Spectrally Narrowed, Wavelength-Stabilized, High-Efficiency and High-Brightness Diodes for Precision Pumping

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ABSTRACT

We report on two different types of diode laser technology. The first one is a Fabry-Perot, spectrally narrowed, high-power, broad-area laser diodes with monolithic wavelength-stabilization technology (WST) using distributed feedback (DFB) technique in the 808nm and 975nm wavelength regions. Such pump lasers are useful for various military applications such as improving the system electrical-to-optical power conversion efficiency and operating temperature range of Nd-doped and Yb-doped DPSS and microchip lasers. The monolithic spectral-narrowing technique is readily applicable at the wavelengths suitable as pump sources for diode-pumped alkali-vapor (DPAL) lasers as well. The second one is a Surface-emitting Distributed Feedback (SE-DFB) laser near 975 nm with high spectral and spatial brightness that is suitable for pumping narrow-linewidth kilowatt-class fiber lasers at the upper transition level for suppressing Stimulated Brillouin Scattering (SBS) and for reducing quantum defect to minimize heating. Specifically, we have demonstrated edge-emitting pump lasers with 3Å at the FWHM emission bandwidth, 0.07nm/℃ thermal wavelength tuning rate and power conversion efficiency of 57% and 62% at 808nm and 975nm respectively. We have also demonstrated single SE-DFB lasers with CW output power of 62 Watts with less than 3Å at the FWHM and high brightness.

Key Words: DFB Laser, SE-DFB Laser, Semiconductor Laser, Multimode Laser, Power Conversion Efficiency

INTRODUCTION

Multimode, Fabry-Perot, semiconductor lasers emitting near 808 nm and 975 nm wavelengths are pump diodes of choice for making high power lasers using Nd- and Yb-as gain media respectively. The output spectrum of these diode lasers has multiple longitudinal modes with an envelope extending approximately 3 nm at the FWHM. The peak of this spectral envelope moves at a rate of 0.32 nm/ ^{o}C. The absorption bandwidth of Nd- and Yb-doped gain media is narrower than emission bandwidth of multimode diode pumps available in the market. Consequently, the diodes for these systems have to be temperature-stabilized with expensive techniques to remain tuned to the absorption band especially for military applications where the system must operate over a wide temperature range. In addition, the out-of-band pump photons are wasted and leads to lower efficiency system. There are numerous military Nd-doped solid-sate laser systems where passive cooling techniques would be highly desirable where the ambient temperature is drifting by many tens of degrees. For these applications, Alfalight's wavelength stabilized technology (WST) with narrow emission band near 808 nm provides a unique solution. These narrow-band pump sources can be used with low-cost passive cooling techniques with overall higher system efficiency over many tens of degrees of temperature variation.

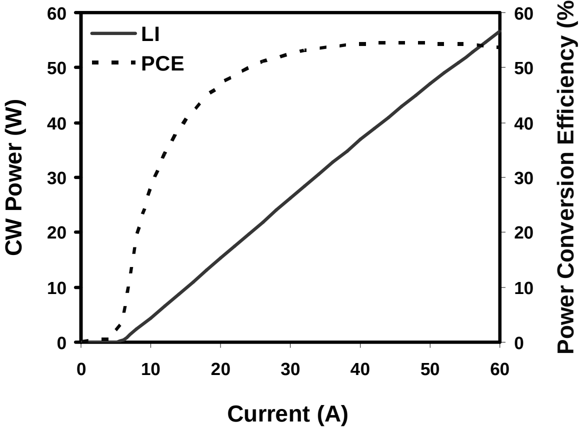

Figure 1. CW L-I and PCE of spectrally narrowed and wavelength-stabilized 808 nm bar onCu heatsink at 25C.

For fiber lasers, there are additional challenges with respect to power scaling due to onset of nonlinear effects such as Stimulated Raman Scattering (SRS) and Stimulated Brillouin Scattering (SBS). High power, multimode 975 nm diode lasers are preferable for pumping the upper transition states of Yb, Er and co-doped fiber lasers. At this pump wavelength, the quantum defect is smaller and the absorption cross-section is much higher relative to the 920 nm transition. Using the 975 nm pump allows the use of shorter gain fibers thus mitigating SRS and SBS especially for high peak power applications. Since the absorption bandwidth at 975 nm is quite narrow (< 9 nm FWHM), either expensive temperature-stabilization measures or very sensitive and expensive external wavelength-locking mechanisms have to be used to take advantage of the 975 nm pump band. Alfalight's WST diodes[1, 2] at 975 nm provide cost-effective, robust and simple solution. This monolithic wavelength-stabilization technique is readily applicable to other wavelengths such as 780 nm and 852 nm for pumping Rb and Cs alkali vapors respectively[3]. Hence, wavelength-locked and emission bandwidth narrowed semiconductor laser is an ideal pump source for DPALs.

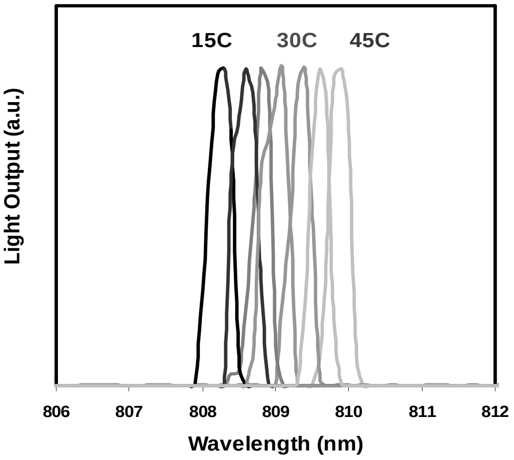

Figure 2. Spectra of 808 nm single emitter DFB laser at heatsink temperature of 15^{o}C to 45^{o}C.

Kilowatt-class, narrow-linewidth fiber lasers have attracted some attention as useful High Energy Laser (HEL) sources for a variety of power-scaling techniques [4]. These sources require amplification of narrow linewidth signals in fibers and are limited not only by SBS but also by the brightness of pump diodes [5]. Brighter pumps than what is currently commercially available will be required to achieve > 1kW of narrow-linewidth fiber power. Furthermore, brighter pumps will allow the fiber laser designers to choose smaller cores for optimal diameter of the gain fiber. This should make SBS suppression using acoustic anti-guides easier to fabricate in fibers.

WAVELENGTH STABILIZED AND BANDWIDTH NARROWED EDGE-EMITTING AND SURFACE-EMITTING DISTRIBUTED FEEDBACK LASER DIODES

Edge-emitting DFB Laser

Edge-emitting DFB lasers were fabricated with a two-step epitaxial growth process. The details of the fabrication process have been previously published[2]. The location of the grating with respect to the fundamental optical mode, etch-depth of the grating and the index of refraction of the overgrown cladding material were judiciously chosen to keep $kL < 1$, where k is the coupling constant and L is the cavity length. Thus the device operates multi(lateral)-spatial mode at a single longitudinal-cavity mode.

Surface-emitting DFB (SE-DFB) Laser

The key attribute of this device is a holographically-generated, curved second-order grating that is etched into the p-cladding with overcoated gold layer. A patterned contact area on this side delineates the contact stripe. This second-order grating deflects guided mode radiation into the surface-normal through first-order diffraction forming an output beam which exits through the substrate and via polished and AR coated window opening in the n-side metal. Simultaneously, this grating also provides feedback into the backward scattered waveguide mode through second-order diffraction producing a narrow spectral output. The curved grating is designed to form an unstable resonator which is known to produce a high degree of lateral mode discrimination with a mode that fills a wide gain region.[6] In addition, the curved and expanding internal wavefronts helps to suppress filamentation. These two features combined together make curved-grating, unstable resonator approach very effective in controlling the lateral mode of broad-area pumped semiconductor lasers.

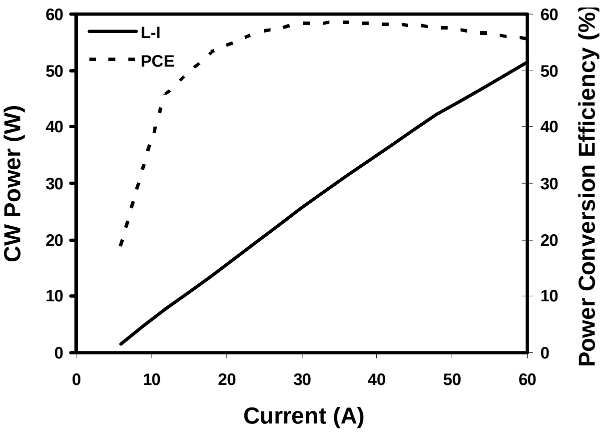

Figure 3. CW L-I and PCE of spectrally narrowed and wavelength-stabilized 975 nm bar on Cu heatsink at 25C.

RESULTS

As a result, 94μm-stripe 808 nm devices were realized with 57 % electrical-to-optical power conversion efficiency at 4 W CW operation and 25^{o}C heatsink temperature. The CW spectral width was measured to be 3 Å at FWHM. The high quality of regrowth is evident from the low operating voltage of less than 2V at 4 A achieved in these devices. The turn-on voltage and series resistance were measured to be 1.57 V and 55 milliohms respectively. Temperature dependence of the spectrum was measured to be approximately 0.65 Å/^{o}C. Output wavelength remained locked at the Bragg condition from 15^{o}C to 45^{o}C heatsink temperature providing over 30 ^{o}C locking range as shown in Figure 2. A 30% fill-factor bar fabricated from this design produced 57 W of CW power at 60A on CS heatsink at 25C as shown in Figure 1. The threshold current for this laser was only 6A with over 1 W/A of slope efficiency.

Similarly, gratings were also implemented into 975 nm diode laser structure to form high power and high efficiency DFB lasers with single emitters demonstrating 62% PCE and 7W of output power at 8A. The turn-on voltage was measured to be 1.30 V. Each of the emitters demonstrated very narrow 3 Å emission bandwidth, which is ten times narrower compared to a Fabry-Perot broad area lasers. Temperature dependence of the spectrum was measured to be approximately 0.7 Å/C. Output wavelength remained locked at the Bragg condition from 10 ^{o}C to 70 ^{o}C heatsink temperature, providing over 60 ^{o}C locking range. A 20% fill-factor bar fabricated from this design produced 52 W of CW power at 60A on CS heatsink at 25C as shown in Figure 3. The threshold current for this laser was only 5A with nearly 1 W/A of slope efficiency.

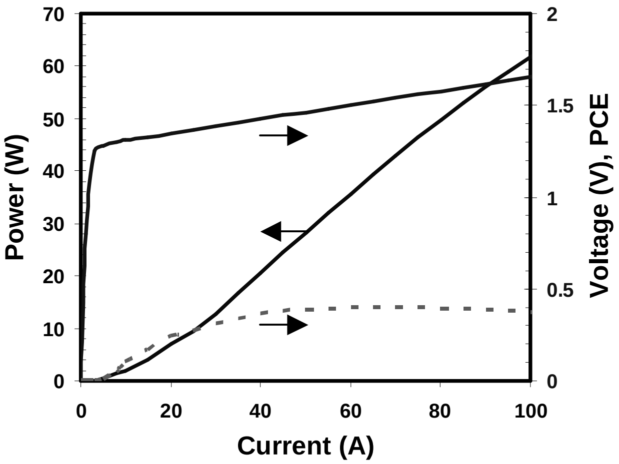

Figure 4. CW L-I-V and PCE of spectrally narrowed and wavelength-stabilized 975 nm SE-DFB laser on Cu heatsink at 25C.

SE-DFB lasers were fabricated near 975 nm wavelength. We demonstrated a record 62 W of CW output power (see Figure 4) from a single semiconductor laser at 25C with a very narrow <3 Å emission bandwidth as shown in Figure 5 from 10 A to 50 A of operation. Greater than factor of 7 improvement in brightness compared to edge-emitter has been demonstrated already and further improvement is underway.

CONCLUSIONS

In conclusion, we have demonstrated 57% wall-plug efficiency from 94μm-stripe DFB laser emitting near 808 nm wavelength. This record high efficiency was achieved due to implementation of low loss, high quality grating with good overgrown cladding layer and a choice of *kL* < 1. In CW operation, spectral width of 3Å at the FWHM was achieved at about 4 W and heatsink temperature of 25^{o}C and bar fabricated from these designs produced 57W of power at 60A and wavelength-locking range of greater than 30^{o}C was also observed. We also demonstrated wavelength stabilization and emission bandwidth narrowing down to 0.3 nm on 975nm diode laser bars with peak PCE of 62% and high output power of nearly 7W at 8A from a single emitter. Bars from this design demonstrated 52W of power at 60A. Finally, we also demonstrated SE-DFB lasers with record high single emitter power of 62W at 25C in CW operating condition.

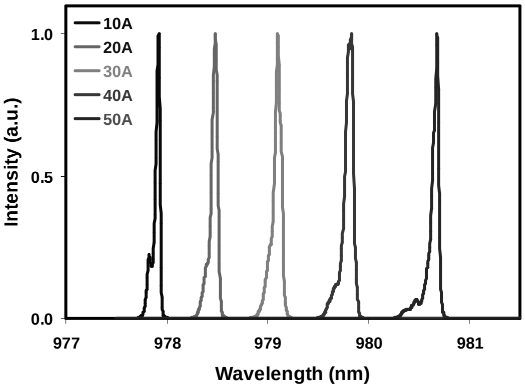

Figure5. Spectra of 976 nm single emitter DFB laser at heatsink temperature of 25C from 10 A to 50A.

ACKNOWLEDGEMENT

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