Progress in Commercial Wavelength-Stabilized High Brightness Diode Sources Suitable for Pumping Yb-doped Fiber Lasers

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ABSTRACT

We report on the performance of a 100 W, 105µm, 0.17 NA (filled) fiber-coupled module operating at 976 nm. Volume holographic (Bragg) gratings are used to stabilize the emission spectrum to a 0.2 nm linewidth and wavelength-temperature coefficient below 0.01nm/°C with virtually no penalty to the operating power or efficiency of the device. The typical fiber coupling efficiency for this design is >90%, enabling a rated operating efficiency of ~50%, the highest reported for a 100W/105µm-class diode pump module (wavelength stabilized or otherwise).

Keywords: high power diode laser, single emitter, fiber coupled module, wavelength locking, reliability

1. MOTIVATION

High power fiber lasers continue to place ever-increasing demands on the brightness of fiber-coupled diode laser pumps. Higher brightness pumps enable increased modal overlap of the pump with the doped fiber core, allowing the use of shorter fiber lengths to suppress nonlinearities. Traditional fiber coupled diode lasers have been based on either bars or fiber coupled single emitters [1,2]. In bar-based systems, the asymmetric beam quality in the fast and slow axis requires the use of expensive micro-optical beam shaping systems, and the optical to optical efficiency is diminished by multiple optical interfaces, imperfect beam shaping, and low fill factor. The brightness of bar-based systems is further limited due to emitter cross heating and bar "smile." High brightness diode laser modules based on arrays of high power broad area single emitters, on the other hand, offer better brightness, improved reliability, and lower cost over equivalent bar-based solutions. The single emitters are capable of being run at high linear power density, increasing the brightness of the diode laser system. By efficiently imaging the diode laser onto the fiber, the high brightness and system efficiency of the single emitters are maintained.

Improved power scaling and efficiency can be achieved by pumping the Yb-doped fiber gain media at 976 nm owing to low quantum defect. This absorption feature is relatively narrow (a FWHM width of ~9 nm), resulting in a requirement for strict temperature control of the diode pump module to achieve optimal absorption. Alternatively, line-narrowed and wavelength stabilized diode lasers can be achieved through wavelength-selective feedback by utilizing external volumetric Bragg gratings (also commonly referred to as VHGs for volume holographic grating) [3,4]. Wavelength locking via external VHG offers advantages such as greatly improved temperature stability, wavelength flexibility and easy implementation into high power diode laser systems. In this paper, we report on the performance of a 100 W, 105µm, 0.17 NA (filled) fiber-coupled module operating at 976 nm. VHGs are used to stabilize the emission spectrum to a 0.2 nm linewidth and wavelength-temperature coefficient below 0.01nm/°C with virtually no penalty to the operating power or efficiency of the device. The typical fiber coupling efficiency for this design is >90%, enabling a rated operating efficiency of ~50%.

2. SINGLE EMITTER PERFORMANCE

The design of nLight's 976-nm broad area diode laser is optimized for simultaneous delivery of high power, high efficiency, and good reliability. The epitaxial structure of the laser diode is grown by metal-organic chemical vapor deposition, followed by standard fabrication procedures that include metal contact deposition, isolation, passivation, and coating. Single emitter chips are then bonded p-side down with AuSn solder to expansion-matched heatsinks. Each device is individually screened by high power test, accelerated burn-in, and multiple inspection processes. The device geometry for the results reported herein consists of a 3.8 mm cavity length and a 95 µm stripe width. The typical optical power and wall-plug efficiency under continuous wave (CW) drive current are shown in Figure 1(a). Operated at a 10W rated use condition, the design delivers ~65% power conversion efficiency with excellent brightness. Figure 1(b) depicts the unlocked lasing spectrum measured at a current of 10 A, with a FWHM spectral width of 3.6 nm. The lateral near-field and lateral/vertical far-field intensity profiles are also plotted in Figure 1(c) and (d), respectively. All data are measured at a heatsink temperature of 25°C. A histogram of peak efficiency for over 2500 devices at 976 nm manufactured over a 6-month period is shown in Figure 2. Over 95% of devices produced demonstrate peak efficiency of 66% or higher.

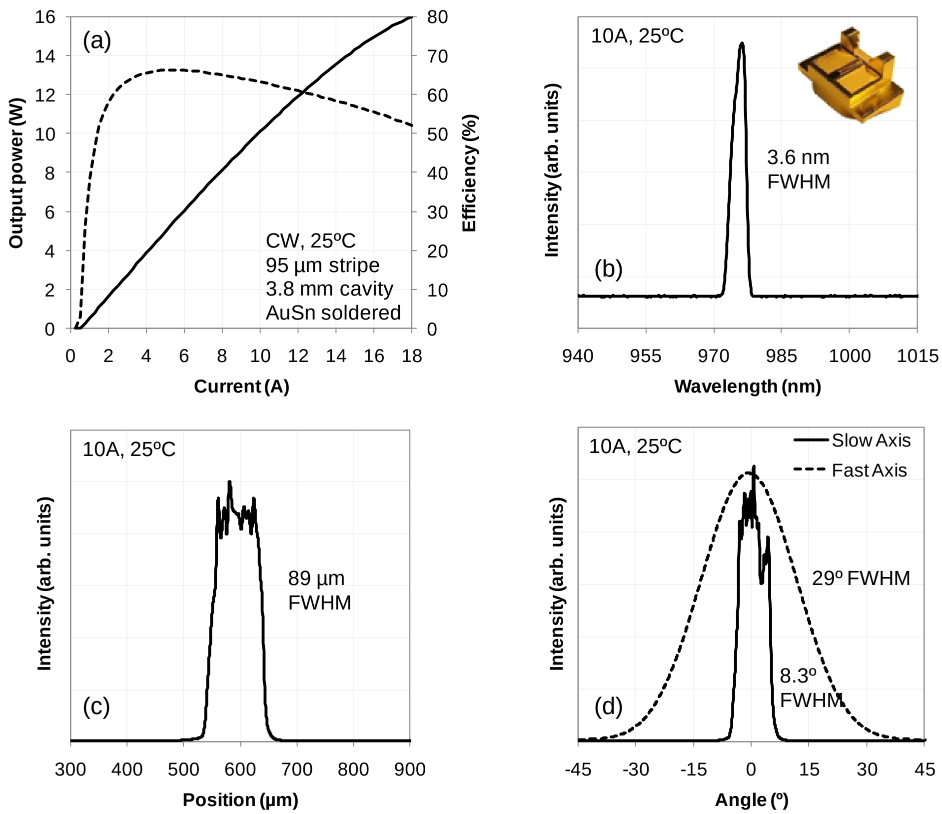

Figure 1: Typical performance of nLight's 95µm stripe, 3.8mm 976-nm single emitter laser design. Shown are (a) power and efficiency vs. drive current, (b) unlocked laser spectrum, (c) near-field and (d) far-field intensity profile.

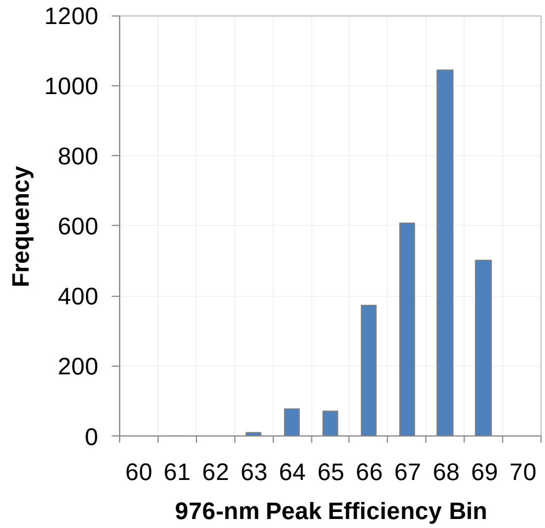

Figure 2: Histogram of peak wallplug efficiency for devices at 976 nm produced over a 6-month period.

3. MODULE DESIGN AND PERFORMANCE

High brightness diode laser modules based on arrays of high power single emitters offer better brightness, reliability, and lower cost over equivalent bar-based solutions. nLight has developed extremely high brightness fiber coupled diode laser packages (so called Pearl™ modules) based on stacked multiple single emitters [5,6]. The single emitters are stacked in a stair-step manner to provide an excellent thermal path from the diode to the cooling plate, maintaining a low junction temperature. This mechanical arrangement conveniently stacks the emitters in the fast axis, maintaining the brightness of the diode lasers. Each diode is individually collimated with fast axis and slow axis lenses, resulting in unsurpassed pointing accuracy and an excellent optical “fill factor.” The geometry of the emitters and corresponding optics are arranged to reduce “dead space” between each emitter, maximizing diode brightness. The two columns of light are combined using polarization multiplexing, and simple focusing lenses couple the collimated beams into the fiber at the appropriate numerical aperture. High fiber coupling efficiency is achieved through well-controlled alignment of the necessary optics. As an example, Figure 3(a) illustrates the fast-axis divergence of a large number of lensed single emitters. These emitters are subsequently assembled in 14 emitter Pearl modules. Figure 3(b) illustrates the distribution of divergences as measured from the ensemble of beams. The mean divergence changes by ~6%, indicating excellent pointing capability, and hence better brightness conservation. Figure 4 illustrates the optical power, wall-plug efficiency, voltage, and lasing spectrum for a 100 W, 0.17 NA (filled) unlocked Pearl module. As shown, the module delivers >50% conversion efficiency and an unlocked FWHM spectral width of 3.6 nm.

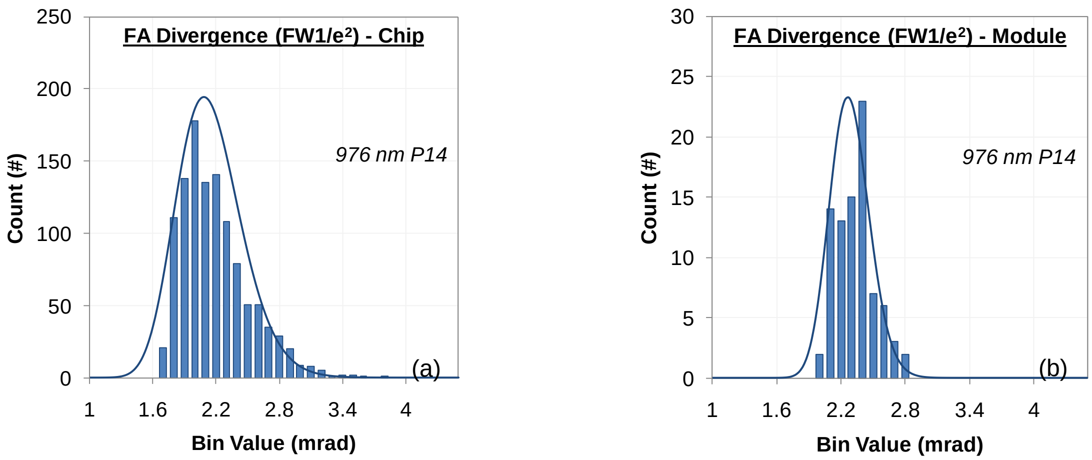

Figure 3: Fast-axis divergence histogram for (a) single emitter chips and (b) 14 emitter Pearl modules.

OPTICAL	
Wavelength, nm	979.0
Output Power, watts	80
Spectral Width, FWHM	3.6
Spectral Width, 1/e^2	6.0
Slope Efficiency, W / A	7.8
Divergence, NA (90% power incl.)	0.12
Wavelength Temp. Coeff., nm / °C	0.35
ELECTRICAL	
Total Conversion Efficiency (ηWP)	50%
Threshold Current, amps	0.43
Operating Current, amps	9.83
Operating Voltage, volts	16.30
Series Resistance, ohms	0.27
THERMAL	
Operational Temperature, °C	25.0
Thermal Resistance, °C / W_{heat}	0.35

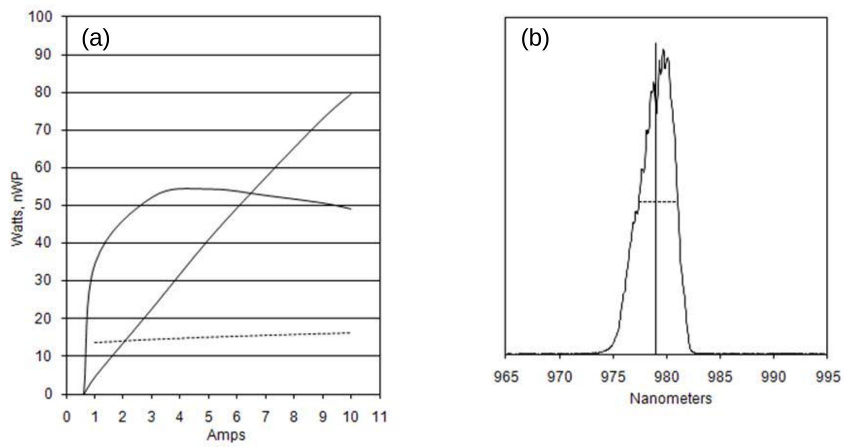

Figure 4: (a) Optical power, wall-plug efficiency and voltage vs. drive current, and (b) lasing spectrum for the unlocked 100 W, 105µm, 0.17 NA (filled) unlocked Pearl module. Table to the left lists optical, electrical and thermal specifications of the module.

4. WAVELENGTH LOCKED ARRAYS

For power scaling and high efficiency pumping of the Yb-doped fiber gain media, the high power diode laser pumps need to provide the spectral brightness and wavelength stability to cover the relatively narrow line at the 976 nm. Narrow linewidth and wavelength stabilization of diode lasers is typically achieved through wavelength-selective feedback that locks the laser to one (or a few) longitudinal modes. The two most common approaches that are utilized in high power diode lasers are internal feedback provided by means of an etched distributed Bragg grating (DFB) [7] and external feedback through external optics such as VHG. VHG is an external optical component in which a periodic variation in index of refraction has been recorded into the photorefractive glass. VHG provides narrow emission bandwidth and a low temperature dependence of emission wavelength. Used as an output coupler for the diode laser, VHG locks the lasing wavelength by effectively forming an extended cavity laser having excellent wavelength-selective feedback. VHG wavelength-locking approach offers great flexibility in wavelength selection, which can be externally tailored to the application without growing complex epitaxy structures as with internal DFB gratings. It decouples diode-self-heating from the wavelength detuning of the feedback structure, further improving the temperature stabilization of the locked diode. External locking also allows independent optimization of the epitaxy design for high performance, and the low internal loss of the VHG itself permits design optimizations that provide zero penalty in the power and efficiency relative to the unlocked design.

nLight developed a locking technique capable of maintaining good locking performance over a wide temperature range with virtually no change to the laser power and efficiency [8]. This technique was also applied to high-power, high-efficiency diode laser arrays, with each emitter of the arrays wavelength-locked to a single grating. Figure 5 shows the performance of such modules operating at 976 nm. The 105µm, 0.17 NA (filled) fiber-coupled module has a rated optical power of 100 W and excellent brightness (~14 MW/cm^2-str)), as plotted in Figure 5(a). VHGs are used to stabilize the emission spectrum to a 0.2 nm linewidth [Figure 5(b)], and wavelength-temperature coefficient below 0.01nm/°C. The typical fiber coupling efficiency for this design is >90%, enabling a rated operating efficiency of 49%. The finished module is rugged, reliable, low-weight, and compact – small enough to be held in the palm of a hand, as shown in the inset of Figure 5.

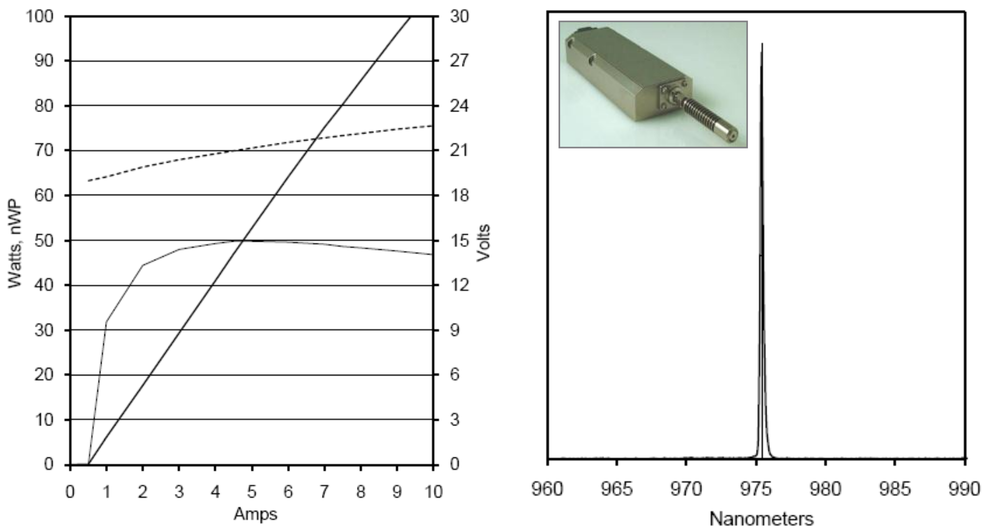

Figure 5: (a) Optical power, wall-plug efficiency and voltage vs. drive current for the 100W 105 µm fiber-coupled module, with a rated operating efficiency of ~49%. (b) Lasing spectrum of the module at the rated use condition. The linewidth is <0.2 nm FWHM with >99% of the total power locked by the VBG. The inset shows a photograph of the module.

5. CONCLUSION

In summary, we report on the performance of a 100 W, 105µm, 0.17 NA (filled) fiber-coupled module operating at 976 nm, for power scaling and high efficiency pumping of the Yb-doped fiber gain media. VHGs are used to stabilize the emission spectrum to a 0.2 nm linewidth and wavelength-temperature coefficient below 0.01nm/°C with virtually no penalty to the operating power or efficiency of the device. The typical fiber coupling efficiency for this design is >90%, enabling a rated operating efficiency of 50% (49% if wavelength stabilized), the highest reported for a 100W/100µm-class diode pump module (wavelength stabilized or otherwise).

6. REFERENCES

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