

## High-power semiconductor lasers at eye-safe wavelengths

Mark L. Osowski, Yossi Gewirtz, Robert M. Lammert, Se W. Oh, Chameli Panja, Victor C. Elarde,  
Laurent Vaissie\*, Falgun D. Patel, Jeffrey E. Ungar

QPC Lasers, Inc.  
15632 Roxford Street, Sylmar, CA 91342

### ABSTRACT

InP based diode lasers are required to realize the next generation of eyesafe applications, including direct rangefinding and HEL weapons systems. We report on the progress of high power eyesafe single spatial and longitudinal mode 1550nm MOPA devices, where we have achieved peak powers in excess of 10W with 50ns pulse widths. A conceptual model based on our recent MOPA results show the path towards scaling to high powers based on spatial beam combination with operating conditions suitable for direct rangefinding applications. We also report on the progress towards high power 14xx and 15xx nm pump lasers for eyesafe HEL systems.

Keywords: Diode, laser, semiconductor, LIDAR, stack, array, eyesafe, brightness

### 1. Introduction

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.

In this article we describe the performance of high efficiency high power InP laser bars at 1470nm and 1532nm as well as high brightness MOPA devices at 1550nm developed at QPC Lasers for applications ranging from surgery to HEL pumping and rangefinder.

### 2. High efficiency high power 1470nm laser diode bars

Among high power eye-safe wavelengths, 1470nm is the wavelength that serves the widest range of applications for two reasons. Firstly, 1470nm is close to a water peak absorption which makes it ideal for cosmetic applications such as skin rejuvenation or acne treatment. Secondly, 1470nm is a wavelength of choice for resonant pumping of Er:Yag for high energy laser pumping.

Leveraging over 20 year of advanced R&D for telecom applications, QPC's team has developed high efficiency diode bars with a typical peak conversion efficiency of 35%. The bars are bonded with indium on CS-mount and typically run at 20°C.

\*Contact: [lvaissie@qpc lasers.com](mailto:lvaissie@qpc lasers.com); tel: (818) 986-0000



SPIE

©2009 COPYRIGHT

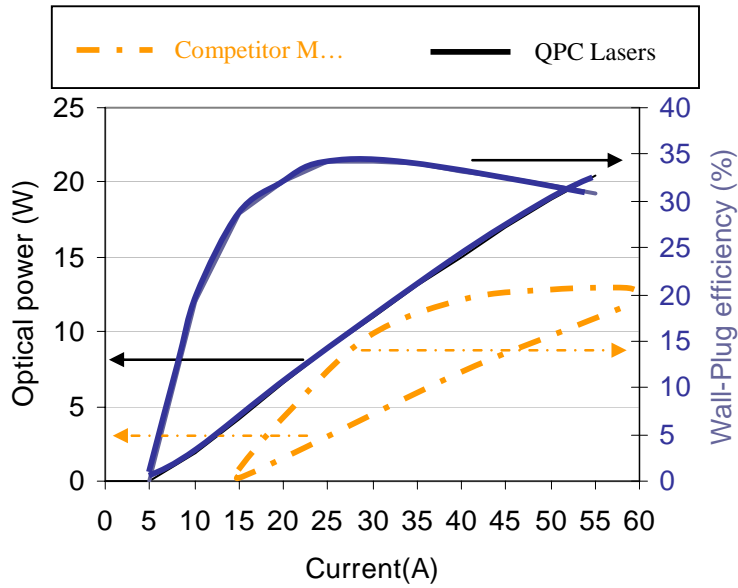


Fig.1: Typical efficiency of QPC's 19 emitter 1470nm 20W CW bar conduction-cooled at 20C. Conversion efficiency of 30% is achieved at 20W CW. Efficiency from competitor M. is shown as reference (data shown at 25C obtained from competitor's website).

Recently, a study on various waveguide designs enabled a significant improvement of slow axis divergence for high power laser diode bars.

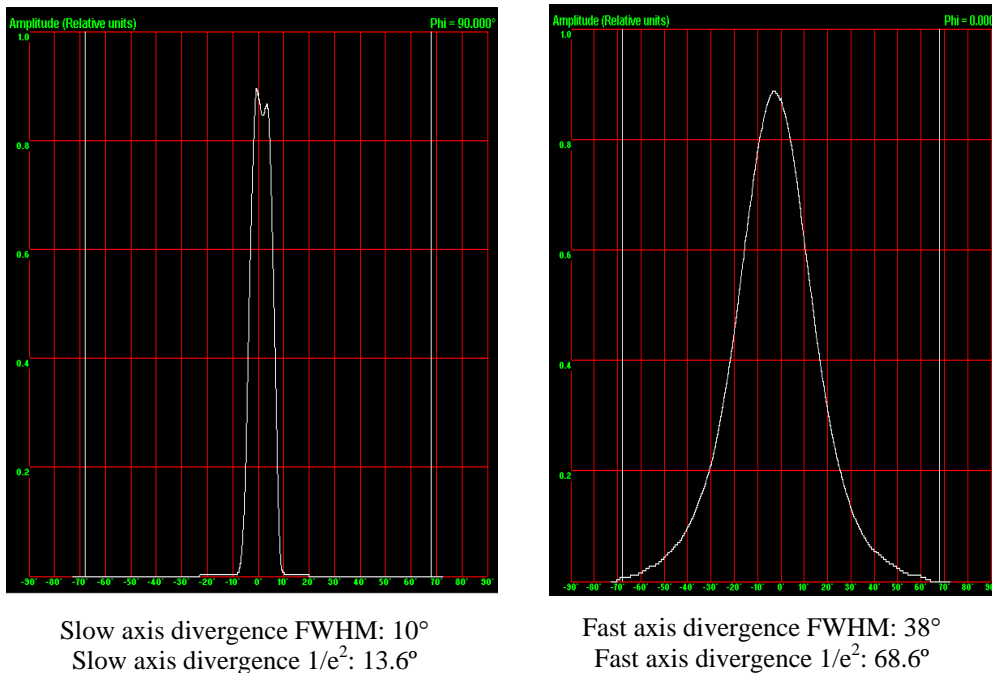


Figure 2: Far field divergence measured from a 100µm wide single emitter at 1470nm. The cavity length is 1.5mm. A 50% reduction of 1/e<sup>2</sup> slow axis divergence was obtained through optimization of the waveguide structure.

High power and high brightness laser diode bars at 13xxnm and 14xxnm have enabled QPC to break through the 100W CW level from a single 400µm core fiber. This is the highest power available from a fiber-coupled module at eyesafe wavelength. This level of brightness associated with compact, efficient direct diode modules facilitates deployment of applications such as LIDAR at 1550nm where lower Rayleigh scattering is observed.

A set of three 1470 nm Fabry-Perot single-bar arrays was tested at CW output power of 20 W per bar, as shown in Figure 3, below. Each array consisted of 19 100 µm wide stripes on 500 µm centers integrated onto a 1 cm wide bar, with cavity length of 1 mm.

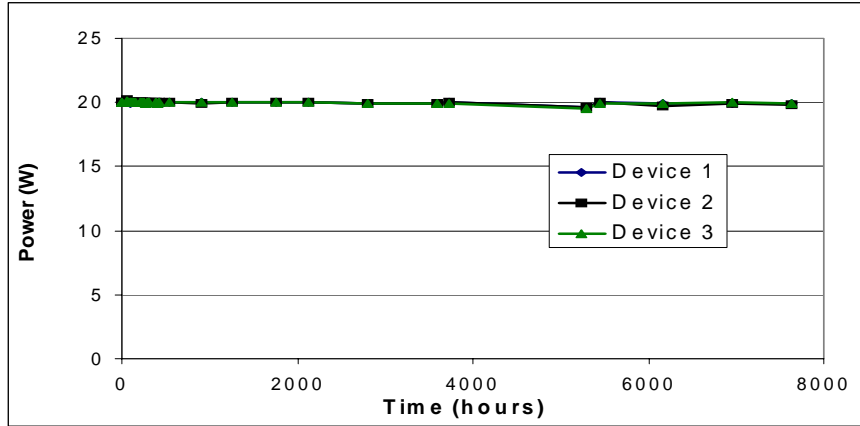


Figure 3: Lifetest trace of 20 W passively cooled 1470 nm arrays.

With close to 8000 hours of test time per device, there is no obvious degradation, either slow or sudden. The loss of even one of the 57 emitters under test would have led to the loss of roughly one watt and been easily resolved by the test system.

### 3. High power 1532nm laser diode bars with Brightlock™ on-chip wavelength stabilization

Many applications for diodes, such as pumping or spectroscopy, cannot tolerate the broad spectra of long wavelength Fabry-Perot diodes and require some form of spectrally-selective feedback to narrow and control the spectrum. A well-known technique utilizes external volume Bragg gratings in the output beam path, but aside from the considerable increase in cost and complexity, there are well known issues with spectral locking efficiency, locking range and optical absorption.

Brightlock™ lasers incorporate planar internal gratings into the epitaxial structure of the laser, and provide the necessary spectrally selective feedback without external components, providing advantages in both performance and manufacturability. Figure 4 below shows a 100W 1532 nm multi-bar fiber-coupled module with spectral width less than 1.2 nm; by comparison, a similar Fabry-Perot module would have been 10 nm or wider.

	Spectral brightness	Athermal operation	Pump efficiency	System Efficiency	Locking range vs current, T	Tunability	Wafer-scale Manufacturing
Flashlamp pumping		●●●●●	●	●			
Traditional diode pumping	●	●	●●●●●	●●●		●●●●●	●●●●●
VBG-stabilized diode pumping	●●●●●	●●●●●	●●●	●●●	●●	●	●
Brightlock diode pumping	●●●●●	●●●●●	●●●	●●●	●●●	●●●●●	●●●●●

Table 1: Feature comparison between various solid state laser pumping methods.

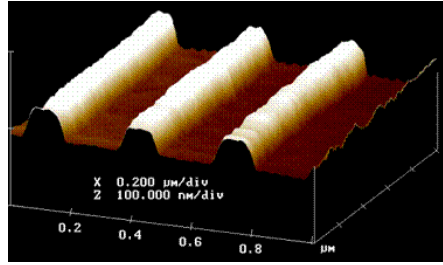


Figure 4: Atomic Force Microscope (AFM) picture of a grating measured on a 1532nm laser chip. The on-chip Brightlock technology enables low cost wafer-scale manufacturing and consistent performance.

The 1532nm Brightlock bars exhibit very high spectral brightness and low far field divergence as shown in figure 4 which enable efficient lensing and coupling into small core fibers.

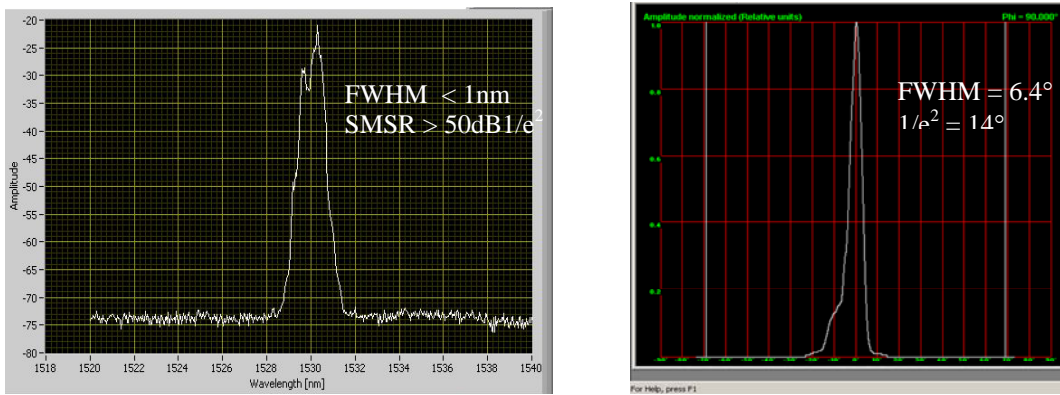


Figure 5: Spectrum on logarithmic scale (left) and slow axis far-field divergence (right) of a typical high power 20W CW conduction-cooled 1532nm Brightlock bar.

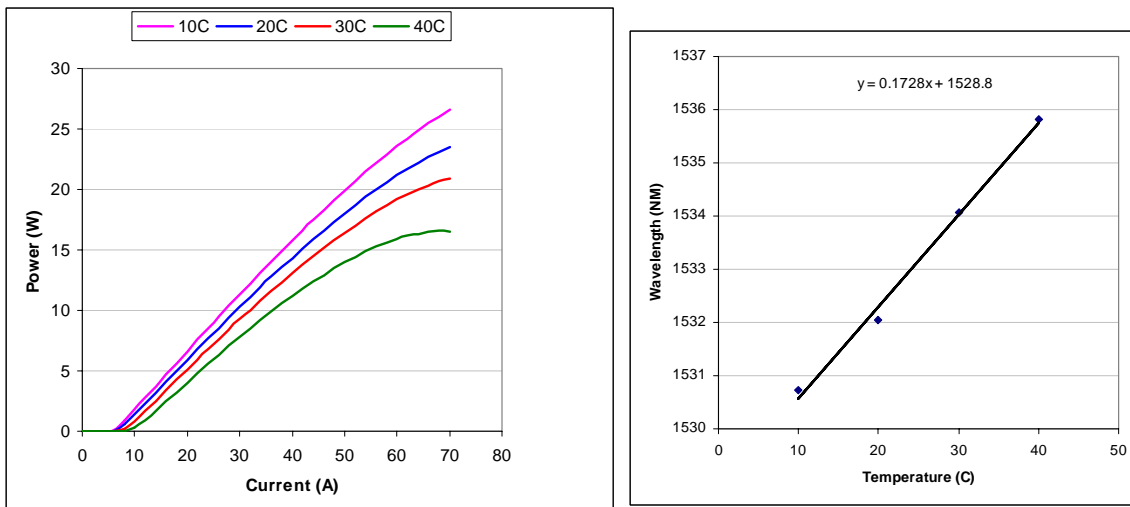


Figure 6: Power and center wavelength from 10 to 40C for a 19 emitter CS-mounted bar at 1532nm.

QPC has developed high power fiber coupled modules at 1532 nm with internal grating based on conduction cooled bars. Figures 7 below show the power versus current of a 1532 nm fiber coupled module with 400 micron, 0.22 NA output operating at 100 Watts at ~50 A. The output spectrum exhibits a spectral width less than 1.2 nm wide, roughly 5-10 times narrower than a similar Fabry-Perot without an internal grating.

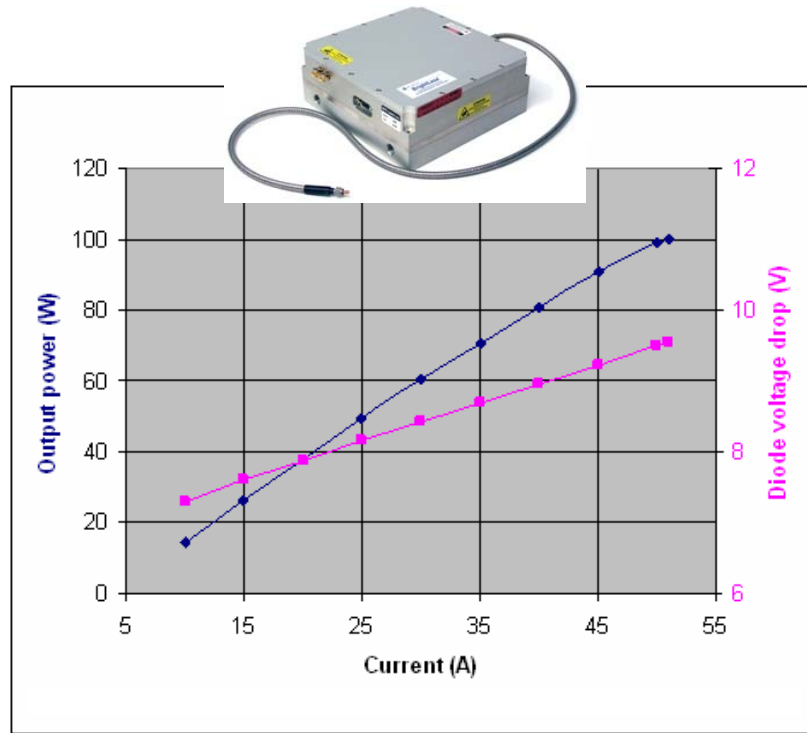


Figure 7: LIV of a 100W, 1532 nm diode laser module with internal grating stabilization

Unlike wavelength stabilization by Volume Bragg Gratings, on-chip internal gratings also enable standard lensing of micro-channel cooled stack arrays. High spectral brightness up to 1kW CW from a 35 bar stack has been demonstrated at 14xx nm.

#### 4. High spectral and spatial brightness from MOPA devices

QPC, with seed funding provided by the US Navy, is developing a new generation of pump modules that will enable high performance fiber lasers/amplifiers suitable for efficient beam combining. These modules, which are based on unique MOPA diode architectures, provide unprecedented pump spatial brightness and are suitable for fiber laser pumping. Moreover, they incorporate Brightlock internal diffraction-grating wavelength stabilization to maintain a narrow emission line centered on the absorption peak. Both of these factors enable short length, reduced nonlinearity fiber lasers and amplifiers.

QPC has recently demonstrated record power from MOPA devices at various wavelengths, with over 10W CW at 1064nm with a single spatial and longitudinal mode, and up to 700mW CW at 1550nm from a single mode fiber, with a linewidth measured at 500 kHz by Yariv's group. When used at pumping wavelength such as 1532nm, these devices will enable scaling of high spatial and spectral brightness resonant pumping to new levels.

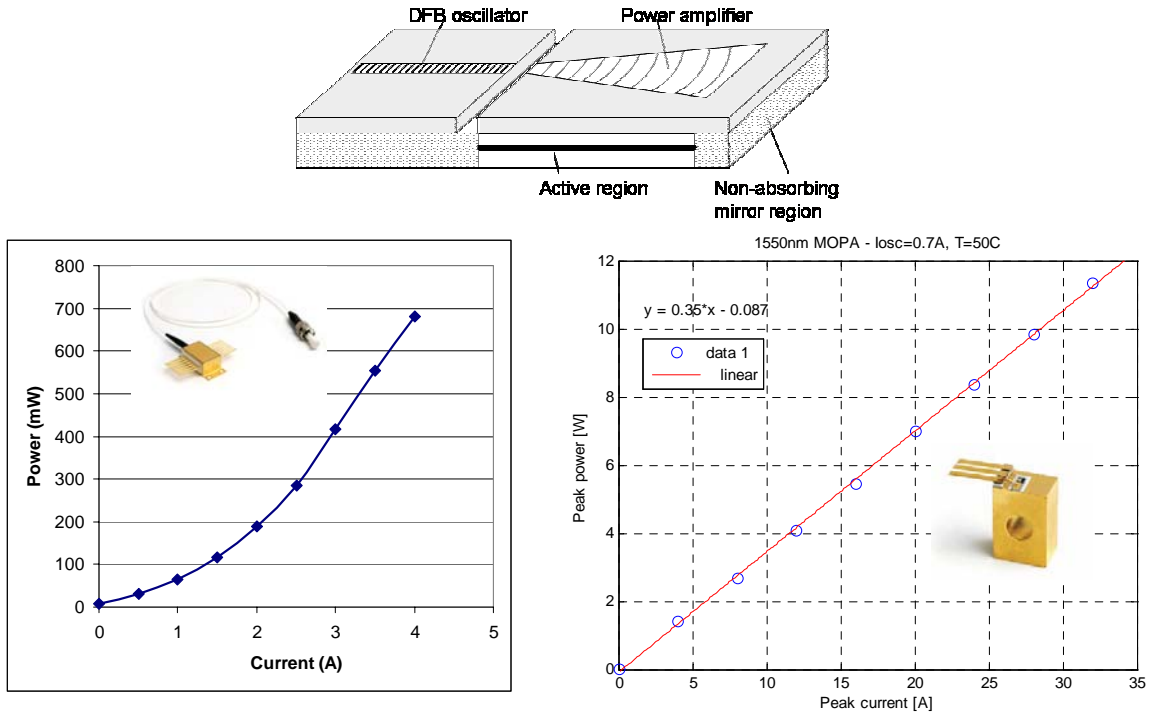


Figure 8: MOPA device at 1550nm produces 700mW CW out of a single mode fiber with a linewidth of 500 kHz (left). Peak power exceeding 10W with 50ns pulse width, 10kHz at 50C is obtained from a C-mounted device.

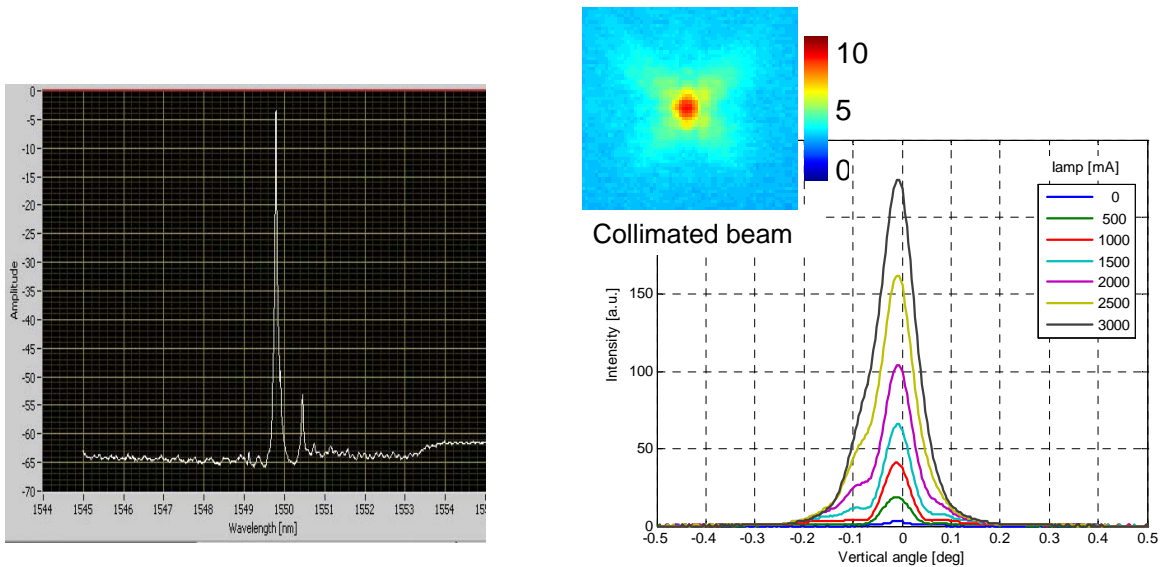


Figure 9: Single longitudinal spectrum from a 1550nm MOPA device (left). A picture of the collimated beam from the butterfly package before focusing optics is shown (right), producing about 1W CW in a linearly polarized high quality beam allowing longer range LIDAR and rangefinder applications.

Given the high spatial beam quality and watt level power achieved from individual MOPA device, it becomes possible to scale up power of fiber-coupled devices using “bar” and “stack” configurations to >150W from a 100 $\mu$ m, 0.15NA fiber. Indeed, the beam product of a 100 $\mu$ m 0.15NA fiber is 30mm•mrad; and the beam product of a 1550nm single

emitter with diffraction limited beam quality is about 2. In theory, one can therefore couple 225 such single emitters arranged in a 15 x 15 matrix into the fiber. However, one needs to consider heat dissipation, bar bonding issues and lens array dimensions, which practically limit the number of emitters per bar to 8 emitters. After FAC lens collimation, each bar is expected to output a ~0.9mm beam with <3mrad remaining divergence. The beams from 2 identical stacks can then be spatially interleaved to output 120W optical power from 80 emitters. Power can then be doubled through polarization combining without sacrificing spatial beam quality. Assuming a reasonable 70% overall optical coupling efficiency, 168W CW power can therefore be obtained from a 100um/0.15NA fiber.

## 5. Conclusions

Applications of eyesafe diode lasers have multiplied over the past few years. Improvement in epi design, growth process control and waveguide structure have enabled 35% efficient high brightness CS-bars with narrow far-field divergence at 1470nm. Such conduction-cooled bars are combined optically to provide 100W CW from a 400um/0.22NA fiber or the first time. High spectral brightness from a CS-bar is also demonstrated using Brightlock on-chip wavelength stabilization, scaling up CW power to kW level from a single micro-channeled cooled stack with <2nm FWHM spectrum with small power penalty of a few percent versus non stabilized arrays. Finally, MOPA devices scale brightness by two orders of magnitude, achieving >700mW CW from a single mode fiber at a single wavelength and polarization, enabling designs that will scale power to levels greater than 150W CW from a 100um/0.15NA fiber.

## ACKNOWLEDGEMENTS

Part of this work was supported by the Naval Air Warfare Center Weapons Division under Contract Number N68936-040C-0028, DARPA ADHELs program, and by the US Army CECOM under contract DAAB07-03-C-L415.