right shows the stabilized spectrum using the single piece VHG-FAC lens.

Not only is the spectral brightness an important factor for the use of VHG-FAC lenses, but collimation characteristics also have to meet diffraction limited quality standards. The collimation quality of the VHG-FAC is measured using a well-known setup where a screen is positioned approximately 3.5 m from the facet and this screen is observed with a CCD camera. To characterize the quality along the cylindrical axis a cylindrical lens is used for imaging of the slow-axis on the screen. The comparison between VHG-FAC and standard FAC made from N-LAF21 (Fig. 7) shows the same high quality level for the VHG-FAC lens.
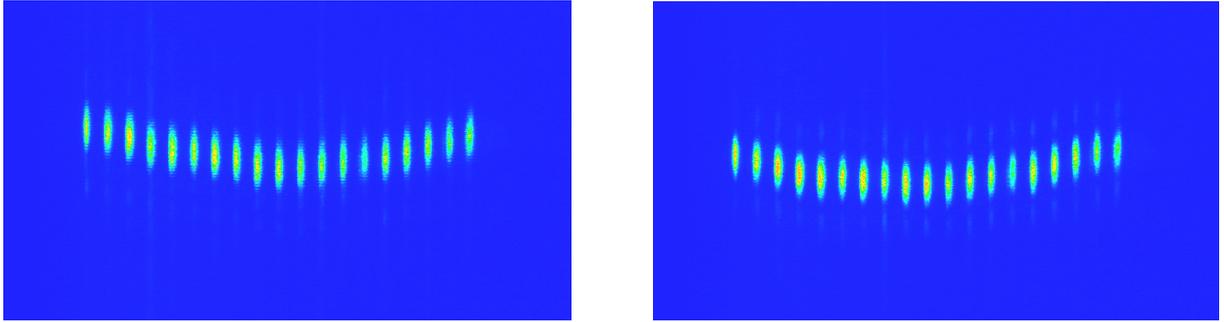
Fig. 7 Far-field intensity profile of the collimated diode laser array measured approximately 3.5 m from the FAC. The right picture shows the "free-running" array collimated using a standard diffraction limited quality FAC lens. The diagram on the left shows the profile using the VHG-FAC lens for collimation.

One of the advantages of the VHG-FAC is that the locking mechanism is insensitive to misalignment of the element (Fig. 3). Fig. 8 shows the far-field profile and corresponding spectrum of the output for different "rolling" angles of the VHG-FAC around the axis parallel to the slow-axis of the array.

Even for an angle of 3° there is no change in the locking behavior. As the remaining degrees of freedom are more critical with respect to collimation quality, the only alignment criterion for the VHG-FAC is the "collimation criterion" that is well known from alignment of standard FAC lenses.
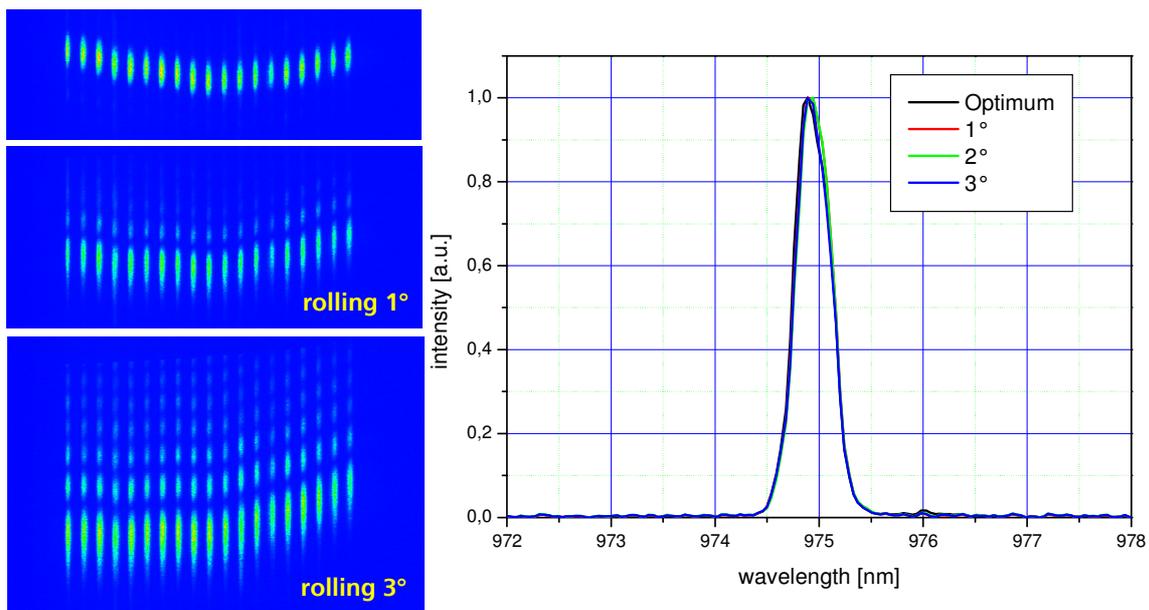

Fig. 8 Spectrum of the collimated beam as a function of "rolling". Pictures on left side show the far-field distribution for optimum alignment and rolling angles from 1° and 3°. Even for a rolling angle of 3° the spectrum remains unchanged so that the only alignment criteria for the VHG-FAC lens are the well known criteria from alignment of standard FAC lenses.

Further experiments were carried out using an actively cooled diode laser array with the same geometrical structure of the emitting zone. Due to the better cooling an output power of 67 W is obtained. Fig. 9 shows the spectrum of the locked array and the free-running spectrum.
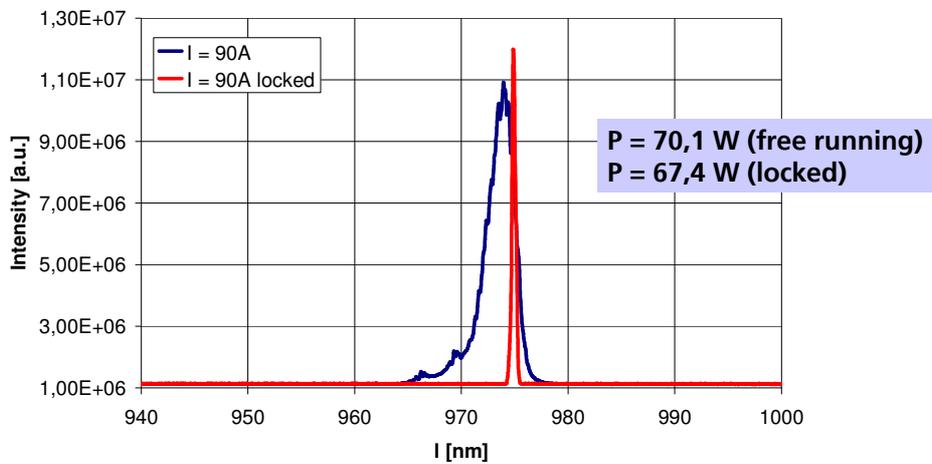

Fig. 9   Spectrum for array mounted on a micro-channel cooler. An output power of 67 W was obtained.

Due to the comparably low refractive index of the VHG material (n=1.45), the geometry of the FAC is steeper than a FAC made from a high index material like N-LAF21. Nevertheless the same collimation quality can be achieved (Fig. 10) and the maximum NA of the lens is 0.65, which corresponds to a full divergence angle of 80°. Therefore typical laser diodes with divergences of approximately 60° (95% power content) will not experience any additional loss.
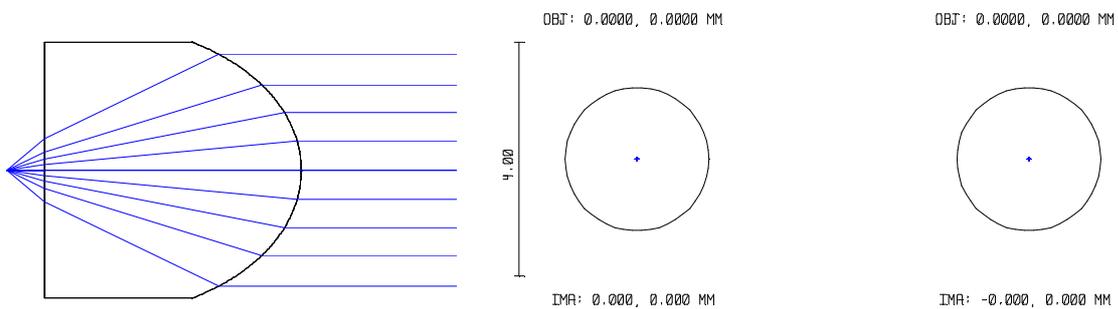

Fig. 10 Raytracing simulation of VHG-FAC. The maximum NA is 0.65, which corresponds to a divergence angle of 80°. Right part shows the spot diagram for two discrete source points being separated by 2µm in object space. As all rays are within the airy-disk, hence the lens has diffraction limited performance..

SUMMARY AND OUTLOOK

An optical element – the VHG-FAC – is presented that can be used for stabilizing, narrowing the wavelength, and collimating the output of high-power diode lasers. The VHG-FAC has the advantage of being a monolithic piece that is easy to align and durable in industrial and commercial manufacturing processes. There is no alignment needed with respect to the locking mechanism. The only criteria for aligning the VHG-FAC are the well-known criteria from FAC alignment. Furthermore, the VHG-FAC is not sensitive to the smile of the diode laser array and the focal length (EFL) can be chosen according to the needs of the application.

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