High brightness semiconductor lasers from 780-1064nm

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ABSTRACT

We present recent advances in high power semiconductor laser bars and arrays at near infrared wavelengths including increased spectral brightness with internal gratings to narrow and stabilize the spectrum and increased spatial brightness with multimode and high power single mode performance. These devices have the potential to dramatically improve diode pumped systems and enable new direct diode applications.

Keywords: Diode, laser, semiconductor, bar

1. Introduction

Conventional edge emitting high power diode lasers have been used in printing, defense, medical, and materials processing because of their compactness, low cost per Watt-hour, and excellent electrical to optical efficiency. While these high power diode lasers are broadly accepted for low brightness applications, their use has been limited due to the low spatial and spectral brightness performance, costly power scaling, and limited range of emission wavelengths. In particular, the spatial beam quality from high power diode lasers is a factor of 10-20 times lower than non-diode lasers such as gas, solid state, or fiber laser counterparts. Moreover, the spectral output of conventional diode lasers is typically an order of magnitude wider than these non-diode systems and is inadequate for efficient wavelength conversion or other pumping applications requiring narrow linewidth. We report here on semiconductor lasers with reduced linewidth and increased spatial brightness.

2. Internal Gratings

High power diode lasers are conventionally formed by inserting a gain-producing active stripe into a resonant cavity formed by reflective facets at each end of the laser. Aside from defining the periodic “comb” of resonant frequencies, this Fabry-Perot cavity provides essentially no wavelength control. Wavelength of emission is instead controlled by the gain spectrum of the semiconductor used as the active layer. Unfortunately, this gain spectrum is “flat” (with width ~ 20 nm), and strongly temperature dependent. As a result, the output spectrum is broad, particularly at high power fluxes, and highly dependent on the operating temperature, typically changing by 0.3 – 0.4 nm per ºC.

For high power devices, external methods have been demonstrated such as the use of using seed lasers in MOPA designs[1], the use of external lenses and bulk gratings[2], or volume Bragg gratings[3]. These external approaches require sensitive alignment techniques, costly additional lasers and or optics, and specially designed coatings. Internal DFB gratings similar to those used in telecom lasers would offer an on-chip solution, but, unfortunately, it is not trivial to adopt this approach for high power diode lasers since they are multi-mode and more difficult to lock.

Figures 1 and 2 show power versus current and the output spectrum of an 808 nm bar operating at 40 Watts at <50 A on a conduction cooled mount. The output spectrum taken at 20 ºC exhibits a spectral width less than 0.4 nm wide, many times narrower than a similar Fabry-Perot without an internal grating.

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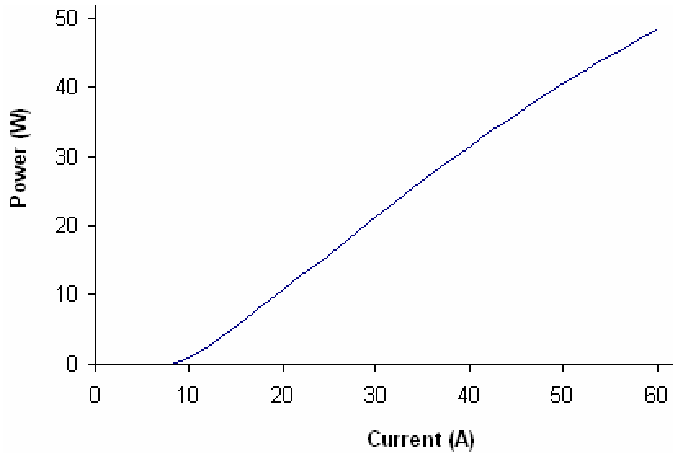

Fig. 1. 808 nm conduction cooled bar with internal grating stabilization, power versus current.

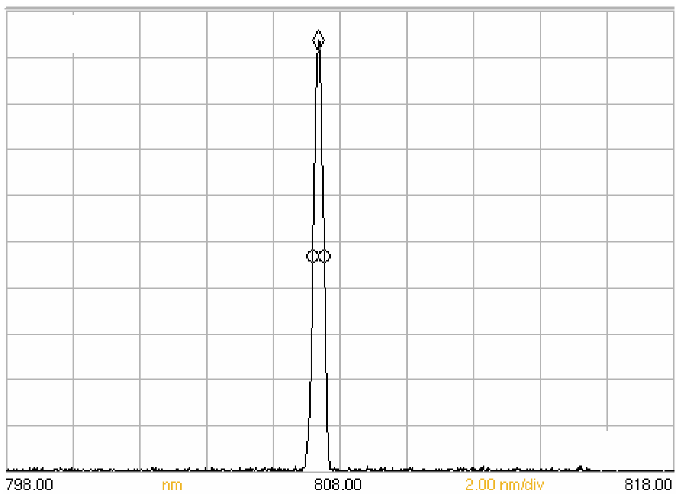

Fig. 2. 808 nm conduction cooled bar with internal grating stabilization.

QPC has also developed fiber coupled modules at 808nm and has demonstrated >35W from a 400 micron 0.22 NA fiber output. The spectral linewidth is ~0.5 nm FWHM and the wavelength temperature coefficient was 0.6 nm per degree Celcius.

QPC has developed single emitters, bars, and fiber coupled modules at 976 nm with internal grating. The power versus current performance for 100 micron conduction cooled single emitters show 5W operation at 6A, and the output spectrum is <0.5 nm FWHM. Figure 3 and 4 show fiber coupled module data, with 22 Watts from a 200 micron, 0.22 NA fiber output. The spectral linewidth is ~0.5 nm FWHM and the wavelength temperature coefficient is 0.7 nm per degree Celcius.

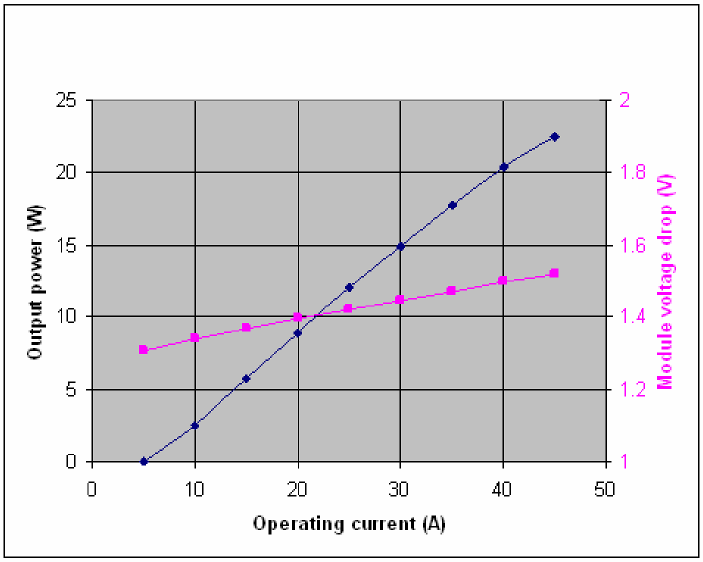

Fig. 3. 976 nm conduction cooled 200 micron 0.22 NA fiber coupled module with internal grating stabilization.

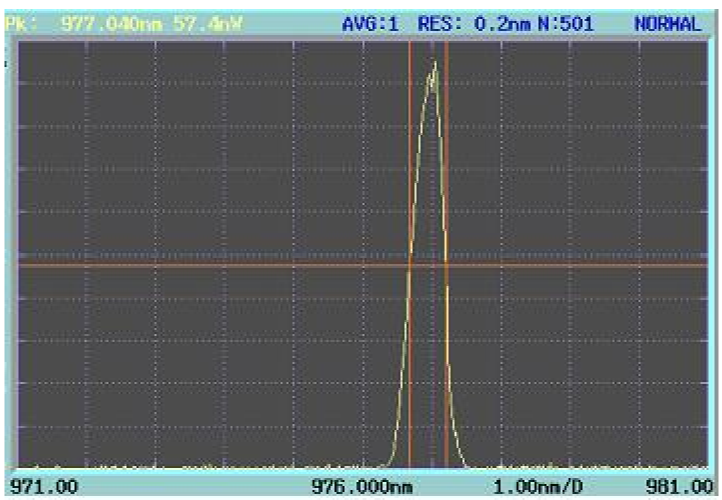

Fig. 4. 976 nm conduction cooled 200 micron 0.22 NA fiber coupled module with internal grating stabilization.

3. High Spatial Brightness

The maximum optical output power of laser diodes in the 800 nm regime is limited by catastrophic optical damage (COD). COD occurs when the facet temperature reaches the melting point of the semiconductor material. The two foremost causes of facet heating are optical absorption of the laser light near the facet and non-radiative recombination of electron-hole pairs at the surface states of the cleaved facet. Inserting a high bandgap, current blocking region at the facet can greatly reduce the optical absorption and facet current leakage.

QPC has developed and optimized a proprietary high power non-absorbing mirrors (NAMs) technology called Brightlase^{TM}. The NAM is created in InAlGaAs laser diodes using an epitaxial regrowth process to produce a region near the facet that is both optically non-absorbing and electrically nonconductive. The inclusion of the NAM triples the COD power and greatly improves the reliability of the laser diode. Shown in Figure 5, the active layer is removed near the facet, and replaced with an epitaxially regrown layer of wide-bandgap Aluminum Gallium Arsenide. This layer isolates the active layer from surface states, and is highly transparent to the laser emission from 800 to 1000nm.

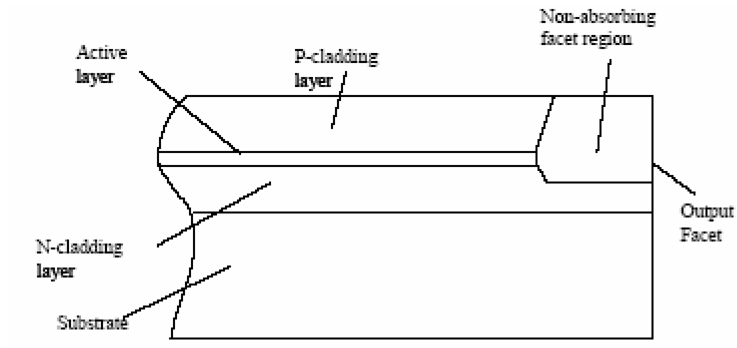

Figure 5

Using this approach, QPC has developed fiber coupled modules at 808nm and has demonstrated >50W from a 100 micron 0.22 NA fiber output with >37% electrical to optical efficiency from the fiber. The spectral linewidth is ~ 2 nm FWHM.

Figure 5: Power versus current for 50W 808nm 100 micron 0.22NA fiber coupled module.

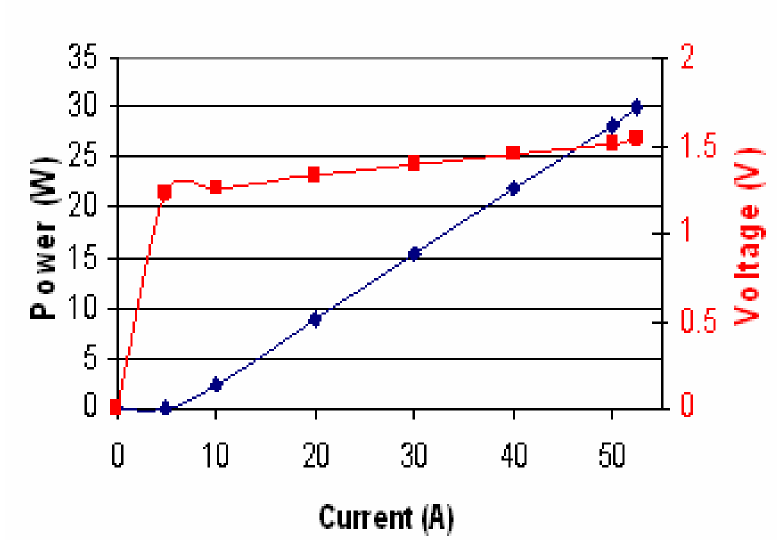

Figure 6: Power and voltage versus current for 30W 1064 nm fiber coupled module, 200 micron, 0.22NA.

In addition to the multimode devices described above, we have developed high power single frequency, single transverse mode devices at 1040 nm for fiber laser seeding and direct applications in the eye-safe regime. Tapered devices have been demonstrated previously, but achieving higher power levels with near diffraction-limited performance has shown to be challenging because of filamentation at relatively low powers and poor yields due to beam quality deterioration at high powers.

Our device design is a two section oscillator-amplifier device consisting of a narrow waveguide section and a tapered gain section. In our design, the beam in the narrow waveguide distributed feedback (DFB) section is laterally confined by a single-mode waveguide which produces a single frequency stable beam. A buried heterostructure (BH) single mode waveguide is used to effectively act as a mode filter. This beam is fed into the tapered gain section, where the mode is allowed to freely diffract and be amplified by a tapered electrical contact. Figure 7 shows a schematic of the device.

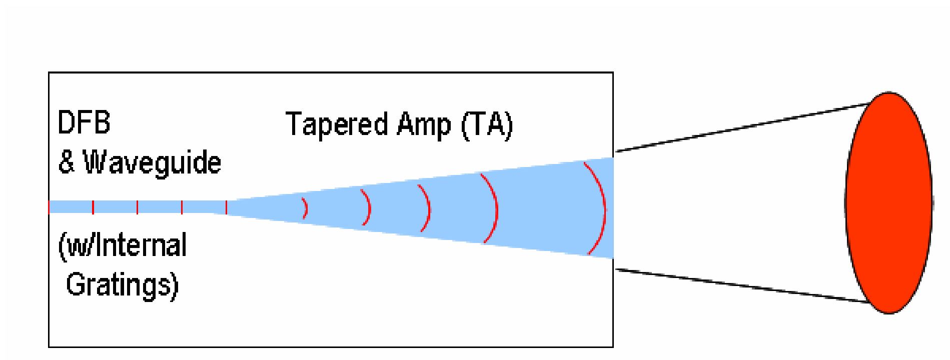

Figure 7. Schematic of 1040 nm single frequency single mode MOPA device

We have demonstrated >3W per emitter from 1040 nm high power, high brightness, high yield tapered lasers with single frequency and single transverse mode operation. Figure 8 shows the CW power versus current curve for such a device with a constant 700mA in the oscillator section.

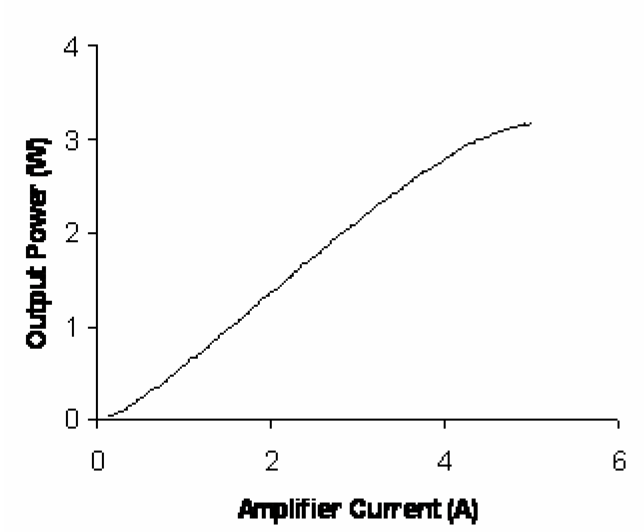

Fig. 8. Power versus current in the amplifier section for 1040 nm single frequency single mode MOPA device.

Figure 9 shows the spectrum for a device at 3 Watt. The line width was measured to be < 50MHz. More than 30dB of suppression was observed.

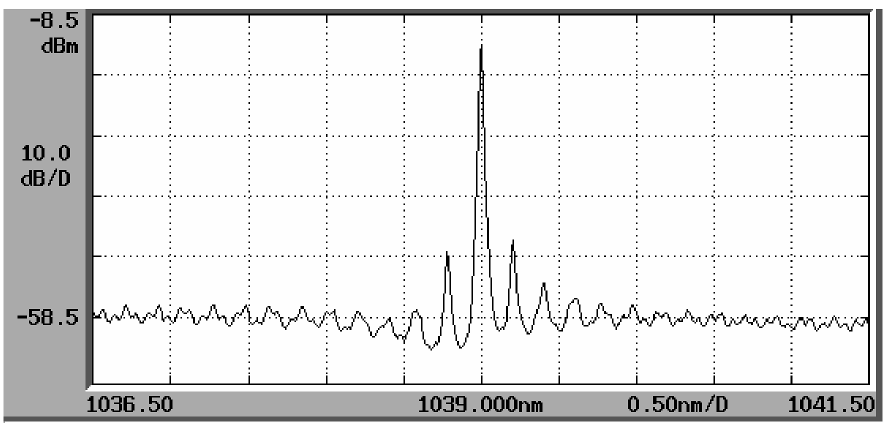

Fig. 9. Spectrum for 1040 nm single frequency single mode MOPA device.

Figure 10 shows the slow axis beam quality measurement, with performance less than 1.2 times the diffraction limit.

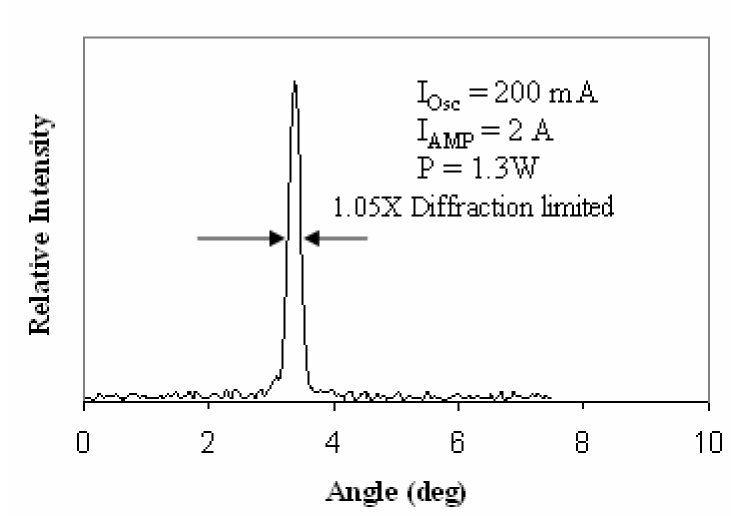

Fig. 10. Mode measurement for 1040 nm single frequency single mode MOPA device.

4. Conclusions

The recent advances in high brightness, high power semiconductor laser technology include 0.5 nm FWHM spectral width from fiber coupled modules with internal Bragg gratings, 50W output from 100 micron fibers at 808 nm, and >3W single mode single frequency performance from 1040 nm tapered devices.

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