High-Brightness Wavelength-Beam-Combined Diode Laser Stacks using a Volume Bragg Grating (VBG)*

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Abstract: Using VBG-stabilized wavelength beam combining of 3-bar diode laser stack, we demonstrate 89.5 W CW with beam quality $M^2 \sim 26$ in the slow-axis and $M^2{\sim}21$ in the fast-axis. The beam combining efficiency is 75%.

OCIS codes: (140.2010) Diode laser arrays; (140.3300) Laser arrays; (140.3290) Laser beam shaping; (140.3410) Laser resonators

We report a robust method of scaling power and brightness from diode arrays and stacks by wavelength beam combining (WBC) using a wavelength-chirped volume Bragg grating (VBG). It has the potential to increase the brightness of fiber-coupled diode laser system by two orders of magnitude. In the experiment using a 3-bar commercial stack of broad-area lasers, we demonstrate 89.5 W CW of beam-combined output with a beam-combining efficiency of 75%. The output beam has a beam quality $M^2 \sim 26$ in the slow-axis and $M^2{\sim}21$ in the fast-axis. This corresponds to a brightness of ~20 MW/cm^{2}sr. To our knowledge, this is the highest brightness broad-area diode laser system.

There are two approaches to WBC of diode arrays and stacks. The first approach is called close-loop WBC[1-3]. The second approach is called open-loop WBC. The open-loop cavity, as shown in figure 1, consists of an array of laser elements, a wavelength-chirped Volume Bragg Grating (VBG)[4], a transform lens, and a diffraction grating. In the horizontal axis, along each bar, each emitter within the bar is controlled by the wavelength-chirped VBG to lase at a wavelength that varies linearly with position. The emission from all emitters within a given bar is spatially overlapped at the grating by the transform lens. The grating is adjusted to provide the proper dispersion such that the diffracted beams from each bar propagate collinearly. This overlaps both the near and far fields of all emitters within a bar such that the beam quality of the combined beam in the horizontal axis is approximately that of a single emitter. The beam quality in the stacking dimension remains unaffected.

We achieve near-ideal wavelength-beam combining of a COTS 3-bar diode stack of broad-area lasers using both approaches. In this report we will discuss only open-loop WBC. The 3-bar stack has 19 emitters in each bar. Each emitter is 150-μm wide and the emitter pitch is 500 μm. Each bar had a low reflectivity (<1%) antireflection-coated front facet and is collimated in the fast-axis by a micro-cylindrical lens. The open-loop WBC cavity consists of a 15-nm/cm wavelength-chirped VBG, a 150-mm cylindrical transform lens, and a gold-coated 2000-g/mm holographic grating on a Zerodur substrate. The peak reflectivity of the VBG was about 15%. The VBG has a 3-mm thickness which corresponds to about 0.1 nm FWHM reflectivity bandwidth. The first order diffraction efficiency from the diffraction grating is approximately 90%.

A typical wavelength versus position (I=35 A) for a single bar is shown in figure 2a. In this figure the wavelength is plotted along the vertical axis while near-field image of the laser bar is plotted along the horizontal axis. Figure 2b shows a high resolution optical spectrum taken at the same operating current. Figure 3 shows the output power (left axis) and beam quality M^2 (right axis) of the 3-bar stack as a function of the applied current. At 50 A, the wavelength-beam-combined output power was 89.5 W which corresponds to a 75% WBC efficiency. Higher combining efficiency can be achieved using lower VBG reflectivity (<10%) and higher diffraction grating efficiency. Near threshold (I~3.5A), the beam propagation quality in the slow-axis for a single bar is close to the diffraction-limit. The beam quality in the slow-axis increases as a function of current up to 35 A after which it remains relatively constant. At the highest applied current of 50 A, the beam combined output from a single bar has

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a beam quality of M^2 ~ 23 in slow-axis and M^2 ~1.5 in the fast-axis. With 3 bars operating, the beam quality is M^2 ~ 26 in slow-axis and M^2~ 21 in the fast-axis. This can be compared with the beam quality for the unmodified stack of M^2~2000 in the slow-axis and M^2~21 in the fast-axis. WBC improves the brightness by almost two orders of magnitude.

We have coupled the wavelength-combined output beam of the three bars into both 200-µm and 100-µm diameter, 0.22-N.A. uncoated fibers. We measured 76 W out of the 200-µm fiber with a 85% coupling efficiency. Coupling into a 100-µm fiber, we measured 52.7 W output power with 68 W of input power or about 77% coupling efficiency. In these experiments, the fiber ends were uncoated. With AR-coated fiber ends, the coupling efficiency would be even higher. The current state-of-the-art COTS fiber-coupled diode laser system has an output power of 35 W from 100-µm, 0.22-N.A. fiber with about 20% wall-plug efficiency.

In summary, we demonstrate a novel and robust method of scaling power and spatial brightness from diode laser stacks using WBC with a linearly wavelength-chirped VBG. This approach will allow efficient fiber-coupling of kW-class.

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1. T. Y. Fan and A. Sanchez, Proc. SPIE **5709**, 157 (2005)
2. V. Daneu, A. Sanchez, T. Y. Fan, H. K. Choi, G. W. Turner, and C. C. Cook, Opt. Lett. **25**, 405 (2000).
3. B. Chann, R. K. Huang, L. J. Missaggia, C. T. Harris, Z. L. Liau, A. K. Goyal, J. P. Donnelly, T. Y. Fan, A. Sanchez-Rubio, and G. W. Turner, Opt. Lett. **30**, 2104 (2005).
4. B. L. Volodin, S. V. Dolgy, E. D. Melnik, E. Downs, J. Shaw, and V. S. Ban, Opt. Lett. **29**, 1891 (2004).

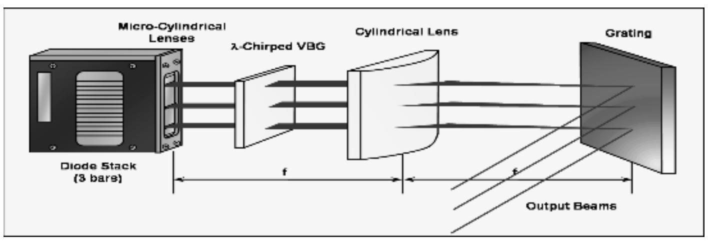

Figure 1: Basic architecture of WBC cavity of diode stack (3-bar stack) using wavelength-chirped VBG.

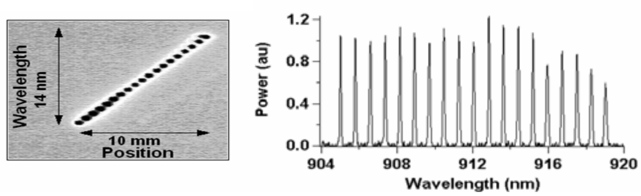

Figure 2: Left: wavelength versus near-field image of 1 bar. Right: shows a high resolution optical spectrum.

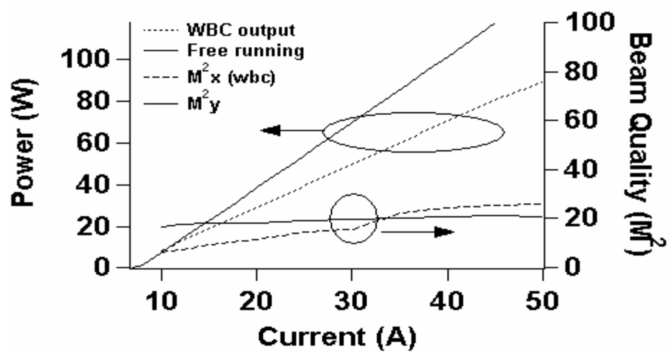

Figure 3: Left axis: output power versus current. Left axis: beam quality versus current.