Hard-Soldered InGaAsP Single Emitter Diode Lasers on CTE-Matched Heatsinks Deliver Record Power

Paul Leisher*, Damian Wise, Kirk Price, Weimin Dong, Mike Grimshaw, and Steve Patterson

nLIGHT Corporation; 5408 NE 88th St., Bldg E; Vancouver, WA 98665; USA

Applications such as direct pumping of rare-earth doped solid state and fiber lasers are driving development of higher power commercial diode lasers operating in the 1400-nm to 2000-nm band[1,2,3]. In this work, we report on recent progress in high-power hard-soldered InGaAsP-based single emitter diode lasers. Peak continuous wave (CW) powers of 4 W, 2.3 W, and 1.4 W are measured at 25 °C for lasers operating at 1470 nm, 1700 nm, and 1940 nm, respectively. Quasi-continuous wave (QCW) power at 1700-nm in excess of >10W (peak) is reported from a single 150-µm stripe emitter and >150W (peak) in a 16 emitter array configuration.

It is well-known that the temperature performance of high power diode lasers operating at and beyond 1300-nm is significantly worse than those which operate below 1000-nm due to a variety of reasons, including Auger recombination[4,5] and intervalence band absorption[6]. Because of this, the manufacture of high-power long-wavelength diode lasers has historically relied on indium solder for attaching cm-long laser bar arrays to high thermal conductivity microchannel-cooled copper heatsinks. Unfortunately, this approach has been shown to have significant negative implications to reliability[7]. Bonding techniques which rely on AuSn 'hard' soldering of chips to coefficient-of-thermal-expansion (CTE) matched heatsinks (such as CuW, AlN, and BeO) have been shown to greatly improve reliability[8], at a cost to the thermal performance of the package. Additionally, trends in brightness requirements have recently spurred a departure from the typical bar array format towards approaches which leverage scalable arrays of single emitter diodes[9].

All three laser structures presented herein are based on the InGaAsP material system and are grown using MOCVD. Careful optimization of the growth conditions is required to achieve good-quality, relaxation-free growth of the highly-strained quantum well active region beyond ~1800 nm. The wafers follow a standard broad area laser fabrication procedure; the laser die are cleaved to 3-mm cavity length, and PR/AR coatings are deposited on the front and back facets, respectively. The single emitters are then bonded junction-down using AuSn solder to CTE-matched heatsinks. Figure 1 illustrates the output power, conversion efficiency, and laser spectrum for the three such devices.

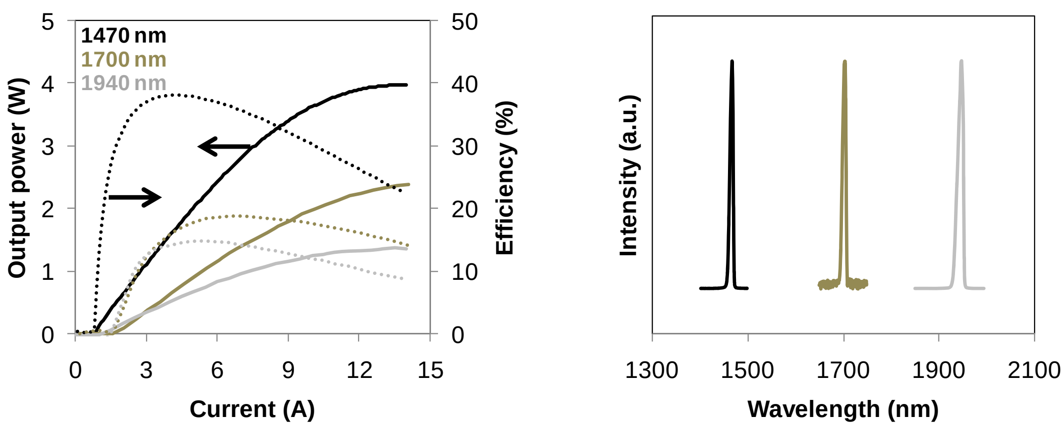

Fig. 1: *(Left) Power and efficiency vs. injection current for hard-soldered 1470-nm, 1700-nm, and 1940-nm InGaAsP-based diode lasers operating CW at 25°C. (Right) CW lasing spectra of the diode lasers at taken 9A, 25°C.*

* Tel: 360.907.8347 Email: paul.leisher@nlight.net

Portions of this work were supported by NASA under contract number NNL07AA08C

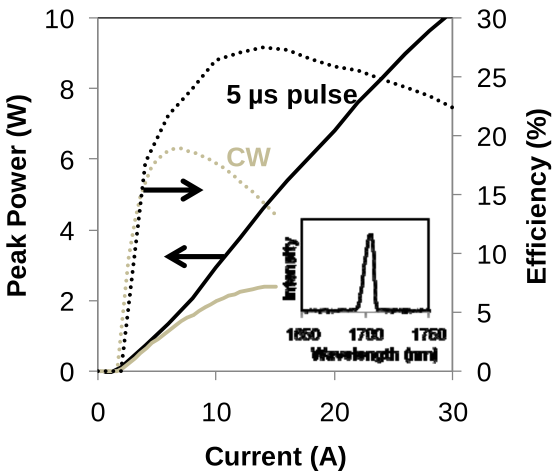

Fig. 2: *Under 5µs pulse, 10% duty cycle QCW operation at 25°C, peak power for the 1700nm laser is increased to >10W. The inset illustrates the optical lasing spectrum taken 9A.*

These improvements to optical power were achieved through changes in the epitaxy design which have enabled scaling of the optical mode volume. By carefully optimizing the total optical loss of the laser, the cavity has been lengthened, while maintaining high efficiency operation, thereby reducing the overall thermal resistance of the hard-soldered diode laser.

Many pumping and direct diode applications rely on quasi-continuous-wave (QCW) operation of the laser source. Under QCW operation, the diode is turned on for time intervals which are short enough to significantly reduce thermal effects, but long enough such that the carrier and photon processes are at steady state. This regime of operation can therefore greatly enhance maximum peak power attainable in long-wavelength diode lasers. Figure 2 illustrates the power and efficiency versus current for the 1700-nm laser operated QCW at 25° C with a 5 µs pulse length and 10% duty cycle.

Sixteen such emitters are then arrayed in a conduction-cooled package format for efficient coupling to a 400-µm-core fiber. The emitters are connected electrically in series[9]. The module is driven under the same operating conditions (5 µs pulse, 10% duty cycle, 25 °C) and the peak power calculated from the time-averaged power detected by on a thermopile. Figure 3 illustrates the peak power and efficiency of the module. Note the unit was unable to be tested beyond 10A due to voltage compliance limitations of the high current QCW power supply. The deviation of the measured module power from the summed emitter power around 9A is attributed the onset of abnormal pulse shaping at such high power levels. As shown, the module delivers >150W peak power at 30A with an operating efficiency in excess of 20%.

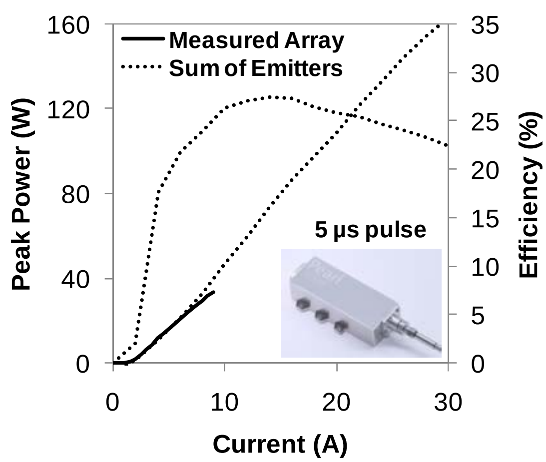

Fig. 3: *Under 5µs pulse, 10% duty cycle QCW operation at 25°C, the sixteen-emitter array delivers >150W peak power at 1700-nm with an operating efficiency in excess of 20%. The inset shows a representative photograph of the module.*

In summary, record powers have been demonstrated across the 1400-nm to 2000-nm band for InGaAsP-based single emitter diode lasers which are hard-soldered to CTE-matched heatsinks. Practical power scaling can be achieved by arraying these emitters in conduction-cooled packages, thereby further enabling a variety of applications including solid state laser pumping, fiber laser pumping, and direct diode use.

[1] D. Garbuzov, I. Kudryashov, M. Dubinskii, *Appl. Phys. Lett.*, vol. 86, 131115, (2005).
[2] S. D. Setzler, *et. al.*, *IEEE J. Sel. Top. Quant. Elect.*, vol. 11, no. 3, pp. 645-657, (2005).
[3] C. D. Nabors, *et. al.*, *IEEE J. Quant. Elect.*, vol. 31, no. 9, pp. 1603-1605, (1995).
[4] H. K. Choi, *Long-Wavelength Infrared Semiconductor Lasers*, New Jersey: Wiley Interscience, (2004).
[5] L. Coldren and S. Corzine, *Diode Lasers and Photonic Integrated Circuits*, New York: Wiley Interscience, (1995).
[6] C. Henry, R. Logan, F. R. Meritt, and J. P. Luongo, *IEEE J. Quant. Elec.*, vol. 19, no. 6, pp. 947-952, (1983).
[7] X. Liu, R. Davies, L. Hughes, M. Rasmussen, R. Bhat, and C. Zah, *J. Appl. Phys.*, vol. 99, no. 1, (2006).
[8] D. Lorenzen, *et. al.*, *Proc. of SPIE*, vol. 6456, (2006).
[9] S. Patterson, *et. al.*, *Proc. SPIE*, vol. 6216, (2006).