High brightness semiconductor lasers

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ABSTRACT

We present recent advances in high power semiconductor lasers including increased spectral brightness using on-chip internal gratings and increased spatial brightness at wavelengths from the near infrared to the eye-safe regime.

Keywords: Diode, laser, semiconductor, bar, stack, array

1. Introduction

Diode lasers in the 780 nm to 1600 nm regime are used in a variety of applications including pumping fiber and solid state lasers, and direct diode materials processing, defense, and medical applications. 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 nm per ºC.

For high power devices, external methods have been used to achieve high spectral brightness 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 or DBR 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.

QPC has recently demonstrated high power semiconductor lasers at 808 nm, 976 nm, 1040nm, 1470 nm, 1532 nm, and 1550 nm that include an internal grating written into the device which provides feedback to narrow the optical spectrum, reduces the wavelength-temperature sensitivity, and ensures that the device operates at the desired wavelength. These devices can dramatically improve performance and reduce cost in diode pumped laser systems and direct diode applications such as medical imaging and Raman spectroscopy.

2. Near infrared wavelengths

Performance of the QPC devices with internal Bragg gratings show unique light-current characteristics and emission spectrum as function of current and temperature as compared to standard devices. The 808 and 980 nm spectra are extremely narrow near threshold (<0.1 nm). At output powers up to 6W per emitter and beyond, the devices are much narrower than Fabry-Perot lasers with typical widths in the 0.1 to 0.4 nm FWHM regime compared to 1-5 nm for a Fabry-Perot. At 20 ºC, the emission spectrum remains locked to grating and narrow spectrum to > 5W and over a broad current range and >40 deg C temperature range. The wavelength dependence on temperature is ~0.07 nm/ºC, 3-4 times smaller than for a Fabry-Perot laser.

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.

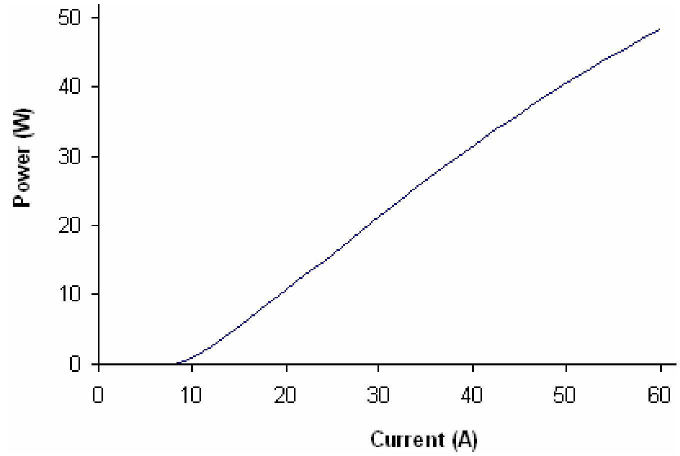

Fig. 1. 808 nm conduction cooled bar with internal grating stabilization, power versus current.

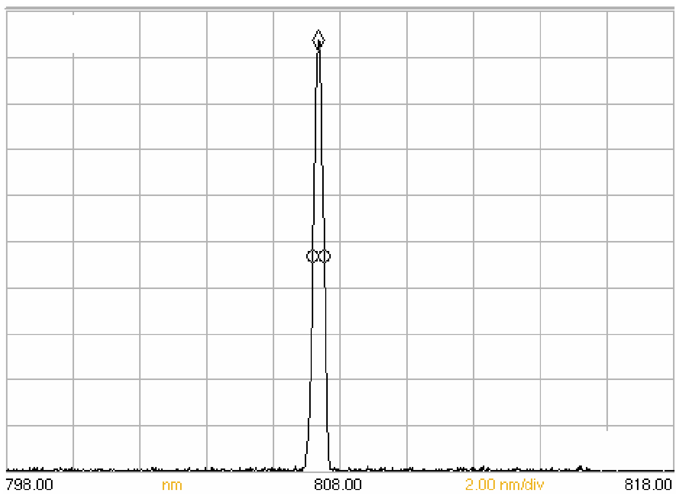

Fig. 2. 808 nm conduction cooled bar with internal grating stabilization.

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.

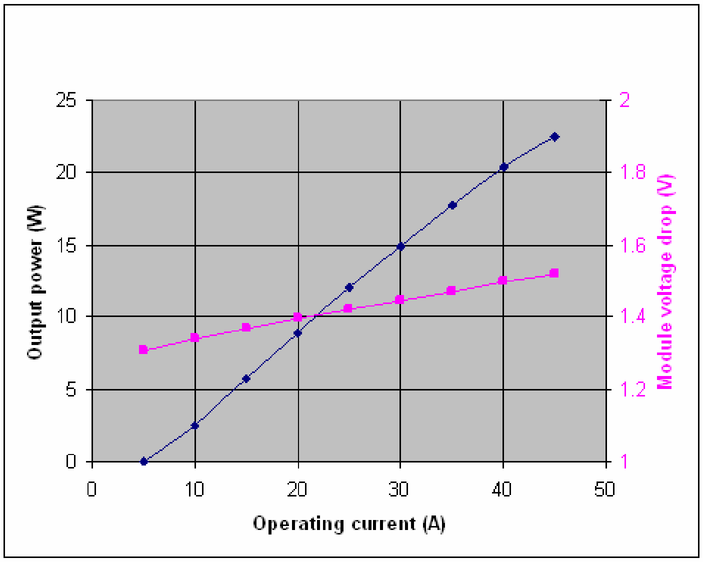

Fig. 3. 976 nm conduction cooled 200 micron 0.22 NA fiber coupled module with internal grating stabilization.

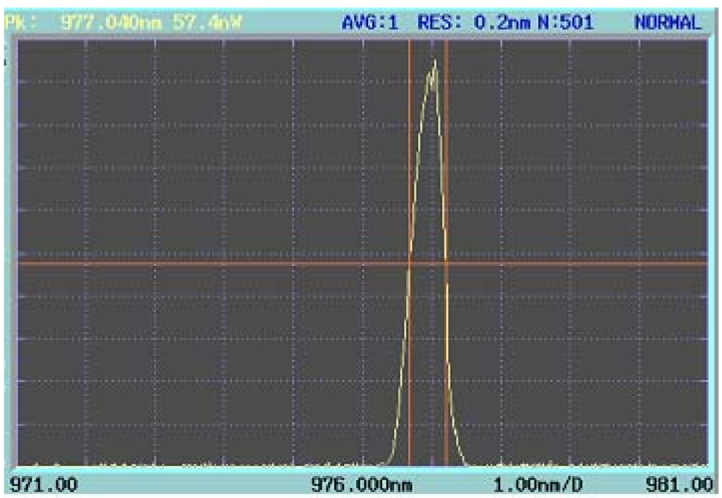

Fig. 4. 976 nm conduction cooled 200 micron 0.22 NA fiber coupled module with internal grating stabilization.

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. See Figure 5 for a schematic.

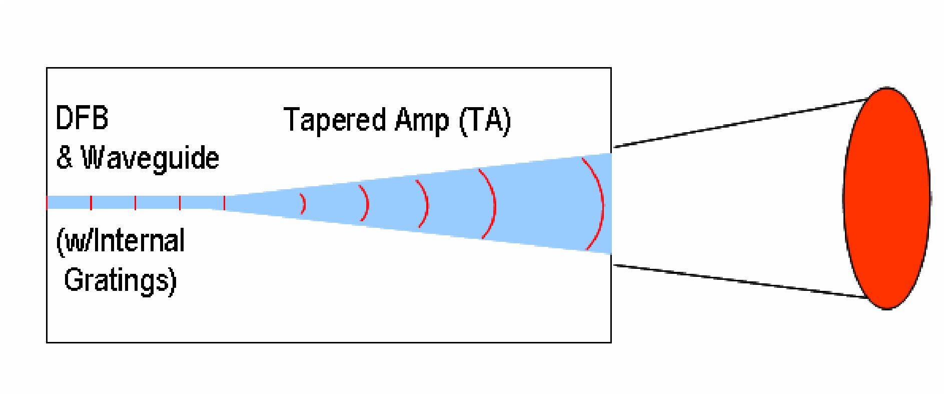

Fig. 5. Schematic of 1040 nm single frequency single mode MOPA device

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 6 shows the CW power versus current curve for such a device with a constant 700mA in the oscillator section.

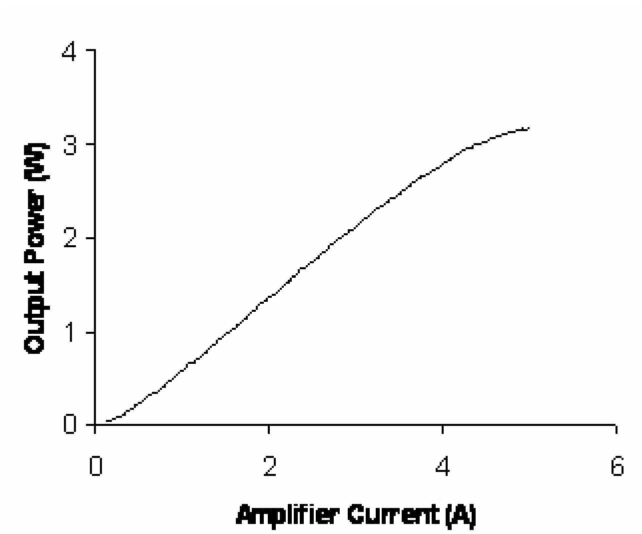

Fig. 6. Power versus current in the amplifier section for 1040 nm single frequency single mode MOPA device.

Figure 7 shows the spectrum for a device at 3 Watt. The line width was measured to be < 50MHz. More than 30dB of suppression was observed. Figure 8 shows the slow axis beam quality measurement, with performance less than 1.2 times the diffraction limit.

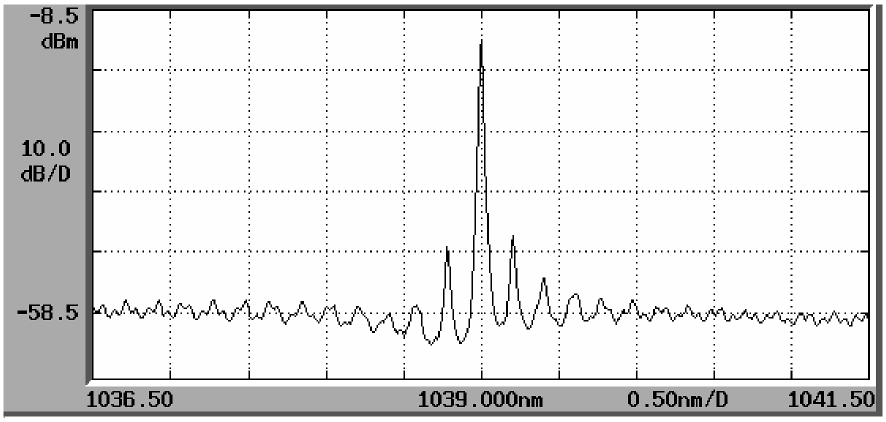

Fig. 7. Spectrum for 1040 nm single frequency single mode MOPA device.

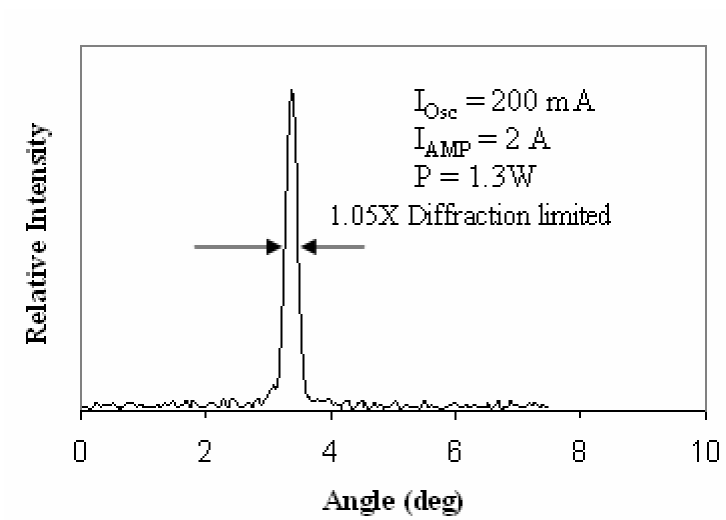

Fig. 8. Mode measurement for 1040 nm single frequency single mode MOPA device.

3. Eye-safe Wavelengths

Diode lasers in the 1400 nm to 1600 nm regime are used in a variety of applications including pumping Er:YAG lasers, range finding, materials processing, and aesthetic medical treatments. In addition to the compact size, efficiency, and low cost advantages of traditional diode lasers, high power semiconductor lasers in the eye-safe regime are becoming widely used in an effort to minimize the unintended impact of potentially hazardous scattered optical radiation from the laser source, the optical delivery system, or the target itself.

Figures 9 and 10 show the power versus current and output spectrum of a 1532 nm bar operating at 20 Watts at 65 A on a conduction cooled mount. The output spectrum exhibits a spectral width less than 1.6 nm wide, roughly 5-10 times narrower than a similar Fabry-Perot without an internal grating.

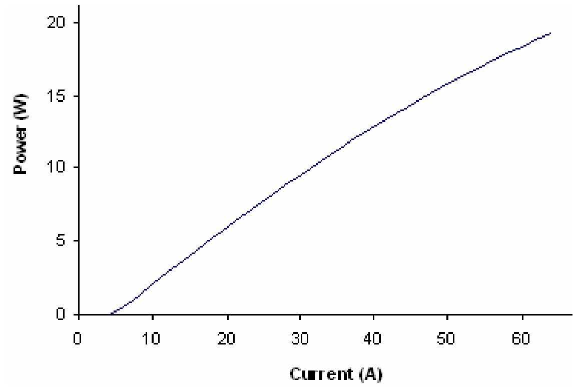

Fig. 9. 1532 nm bar with internal grating stabilization, power versus current performance

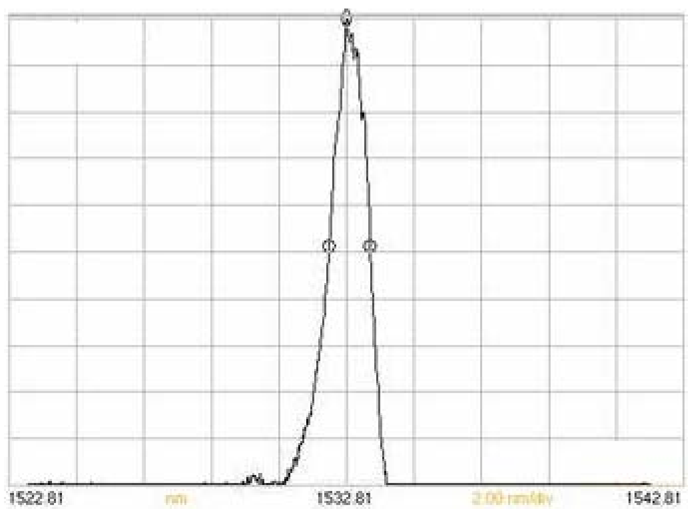

Fig. 10. 1532 nm bar with internal grating stabilization, output spectrum at 20 W, showing <1.6 nm FWHM.

Figures 11 and 12 show the power versus current and output spectrum of a 1532 nm water cooled stack operating at 175 Watts at 95 A on a conduction cooled mount. The output spectrum exhibits a spectral width less than 2 nm wide, roughly 5-10 times narrower than a similar Fabry-Perot without an internal grating.

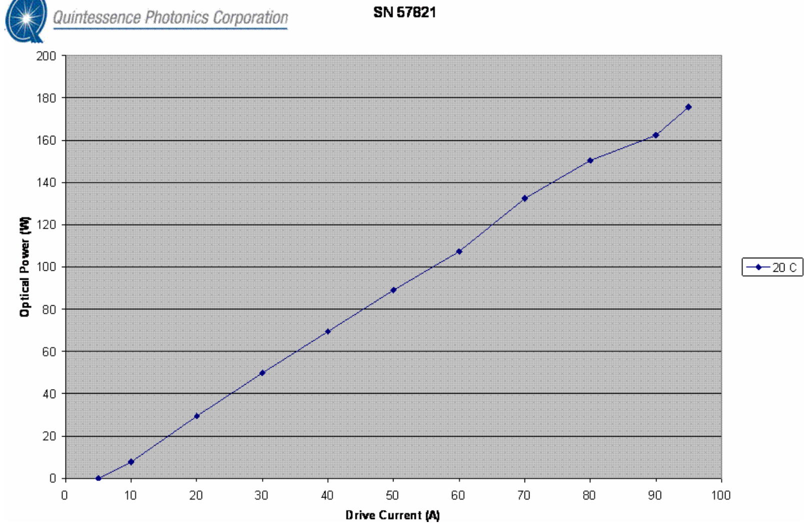

Fig. 11. 1532 nm water cooled stack with internal grating stabilization, power versus current performance

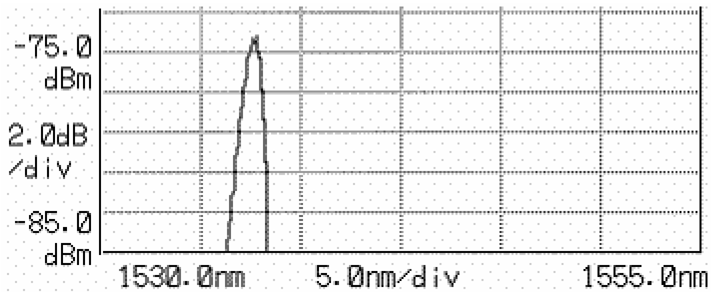

Fig. 12. 1532 nm stack with internal grating stabilization, output spectrum at 175 W, showing <2 nm FWHM.

QPC has also developed devices at 1470 nm with internal grating and achieved >1.4 W a <5 A from 100 µm wide stripe lasers on a conduction cooled mount. The output spectrum at 20 ºC and exhibits a spectral width < 1 nm wide, roughly 10 times narrower than a similar Fabry-Perot without an internal grating. The wavelength dependence on temperature of the 1470 nm and 1532 nm devices is <0.1 nm/ºC, >3 times smaller than a F-P laser.

4. Conclusions

The recent advances in high brightness, high power semiconductor laser technology include 40W 808nm bar performance with <0.4 nm FWHM spectral width with internal Bragg gratings, <.5 nm FWHM from 976nm 200 micron 0.22NA fiber coupled modules internal Bragg gratings, >3W single mode single frequency performance from 1040 nm tapered devices, and < 2nm FWHM spectral with from 175W 1532nm high power stacks.

ACKNOWLEDGEMENTS

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