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The Coherent Coupled Output of a Laser Diode Array Using a Volume Bragg Grating

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1. Introduction

High-power laser diode array (LDA) is characterized by higher overall efficiency with a longer operating lifetime than any other laser types. The compact construction of LDA's is extremely attractive for applications such as material processing, solid-state laser pumping, free space communications, and numerous medical procedures.

However, LDA's face a number of challenges in terms of beam quality improvement and bandwidth reduction. Among the numerous methods used to improve the performance of high-power LDA's, the external cavity has been accepted as an effective method [1–3]. Apollonov et al. achieved two lobes of the out-of-phase mode in the far field using the Talbot cavity with phase compensation [4, 5]. In-phase mode selection could be achieved by tilting the cavity mirror at a low injection current

(I<20 A)[6] .With amplitude compensation, an in-phase mode that produced a single lobe in the far-field was selected[7], but the phase locking was local and not all of the emitters were completely locked, and this resulted in a high pedestal. However, there was still a problem with phase-locked emitters of LDA with in-phase mode high-power output. In this work, a volume Bragg grating (VBG) and a transforming lens were employed to diffract coupling between emitters of broad area multi-stripe lasers in the external cavity. The in-phase mode output produced a single lobe in the far-field.

The experimental setup is shown in Fig. 1. A C1-60 laser diode array from nLIGHT Corporation was used, consisting of 49 emitters with a diode width of a=100μm and a spacing period of d=200 μm, a free running wavelength at 808nm within a bandwidth of 4 nm. It was packed into a patented sandwich structure in order to reduce the "smile" effect. The back face was coated with a high-reflection coating and the front face of the array was coated with an antireflection coating, so as to eliminate oscillation caused by the internal cavity. A cylindrical micro lens from LIMO, f = 91μm, NA = 0.8, was used to collimate the beam of the laser diode array in the fast-axis direction. A 38mm focal length cylindrical lens was used to transform the beam of the laser diode array in the slow-axis direction. A 0.62mm thickness VBG from PD-LD Corporation, with 15% diffraction efficiency at 807.8nm, was placed in the focal plane of the transforming lens. A convex lens and CCD were used to detect the far-field output beam. The experiment was carried out using a current of 40 A, and a heat sink temperature of 12 °C.

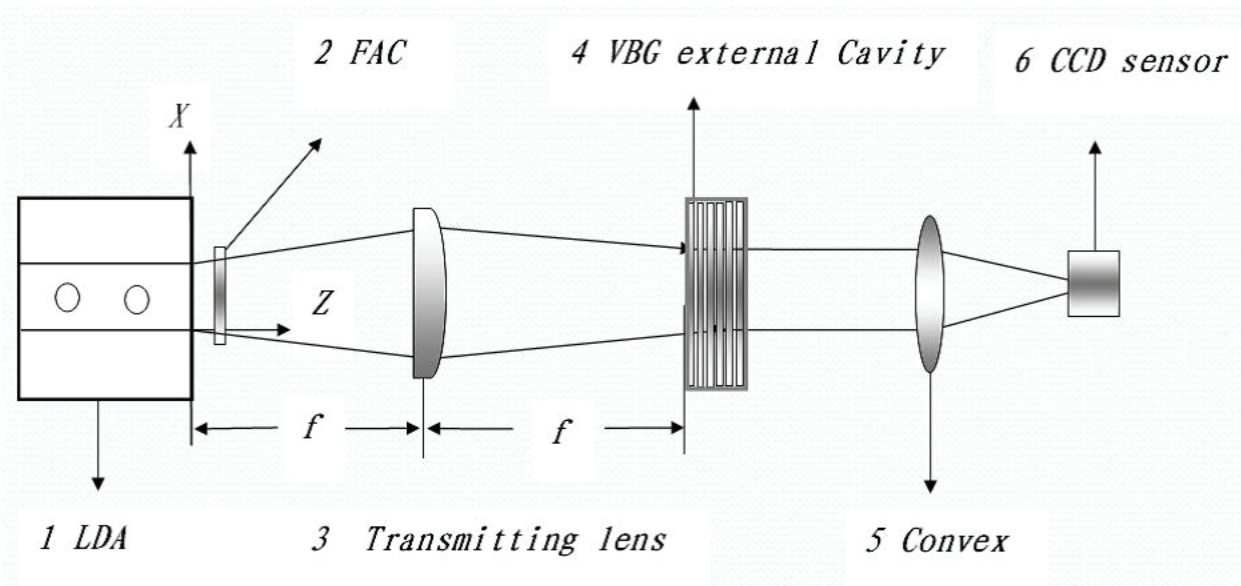
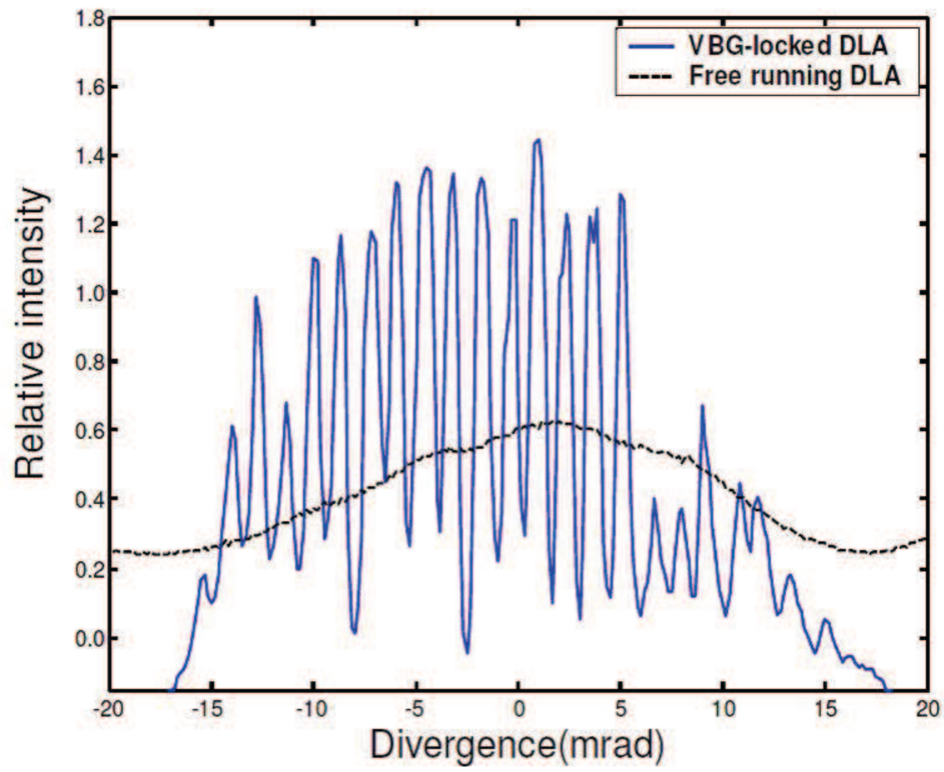
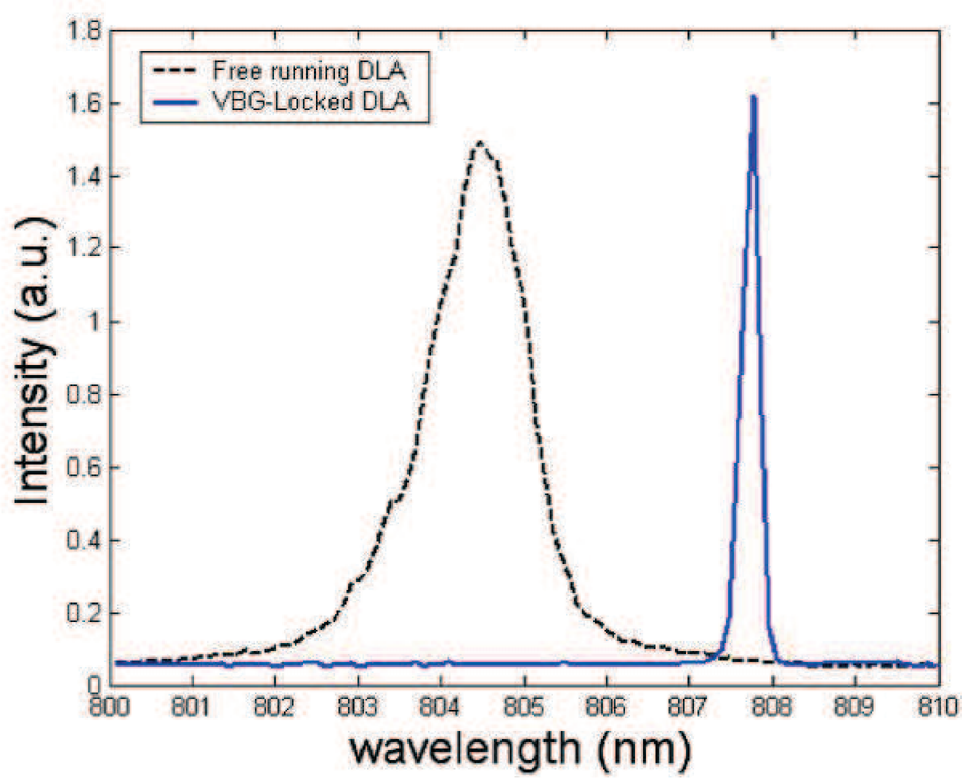


Fig. 1. Experiment setup for VBG external cavity phase-locking.

In the preliminary experiment, an FAC was used to align the output beam in the fast-axis direction. The transform lens was placed one focal distance away from the diode array, putting the front focal plane just on the output surface. A VBG was used as the external cavity and it was set at the rear focal plane of the transform lens so that the front surface of the VBG and the diode array output surface formed a conjugate plane of the transform lens. The emitting surface of the diode array was on waist of the cavity. The transform lens functioned in such a way that the VBG surface was positioned at the waist of the radiated beam. Thus the emitting light diffracted from the VBG directly returned to the diode cavity as self-emitter feedback. Consequently, the output laser distribution in the slow-axis direction was a series of peak values of power, with each peak corresponding to a broad-area laser emitting element, as shown in Fig.2 (a). Due to the spectral selectivity of the VBG, the wavelength of all the emitters diffracted from the VBG was locked at 807.8nm, which was just the center wavelength of the VBG spectral selectivity with normal incidence. The FWHM of the spectral profile was reduced from 1.7nm to 0.2nm, as shown in Fig.2 (b). Because the narrow angular acceptance of the VBG strongly reduced the total amount of the uncollimated light diffracted from the VBG, as calculated in Fig.3, the divergence of the beam in the resonator was suppressed, and the output beam quality was improved. However each emitter was incoherently lasing. This was similar to the wavelength stabilization and spectrum narrowing of high power multimode laser diode arrays by VBG [8].



(a)



(b)

Fig. 2. The output far field intensity distribution (a), and spectrum (b) of VBG-locked LDA.

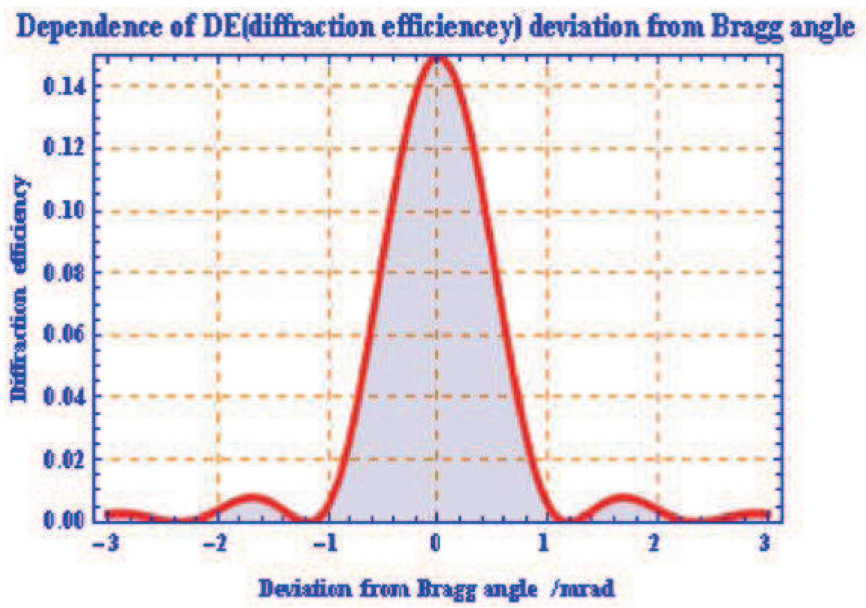
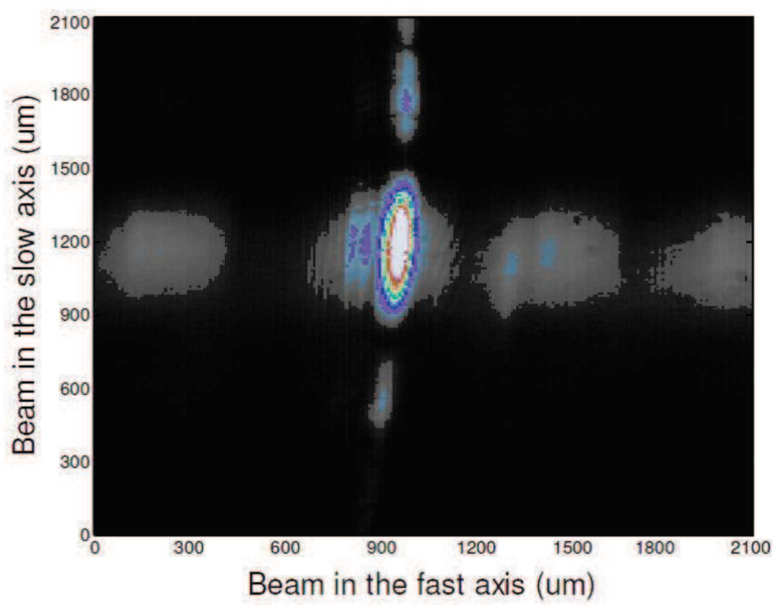


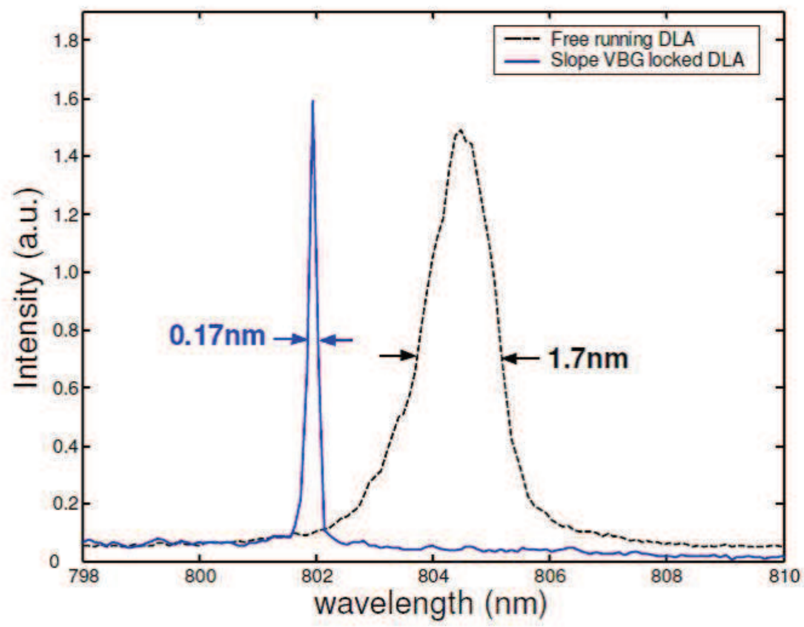
Fig. 3. Dependence of diffraction efficiency on deviation from Bragg angle.

Next, second stage experiments were performed for coherent coupling output. By carefully adjusting the VBG in the slow-axis direction by a small angle, a single lobe coherent light was obtained, as shown in Fig. 4(a). The oblique incidence angle of the VBG was about 1.5 degrees in the slow-axis direction. Measuring the output laser beam, the center wavelength of single lobe coherent light was 801.9nm, the FWHM of the spectral profile was 0.17nm (Fig. 4(b)), the far-field divergence was 1.47mrad (Fig. 4(c)), and power concentrated on the central lobe was 3.67W.

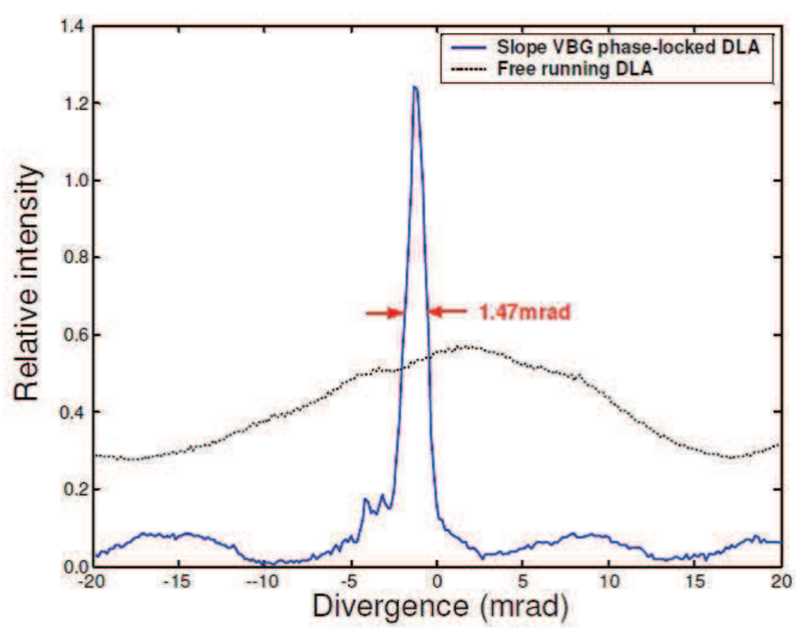


(a)

Fig. 4. The far field intensity distribution of a slope VBG coherent coupled LDA (a), output spectrum (b), and far-field divergence (c).



(b)



(c)

Fig. 4. The far field intensity distribution of a slope VBG coherent coupled LDA (a), output spectrum (b), and far-field divergence (c). (Continuation)

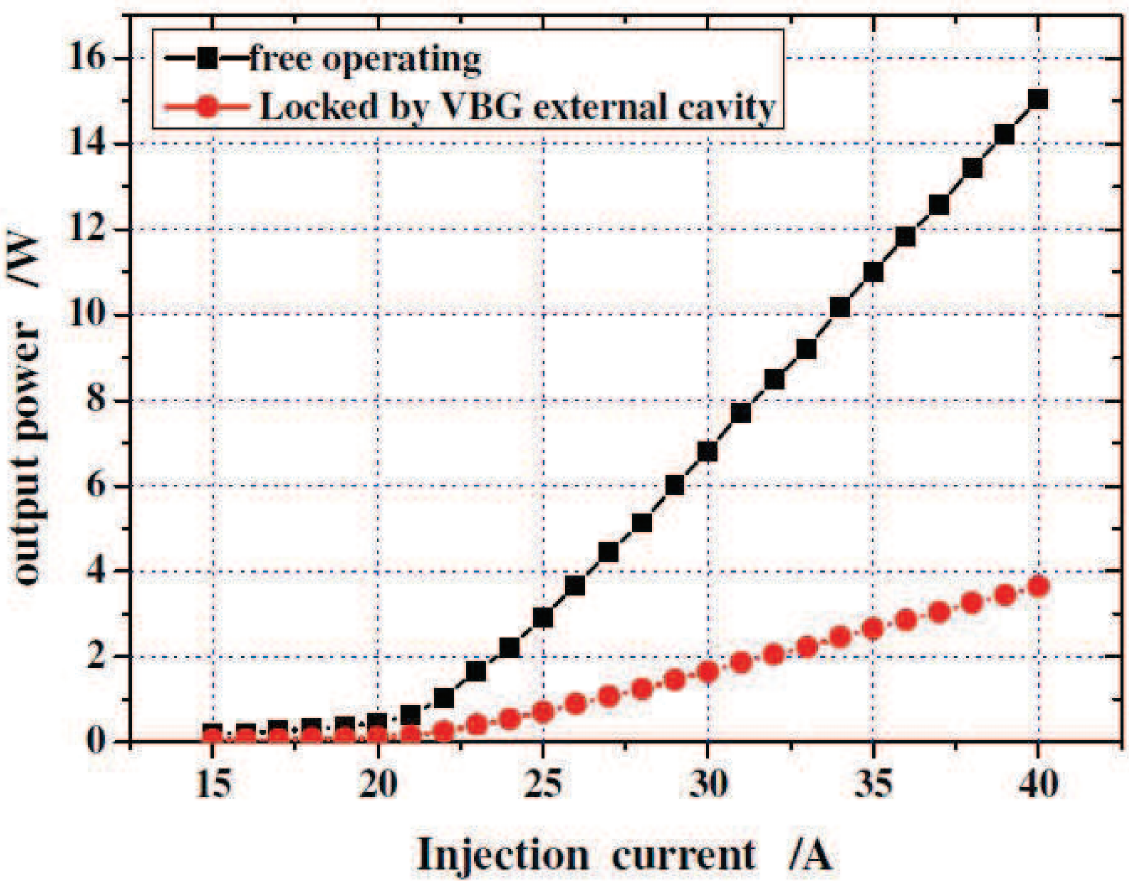
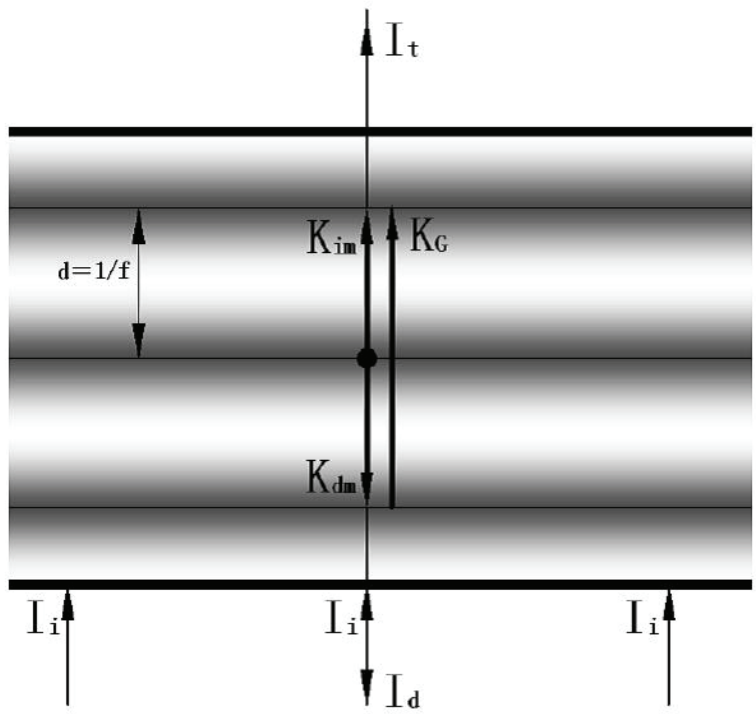
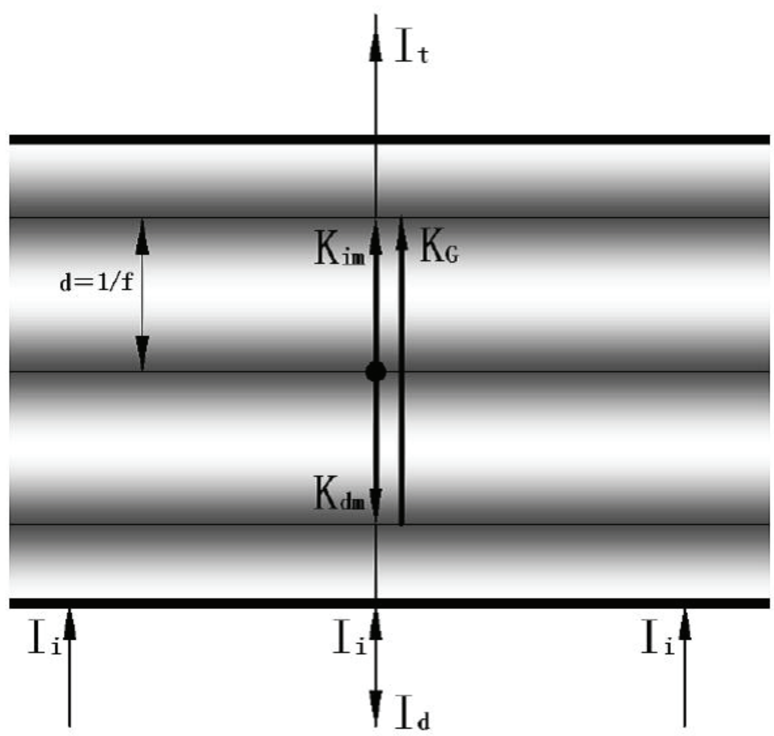


Fig. 5. Output power of DLA with slope VBG locked and free running.

The experimental results can be explained as follows. In the two cases considered, for incident rays that were normal and oblique into the VBG, diffraction followed a different trace pattern. For normal incidence into the VBG, the three rays of incidence (Ii), diffraction (Id) and transmission (It) were coaxial. The wave vectors of the incidence beam (Kim), diffraction beam (Kdm) and grating wave vector (KG) were also coaxial inside the grating medium, as shown in Figure 6(a). So, the exiting light diffracted by the VBG returned directly into its own path and the output wavelength was 807.8nm, which was the grating central wavelength determined by the grating spectral selectivity. For oblique incidence into the VBG, the rays of Ii, Id, It, and the wave vectors of Kim, Kdm, KG were not coaxial, as shown in Figure 6(b). It was easily found that the equivalent grating period was reduced, so the center wavelength of the VBG decreased from 807.8nm to 801.9nm. Because of the non-coaxiality of the incidence ray (Ii) and diffraction ray (Id), there was a space at the grating surface. The space could be estimated by applying energy and momentum conservation of the wave vectors of Kim, Kdm, KG inside the grating medium, and using grating parameters [9]. For a thickness of 0.62mm and a 15% diffraction efficiency of the VBG, the space was about 10.5μm. Also, the diffracted ray (Id) diverged over an extended area. Considering a 1 degree angular acceptance of the VBG with the light path back to the diode array surface, the extended area of the diffraction ray(Id) was about 330μm. So the emitting light diffracted by the VBG could return to the adjacent emitter of the diode array, which had an emitter width of 100 μm and a spacing of 200 μm, and they would couple with each other in the same mode. In this way coherent output was obtained.



(a)



(b)

Fig. 6. The rays and wave vectors of normal incidence (a), and oblique incidence (b) of the VBG.

The measured far-field divergence was larger than the diffraction limit for the array (theoretical value is about 1.0 mrad), indicating that not all of the emitters were completely locked to the in-phase mode. Single lobe coherent coupled output power was only 3.67W out of 15W of free running output power. We suggest that the degree of coherent output was indeed limited by some emitters, which were not locked due to the smile effect or manufacturing variations and thermal gradients of LDA. These resulted in degradation of coupling strength between adjacent emitters, limiting the scalability of the array power.

In conclusion, we demonstrated a method to coherently couple the output and suppress the bandwidth of a LDA, based on external cavity feedback among adjacent emitters with a VBG. One single lobe mode was achieved in the far-field pattern with an output power of 3.67 W, a FWHM spectral profile of 0.17nm and a far-field divergence of 1.47 mrad. We propose that coherent coupling with an external VBG can allow for scaling to a level of 10 W in single lobe mode, improving coupling strength by compressing the coupling zone, and improving manufacturing technology as it decreases the "smile" effect and the thermal gradient. This method provides a potential laser source for applications in material processing and pumping solid-state lasers.

This work was supported by the National Natural Science Foundation of China under Grant No. 10276003, 60678014, and the Natural Science Foundation of Beijing under Grant No. 4051001.

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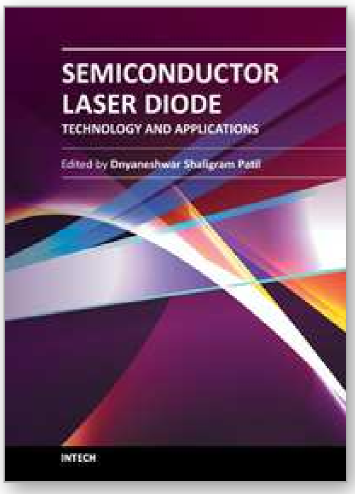

Semiconductor Laser Diode Technology and Applications
Edited by Dr. Dnyaneshwar Shaligram Patil

ISBN 978-953-51-0549-7
Hard cover, 376 pages
Publisher InTech
Published online 25, April, 2012
Published in print edition April, 2012