Spectrally Narrowed and Wavelength-Stabilized High-Power, High-Efficiency 808 nm and 975 nm Diode Laser Pumps

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ABSTRACT

Spectrally narrowed, high-power, broad-area laser diodes with monolithic wavelength-stabilization technology (WST) using distributed feedback (DFB) technique have been developed 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 neodymium-doped DPSS/microchip lasers, pumping alkali vapor lasers and fiber lasers with low quantum defect. Specifically, we have demonstrated pump lasers with 3Å at the FWHM emission bandwidth, 0.07nm/℃ thermal wavelength tuning rate and power conversion efficiency of 52% and 62% at 808nm and 975nm respectively.

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

INTRODUCTION

Multimode, Fabry-Perot, semiconductor diode lasers emitting near 808 nm and 975 nm wavelengths are of particular interest for pumping Nd- and Yb-doped solid state gain media respectively. The output spectrum of these diode lasers has multiple modes with an envelope extending approximately 3 nm at the FWHM. The peak of this envelope moves at a rate of 0.32 nm/ ^{o}C. Typically, the absorption bandwidth of Nd- and Yb-doped gain media is narrower than emission bandwidth of multimode diode pumps available in the market. As a result, the diode laser pumps for these systems have to be actively temperature controlled with costly feedback mechanisms to ensure that no appreciable detuning occurs between the center of the pump wavelength and the absorption peak. In addition, the out-of-band pump photons are not used. There are numerous solid sate laser applications where inexpensive passive cooling techniques would be preferable while tolerating many tens of degrees of ambient temperature drift. In the case of fiber lasers, there are additional challenges with respect to power scaling due to nonlinear effects such as Stimulated Raman Scattering (SRS) and Stimulated Brillouin Scattering (SBS). Multimode 975 nm diode lasers are of particular interest for pumping the upper transition states of Yb, Er and co-doped fiber lasers. At this pump wavelength, the quantum defect is minimal and the absorption cross-section is much higher relative to the 920 nm transition states. Hence, shorter gain fibers can be used to mitigate deleterious nonlinear effects that can occur in high peak power application. However, the absorption bandwidth at 975 nm is quite narrow (< 9 nm FWHM). As a result, either expensive thermal stabilization measures or very sensitive external wavelength-locking mechanisms have to be employed. Monolithically wavelength stabilized[1, 2] and emission bandwidth narrowed, high power 975 nm semiconductor diode laser pumps provide a unique solution that is cost-effective, robust and simple to deploy. This monolithic wavelength-stabilization technique is applicable to other wavelengths such as 780 nm and 852 nm for pumping Rb and Cs alkali vapors respectively especially due to the narrow spectral output of only 0.3 nm at FWHM. This feature has a far reaching implication for Diode-pumped Alkali-vapor Laser (DPAL) for two reasons. Firstly, the optical-to-optical power conversion efficiency increases inversely with emission bandwidth of the pump source and, secondly, the narrowest line-width diodes allow use of lowest He pressures needed for collisional broadening, maximizing both the peak laser emission cross section and the absorption of the pump by the alkali vapor[3]. Hence, wavelength-locked and emission bandwidth narrowed semiconductor laser is an ideal pump source for DPALs.

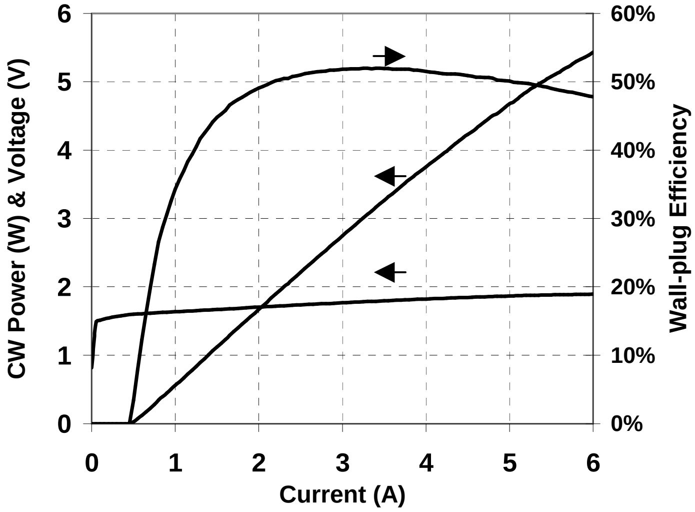

Figure 1. L-I-V and wall-plug efficiency of 808 nm broad area DFB laser at 25°C heatsink temperature.

WAVELENGTH STABILIZED AND BANDWIDTH NARROWED DIODES

The DFB lasers were made with a two-step epitaxial growth process. The first growth comprised formation of separate confinement heterostructure (SCH), terminated with a thin layer of cladding layer. Second-order gratings were fabricated in this layer using holographically exposed photoresist patterning and subsequent transfer of these grating patterns onto the underlying cladding layer using a dry-etching technique. Remaining upper cladding layer and the p^+-cap layer were then grown to complete the laser structure. 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. Additionally, effort was made to fabricate smooth grating surface and regrowth conditions were optimized for low interface loss.

As a result, 94µm-stripe and 2 mm long 808 nm devices were realized with 52 % wall-plug efficiency at 4 W CW operation and 25^{o}C heatsink temperature as shown in Figure 1. The threshold current for this laser was only 450 mA with 4%/95% AR/HR coating on the facets. The CW spectral width was measured to be 3 Å at FWHM at the peak efficiency and remained so even at over 5 W of CW operation. The high quality of regrowth is evident from the low operating voltage of less than 2V at 6 A achieved in these devices as shown in Figure 1. 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 0.67 Å/^{o}C. Output wavelength remained locked at the Bragg condition from 35^{o}C to 65^{o}C heatsink temperature at 2W, providing over 30 ^{o}C locking range as shown in Figure 2.

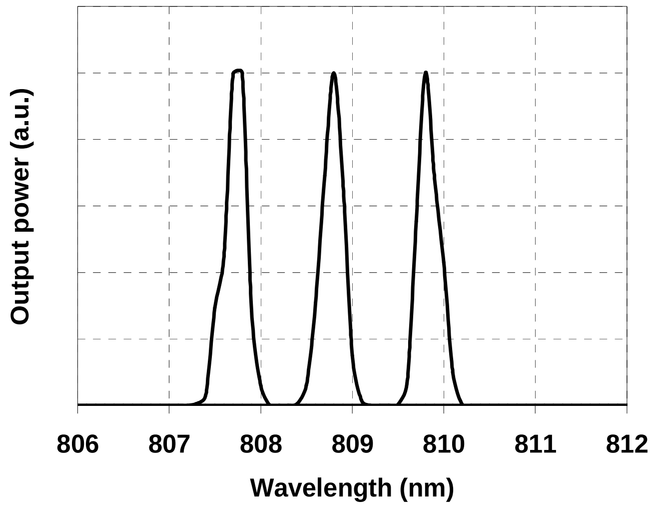

Figure 2. Spectra of 808 nm single emitter DFB laser at heatsink temperature of 35^{o}C, 50^{o}C and 65^{o}C and 2W CW output power.

Similarly, gratings were also implemented into 975 nm diode laser structure to form high power and high efficiency DFB lasers. The high quality of regrowth is evident from the low operating voltage achieved in these devices as shown in Figure 3. The turn-on voltage was measured to be 1.30. Each of the emitters demonstrated very narrow 3 Å emission bandwidth, which is ten times narrower compared to a Fabry-Perot broad area laser. 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.

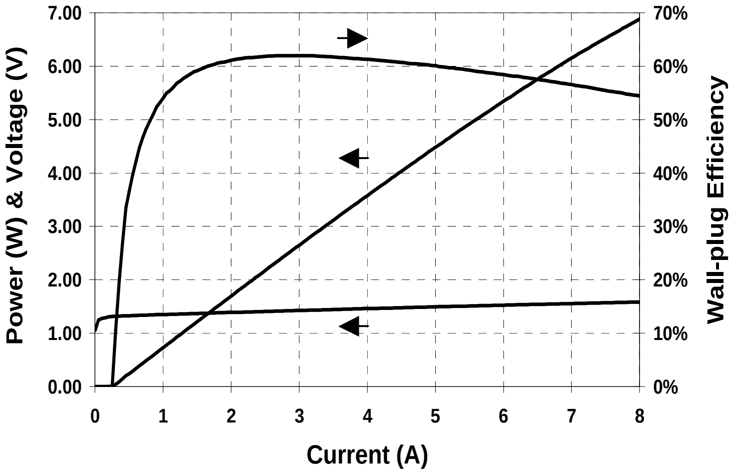

Figure 3. L-I-V and PCE of DFB 975 nm diode laser showing a peak PCE of 62% at 25C.

CONCLUSIONS

In conclusion, we have demonstrated 52% wall-plug efficiency from 2mm long, 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 4Å at the FWHM was achieved at power levels > 5 W and heatsink temperature of 25°C. Furthermore, wavelength-locking range of greater than 30°C was also observed. Further optimization is underway. 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.

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[1] C.H. Chang, T. Earles and Dan Botez, "High CW power, narrow spectral-width (<1.5 Å), 980 nm broad-stripe distributed-feedback lasers", Electronics Letters, 36, 954-955 (2000).

[2] M. Kanskar, Y. He, Jason Cai, C. Galstad, S. H. Macomber, E. Stiers, D. Botez and L.J. Mawst, "53% Wall-plug Efficiency 975 nm Distributed Feedback Broad Area Laser", Electronics letters, **41**, 33-35 (2005).

[3] W.F. Krupke, R.J. Beach, V.K. Kanz, and S.A.Payne, "Diode Pumpable Rubidium Laser," OSA TOPS, Vol. 83, Advanced Solid-state Photonics pp. 121 (2003).