QPC Lasers
by Laser Operations LLC

Photonics Online

Brightlock® pump diodes take the heat out of high power lasers

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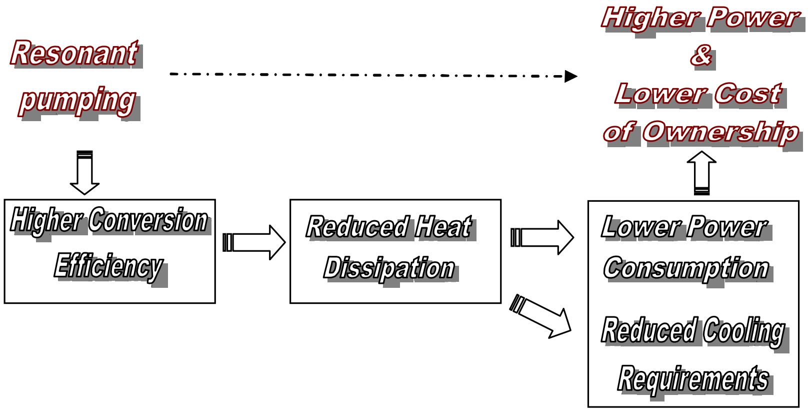
Introduction

Power scaling of diode pumped lasers has accelerated dramatically over the past ten years, breaking through the 100 kW barrier for the first time in 2010 [1] and 10kW from a single mode fiber a few months earlier [2]. Looking forward, in addition to keeping the power scaling curve on the upswing, system designers are now faced with the incredible challenges of minimizing:

- Heat dissipation
- Power consumption
- Cost of ownership

1. Resonant pumping of high power lasers

In order to address these challenges, high power laser groups have recently turned increasingly to resonant pumping. The concept is based on the basic observation that pumping an active material close to its emission wavelength reduces the quantum defect of the transition of a laser system, therefore improving its conversion efficiency.



However resonant pumping typically relies on wavelengths that often present narrow absorption linewidths that require high spectral brightness pumping sources. For example, Yb fiber lasers benefit from pumping at 976nm due to the lower quantum defect than at shorter wavelengths, which generate higher efficiencies. Besides, higher absorption means that shorter fiber lengths are used, therefore limiting deleterious non-linear effects [3]. Similarly Er:Yag, a leading candidate for “eyesafer” DPSS lasers, has been investigated at resonant wavelengths of 1532nm [4] and more recently at 1452nm, generating over 400W CW at 1645nm [5]. Several other major laser media benefit from resonant pumping, such as Nd:Yag pumped at 880nm or 885nm [6], as well as Alkali lasers which rely on narrow line pumping of Rb at 780nm.

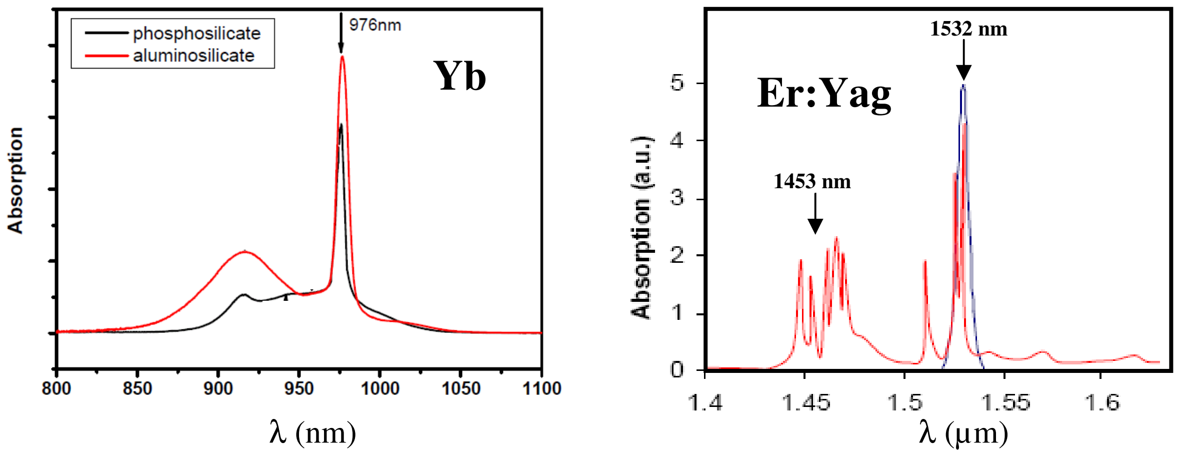


Figure 1: Absorption spectra of Yb doped fibers [1] and Er:Yag DPSS crystals showing high absorption and lower quantum defects at resonant pumping lines of 976nm, 1452nm and 1532nm.

2. Brightlock®: On-chip wavelength stabilization

Conventional laser diodes today are highly efficient but suffer from broad linewidth, lack of control over center wavelength, and significant dependence versus temperature.

In order to overcome these challenges and leverage resonant pumping, a novel technique of wavelength stabilization based on internal diffraction gratings embedded inside the semiconductor chip was developed for the QPC Lasers product line. These devices are fabricated using a wafer-based process, with the gratings defined after a first epitaxial growth by optical lithography into a photoresist layer, followed by etching, then finalized during a re-growth process. The process has been successfully implemented in both GaAs and InP material at various wavelengths such as 795nm, 808nm, 976nm, 981nm, 1453nm, and 1532nm.

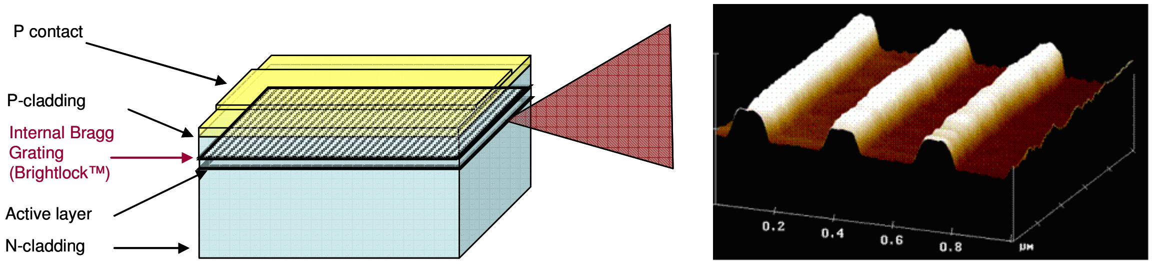


Figure 2: Schematic of Brightlock® chip highlighting embedded grating written at wafer level during MOCVD epitaxial growth (left). Atomic Force Microscope picture of internal grating (right).

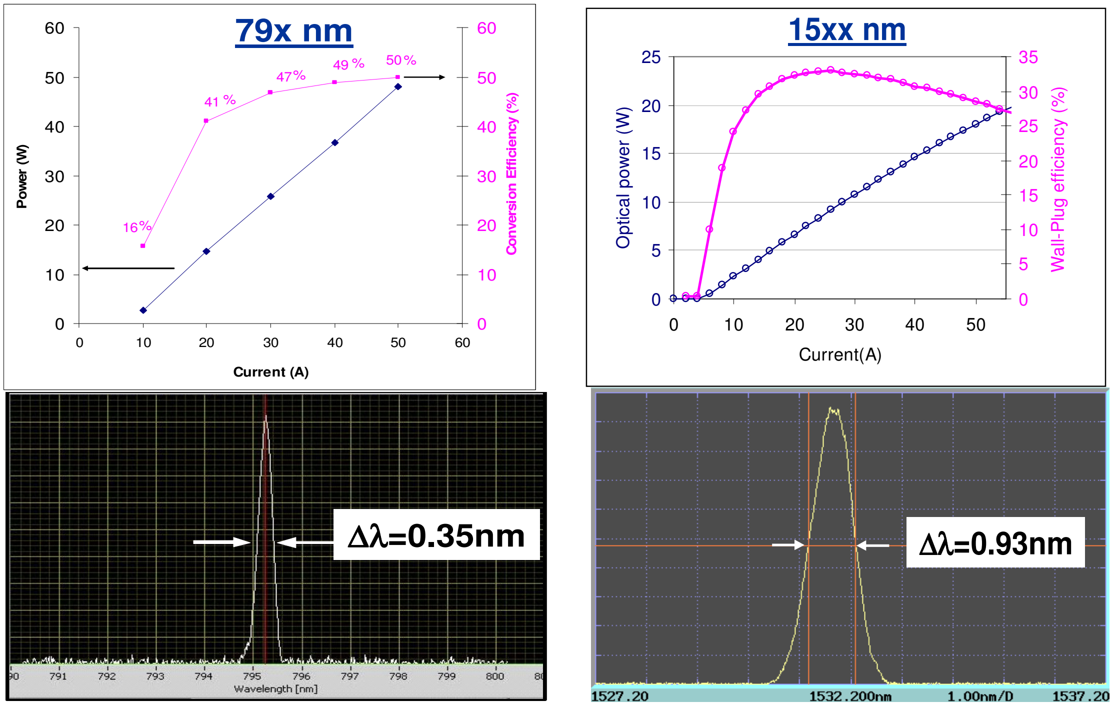


Figure 3: Typical efficiencies and spectra of 19 emitter array in GaAs and InP material systems.

Parameter (short wavelength)	Brightlock®	Conventional diodes	VBG [partially from 7]
Center wavelength	±1 nm	±3nm	±0.8nm
dλ/dT	0.07 nm/℃	0.3nm/℃	0.01nm/℃
Linewidth	<1 nm	<5 nm	<0.5 nm
Efficiency (typical @ 79x nm)	45-50%	50-55%	45-50%
Manufacturing cost	Low	Low	High (component + alignment)
Operating temperature range	50℃	> 70℃	30℃
Alignment sensitivity	none	none	<1 mrad
Vertical stack power scaling	Yes	Yes	Limited*

**Requires lensing. High sensitivity to bar smile and alignment.*

Figure 4: Comparison of laser diode technologies.

2. Brightlock®: some practical examples

a. 808nm

As the workhorse of DPSS industrial applications, 808nm is widely used in most laser systems today. However, when it comes to applications requiring high spectral brightness and low sensitivity to temperature, conventional laser diodes cannot satisfy the stringent requirements of Nd:YVO4. Below is shown the absorption linewidth of a typical Vanadate crystal superimposed with the actual emission spectrum of a Brightlock chip from 30°C to 60°C, demonstrating locking over a wide operating temperature range and, more importantly, good overlap of the two curves which allows for high absorption of the pump light, and enhanced power stability and conversion efficiency.

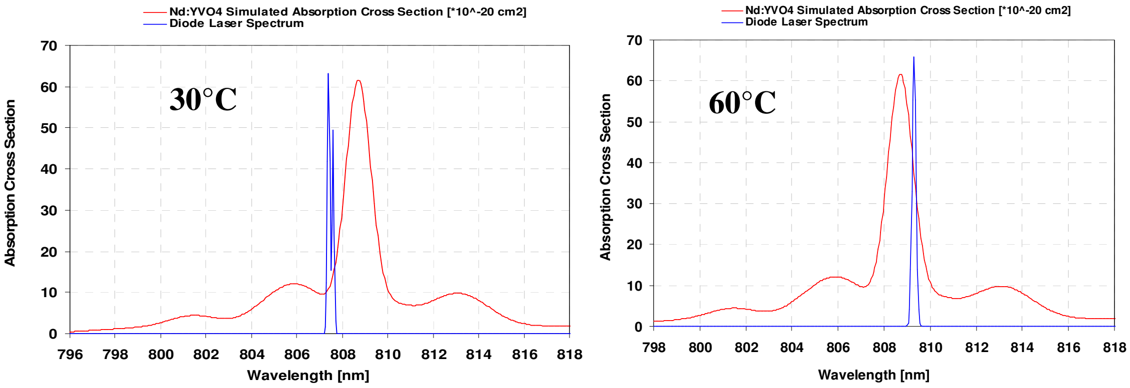


Figure 5: Spectra of 808nm Brightlock 20um wide emitter chip superimposed with absorption spectrum of Vanadate crystal from 30°C to 60°C.

b. 976nm

A single bar-based module with 6 fiber-coupled channels demonstrates 330W CW at 976nm with linewidth of less than 0.5nm.

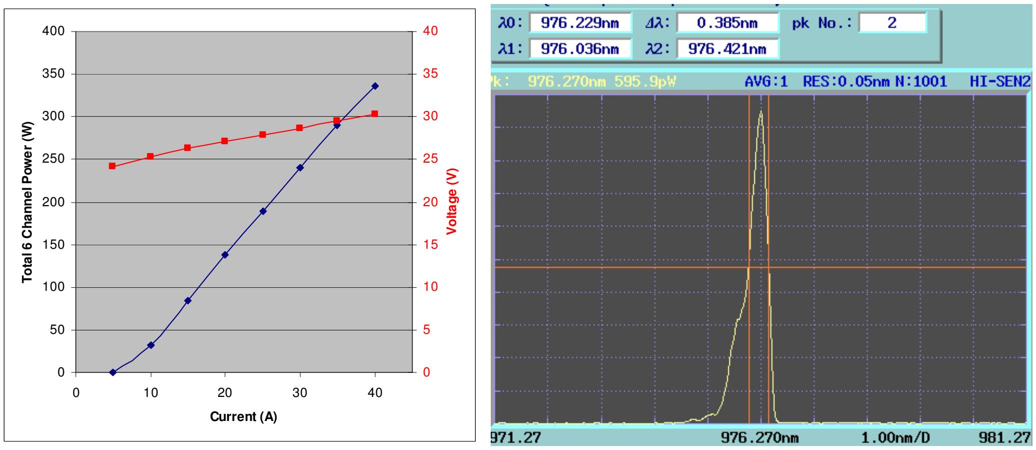


Figure 6: On-chip grating stabilization of laser diodes enables high power, narrow bandwidth and reduced sensitivity to temperature. A 6 channel module is shown here producing 330W at 976nm with <0.5nm bandwidth for fiber laser pumping.

c. 1532 nm

Using Brightlock® InP bars grown by MOCVD, Laser Operations completed and delivered in late 2009 the first wavelength stabilized laser diode stack to reach 10 kW CW. The integration of gratings inside the laser chips epitaxial structure allowed for full collimation in both slow and fast axis of the 10kW CW stack to less than two degrees.

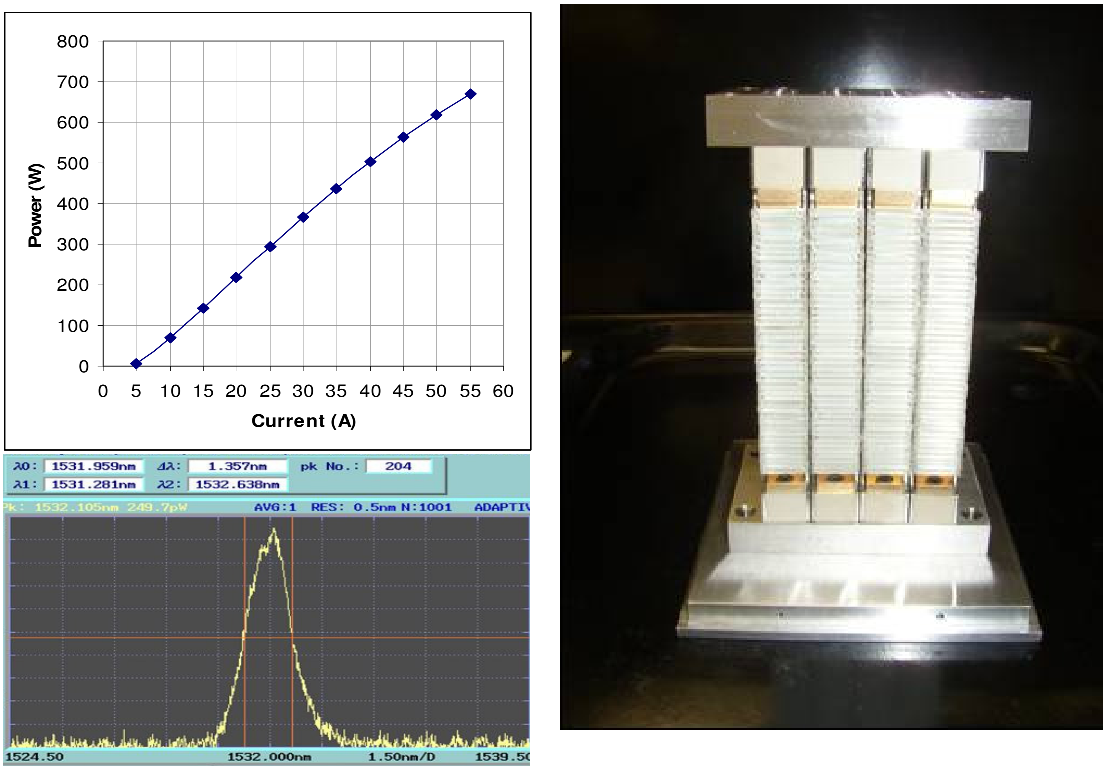


Figure 7: Picture of 4 x 42 bar vertical diode array of Brightlock® bars at 1532nm (right). The arrays are collimated in fast and slow axis to less than two degrees (FWHM). Power versus current and spectrum of 1.4nm for the full 4 stacks module is shown (left).

Conclusion

Resonant pumping architectures enable scaling of high power lasers by improving conversion efficiency, reducing thermal effects and cooling requirements. Brightlock® pump diodes, based on internal gratings directly embedded in the semiconductor epitaxial structure, meet the stringent spectral requirements of resonant pumping by providing 3X higher accuracy center wavelength, 4X reduction of wavelength-temperature coefficient, and up to 10X reduction of spectral linewidth over conventional laser diodes with demonstrated scaling up to 10kW CW.

[1] Northrop Grumman Scales New Heights in Electric Laser Power, Achieves 100 Kilowatts From a Solid-State Laser, Northrop Grumman Corporation press release,

Redondo Beach, Calif., March 18, 2009 (Globe Newswire).
http://www.irconnect.com/noc/press/pages/news_releases.html?d=161575

[2] IPG Photonics. http://www.ipgphotonics.com/Collateral/Documents/English-US/PR_Final_10kW_SM_laser.pdf

[3] Nufern, White Paper, Diode Pump Requirements For High Power Fiber Lasers, November 01, 2007.

[4] “Latest developments in resonantly diode-pumped Er:YAG lasers.” Igor Kudryashov, Dmitri Garbuzov, Mark Dubinskii, Laser Source Technology for Defense and Security III, edited by Gary L. Wood, Mark A. Dubinskii, Proc. of SPIE Vol. 6552, 65520K, (2007).

[5] “400W Resonantly Pumped Cryogenic Er:YAG Slab Laser at 1645nm”, Michael J. Shaw, Scott D. Setzler, Kenneth M. Dinndorf, James A. Beattie, Mark J. Kukla, Evan P. Chicklis, ASSP 2010, San Diego CA.

[6] “In-band pumping of nd-based solid-state lasers,” Nicolaie Pavel, Romanian Reports in Physics, Vol. 60, No. 4, P. 995–1012, 2008.

[7] “Wavelength stabilized high-power diode laser modules,” B. Köhler, T. Brand, M. Haag, and J. Biesenbach, in “High-Power Diode Laser Technology and Applications VII,” M.S. Zediker ed. Proc. SPIE 7198, 10 (2009).