Overview on New Diode Lasers for Defense Applications

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ABSTRACT

Diode lasers have a broad wavelength range, from the visible to beyond 2.2µm. This allows for various applications in the defense sector, ranging from classic pumping of DPSSL in range finders or target designators, up to pumping directed energy weapons in the 50+ kW range. Also direct diode applications for illumination above 1.55µm, or direct IR countermeasures are of interest. Here an overview is given on some new wavelengths and applications which are recently under discussion. In this overview the following aspects are reviewed:

- High Power CW pumps at 808 / 880 / 940nm
- Pumps for DPAL – Diode Pumped Alkali Lasers
- High Power Diode Lasers in the range > 1.0 µm
- Scalable Mini-Bar concept for high brightness fiber coupled modules
- The Light Weight Fiber Coupled module based on the Mini-Bar concept

Overall, High Power Diode Lasers offer many ways to be used in new applications in the defense market.

Keywords: DILAS , diode laser, defense applications, high power

1. INTRODUCTION

As some of the earliest lasers around, semiconductor lasers gained strong interest because of their small size and high efficiency. Especially, in defense and avionics applications these are two key requirements on high-power diode laser based light sources. Starting being used in applications such as target designators, rangefinders, illuminators and infrared countermeasures (IRCM), today's usage of high-power diode lasers go far beyond the applications mentioned above. The wish for directed energy laser weapons brings up the need to concentrate the electro-optical design on a final goal for the weight per output power of < 5 kg/kW. With target output powers of 150kW and more, plus the drivers and cooling, this results in devices >1000kg. Section 2 and 3 will cover recent achievements in terms of power per diode laser bar.
High power diode lasers with wavelengths between 1µm and 2µm are covered in section 4, allowing illumination at 1460-1550nm, or even in the range of 1940-2200µm.
A new concept of fiber-coupled high power diode laser devices for fiber laser pumping is described in section 5, based on designing chip structures optimized for fiber coupling, together with precision mounting in automated optical assembly processes.

2. HIGH POWER CW PUMPS AT 808 / 880 / 940nm

The programs for the development of DPSS Lasers in the 50+ to 100kW range, based on disk, rod, slab or zig-zag configurations, require very high-power pump modules based on wavelengths suitable for Nd3+ or Yb3+ pumping. Since the opto-mechanical design of such lasers, together with the mentioned weight constraints, does not allow to use very large laser diode stacks, ideally the output power per cm² of the aperture is increased. Results shown are based on soft soldered laser diode bars, which are used for vertical bar-to-bar pitch reduction, in this case to 1.8mm, together with high power operation up to 190W per bar. Vertical stacks based on up to 29 of such 50% fill factor bars, result in optical output powers of up to 5kW/Stack. These results are shown in Figure 1.

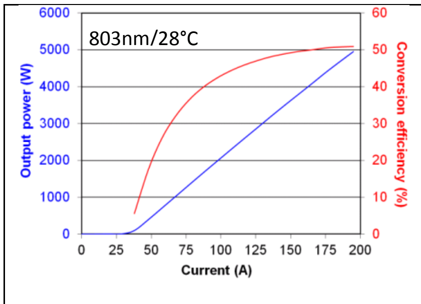

Fig. 1a: 803nm 29-bar stack at28°C

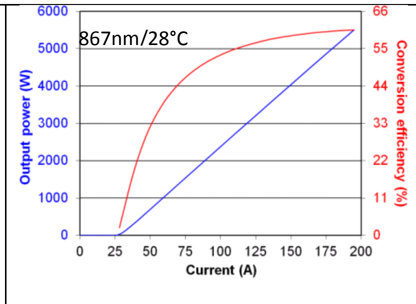

Fig. 1b: 867nm 29-bar stack at 28°C

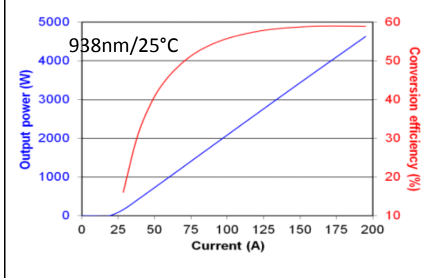

Fig. 1c: 938nm 25-bar stack at 25°C

Fig. 1: P-I-E curves for high power diode laser stacks, corresponding to power levels of up to 190W CW per bar.

The table summarizes the results of these stacks together with data on the spectral width and the fast axis divergence after lensing, using a spherical cylindrical lenses (FAC).

Wavelength (nm)	**Peak efficiency**	**Power @ peak efficiency (W)**	**Max tested power (W)**	**Max power per bar (W)**	**Spectral width (90% power)**	**FA divergence (mrad, 90% power)**
802	50.6% at 28°C	4956	4956	171	4.5	11
867	60.5% at 28°C	5506	5506	190	4.3	10
940	59.0% at 25°C	4365	4628	185	5.0	3

With such high-power laser bars various concepts for DPSS lasers can be realized based on stack-pumping of either disk, rod, slab or zig-zag configurations. The wavelength variety allows also testing of different host materials and active dopants.

3. PUMPS FOR DPAL – DIODE PUMPED ALKALI LASERS

To overcome the limitations of DPSS Lasers at the 50+ kW level in terms of thermal management, an alternative way was proposed, based on the diode pumping of alkali vapor lasers (DPAL). Such gaseous media does not suffer from the thermal management issues like DPSS lasers and may give a route beyond 100+ kW lasers for the use in missile defense applications. Since gaseous media are relatively free of spectral broadening due to the lack of crystal fields as in solid state materials, the absorption lines of such gaseous media are pretty narrow. The situation improves by using inert buffer gas at high pressure to get some spectral broadening. Nonetheless, the advantages in thermal management are being made on the cost that the high-power diode lasers have to be forced onto narrow line width operation by external feedback using so called Volume Bragg Gratings (VBG) or Volume Holographic Gratings (VHG).
The lower pump power will be partly compensated by the lower quantum defect when pumping the alkali vapors. Results for the important wavelength range for pumping of Cesium (852nm), Rubidium (780nm), Potassium (766nm) and even Lithium (670nm) are shown in Figure 2a-d, yet without spectral line narrowing.

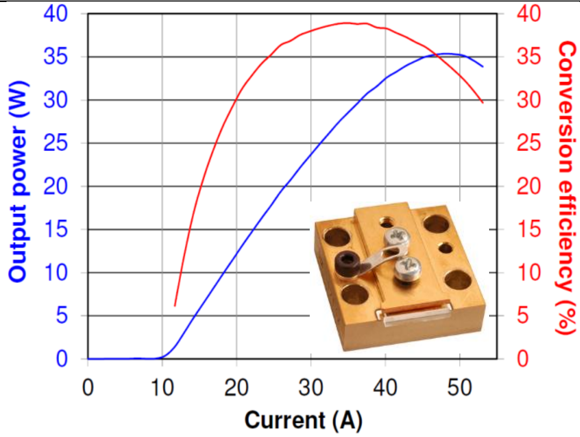

Fig. 2a: 670nm data for Lithium (Li) pumping, at 20°C, based on conduction cooled heatsinks

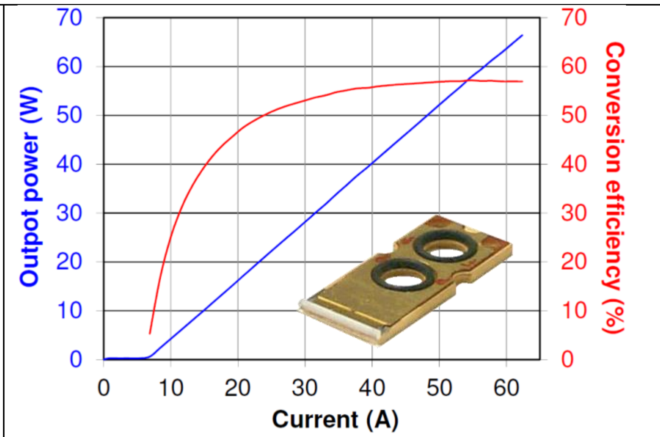

Fig. 2b: 766nm data for Potassium (K) pumping, at 20°C, based on micro-channel cooled heatsinks

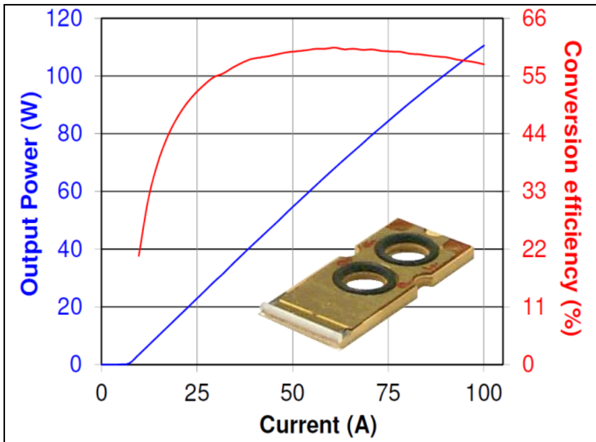

Fig. 2c: 780nm data for Rubidium (Rb) pumping, at 20°C, based on micro-channel cooled heatsinks

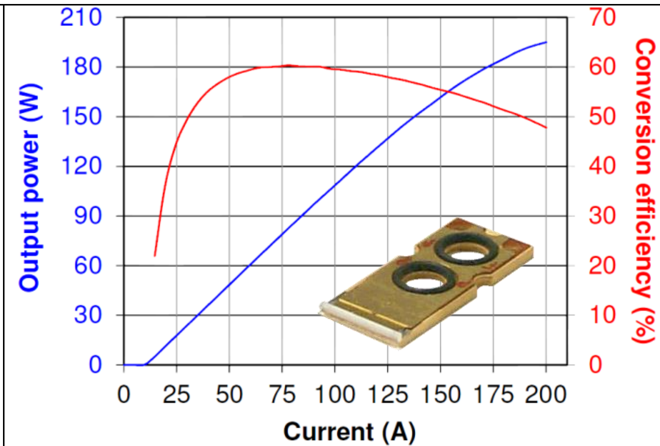

Fig. 2d: 852nm data for Cesium (CS) pumping, at 20°C, based on micro-channel cooled heatsinks, 30% FF bar

All results in Figure 2 are based on low fill factor bars with an emitter pitch of 500µm. 20%FF for 670nm, 766nm and 780nm, and 30%FF bar for 852nm. As 670nm material is based on a different material composition (InGaAsP), the lower power performance is expected. All other wavelengths are based on AlGaAs structures.

These low fill factor bars enable the lensing with FAC and SAC (slow axis collimator), to enhance optical feedback when VBG's are used.

4. HIGH POWER DIODE LASERS IN THE RANGE > 1.0µm

In the range above 1µm, some important diode laser wavelengths are now available with high power. Results are shown for fiber-coupled modules in the range of 1470nm, 1532nm and 1910nm for pumping applications, as well as high power QCW stacks at 1550nm for illumination purposes.

Figure 3 shows the P-I curves (ex fiber) and spectra of three conduction cooled CW bars, with three different wavelength (1470nm, 1520nm and 1550nm), which are integrated in one fiber-coupled module. Each wavelength can be addressed separately, hence allowing different wavelength and wavelengths mixtures propagating along the fiber. Such multi-wavelength modules can be used for illumination or counter-measures e.g. other wavelength mixtures have also been realized such as 980nm/1470nm, or 808nm/980nm.

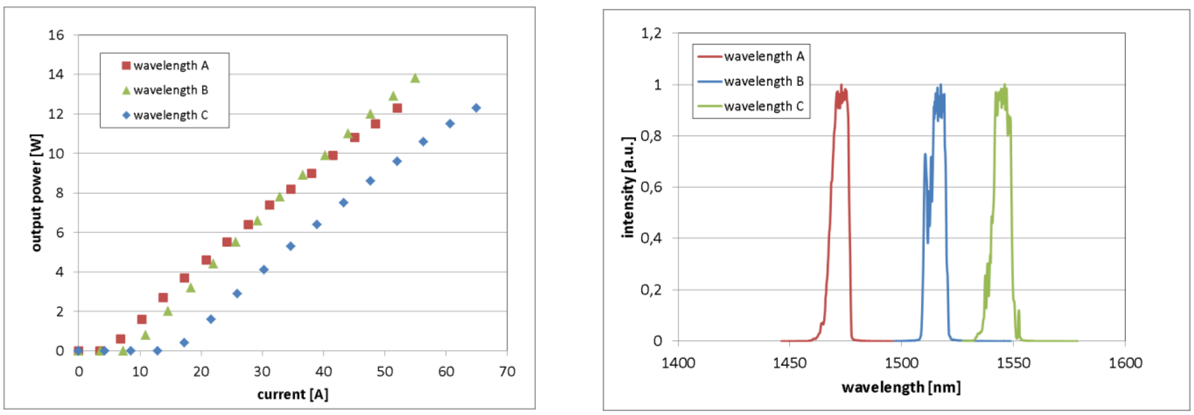

Fig.3.: individual P-I-curves and spectra for the three bars combined in a single fiber output of 400µm, NA0.22

The results for a six-bar based, conduction cooled fiber-coupled module used for pumping Er3+-Lasers at 1532nm is shown in Figure 4. The narrow line of <0.5nm FWHM is based on the use of VBG's. Internally each bar is collimated and has a VBG. The beams of the six bars are combined using spatial and polarization multiplexing.

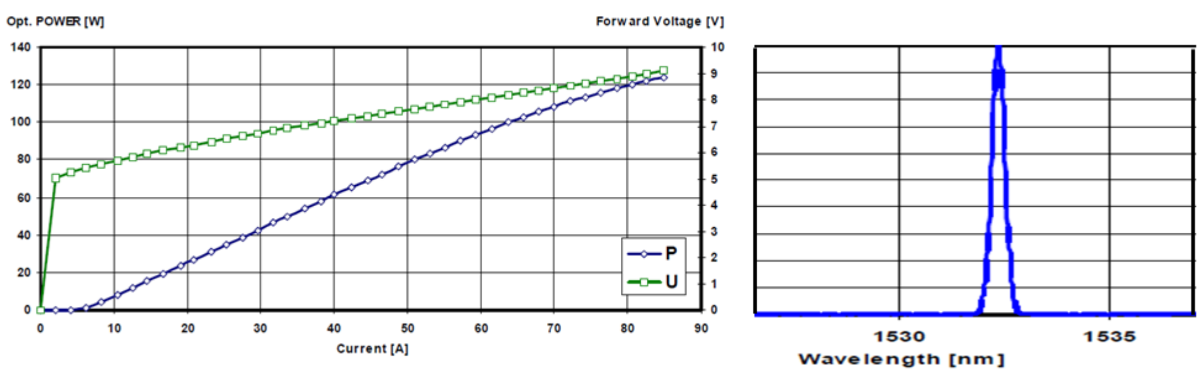

Fig. 4.: spectrally line narrowed, fiber-coupled module (400µm, NA0.22), based on six conduction cooled bars at 1532nm, □□ < 0.5nm FWHM.

For some gated imaging applications 1550nm laser diodes can be used in pulsed mode. A conduction cooled 20-bar-stack with 1.6mm vertical pitch suitable for fast axis lensing is displayed in figure 5. Since here still a low fill factor bar was used, also slow axis lensing is possible.

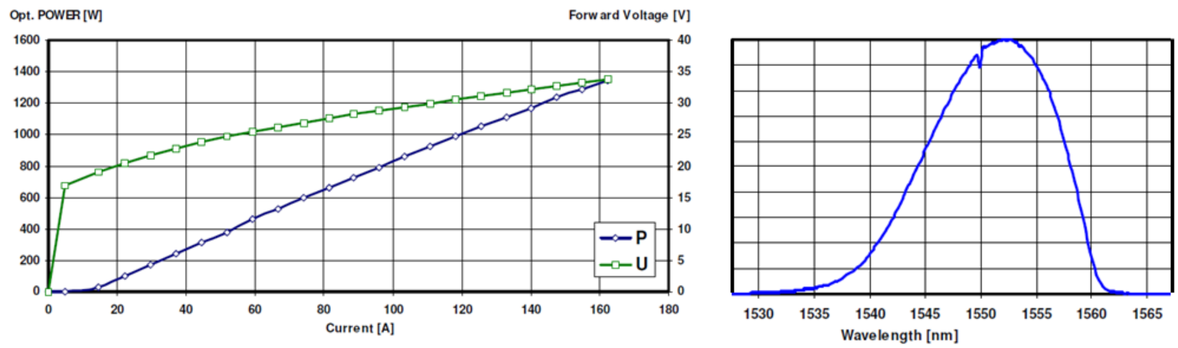

Fig. 5: results are shown for a QCW, conduction cooled 20-bar stack at 1550nm, operating at 70W peak power per bar (1%dc, 60Hz)

Also of interest are high-power diode sources in the 1910-2000nm range for direct or pumping application. The example below illustrates a fast axis collimated 10-bar stack, based on micro-channel cooled heatsinks. Externally wavelength are stabilized, such stacks have been used to pump Ho3+:YAG

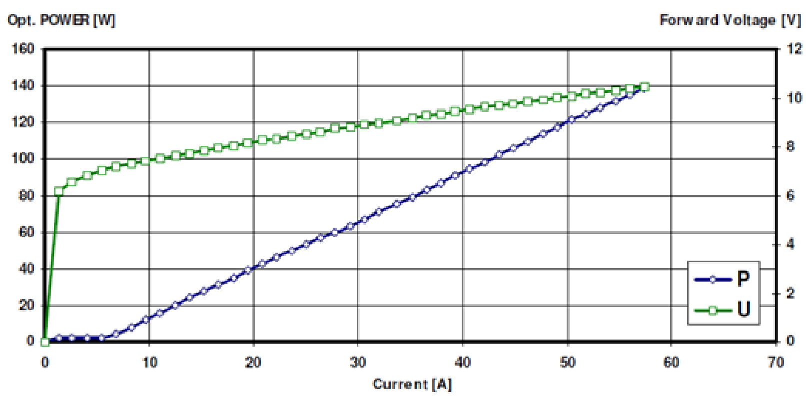

Fig. 6: PUI-curve of a 10-bar, 150W micro-channel cooled CW stack, operating at 1920nm, at 20°C, WPE of >22%.

5. SCALABLE MINI BAR CONCEPT FOR HIGHT BRIGHTNESS FIBER-COUPLED MODULES

Through the development of specialized chip structures, specifically designed and optimized for the use in pump modules of fiber lasers, laser diode bars are used in automated production and fiber-coupling, whilst achieving a reduced thermal influence on neighboring emitters.

Traditionally, a diode laser bar can be described as an arrangement (array) of lithographically defined laser emitters on a very thin, epitaxial grown layer. This chip usually has a width of 10mm and a resonator cavity of the emitters of 1mm, which is approximately one order of magnitude smaller than the array width.
In the first uses of high-power diode lasers, the available optical power was usually limited by the damage threshold (COMD = catastrophic optical mirror damage) of the optical mirror coating on the facet, which led to power scaling by widening the emitters and increasing their numbers. This leads to a higher optical beam divergence, caused by the wider emitters, and to a higher thermal influence on neighboring emitters, known as thermal crosstalk, ultimately leading to the loss of beam-shaping for each single emitter.
Further development in the field of optical facet coatings has led to much more robust mirrors, enabling power scaling by using greater resonator lengths and narrower emitters (lowering divergence) and greater distances between emitters (reducing thermal crosstalk). Such a diode laser bar has an almost square footprint, so the cavity length is in the range of the array width, whilst having a number of emitters only 25% of that of standard bars. This leads to an active volume which is comparable to that of standard bars, leading to a similar optical output power. In scientific literature, these bars are often called Mini-Bars, Super-Bars or “T-Bars” (tailored bars). The large gap between the emitters also allows for the use of easily manufactured SAC-lens arrays (SAC = slow axis collimation) for the collimation of all emitters. The reduced divergence, caused by the reduced emitter size, also makes fiber-coupling notably easier.
Automated hard-solder mounting techniques are already in use today for standard laser diode bars and are also implemented for the above-mentioned Mini-Bars. Due to the reduced width of these Mini-Bars, the flatness of the mounted bars (also known as smile) is greatly reduced when compared with a 10 mm wide diode laser bar. By virtue of this flatness, the subsequent optical alignment of FAC lenses (to collimate the divergence perpendicular to the mounting plane) and SAC lens arrays (to collimate each emitter in the mounting plane) is easier and can thus be automated.
A module has been realized based on a planar arrangement of 7 Mini-Bars and micro-optics for beam shaping. For fiber coupling all beams are taken out of the 2-D-plane and are coupled cladding free into a 200µm NA0.22 fiber. The compact size of the base module (130 x 65 x 39 [mm]) combined with the low weight of < 1 kg allows for a close arrangement of such modules (see Fig. 7). This makes it possible to use 12 pump modules, for example, to achieve a total pump power of 12 x 135 W = 1.620 W, which is sufficient to create a 1 kW fiber laser module for industrial applications as one can see in Figure 7. There is potential to further scale the power up to 200+ W per module. The level of integration requires cooling of the base plate with industrial water.

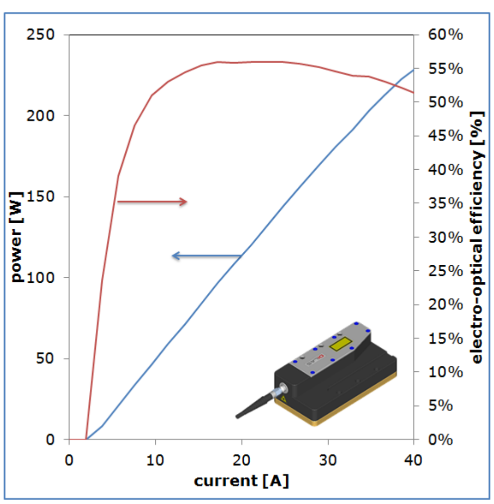

Fig.7: P-I-E diagram for a Mini-Bar based, fiber-coupled module, with 200µm, NA0.22. Also shown is an arrangement of such modules for use in fiber laser pumping.

6. THE LIGHT WEIGHT FIBER COUPLED MODULE BASED ON THE MINI BAR CONCEPT

Based on the Mini-Bar concept, we also demonstrate a very lightweight version, suitable for portable applications. By the use of lightweight material, as well as optimizing designs a very compact module with the size of 87 x 65 x 45 mm^3 has been realized and it offers a weight of <300g, at the same time delivering 300W out of a 200µm, NA0.22 fiber. These weight -size advantages, together with its high electro-optical efficiency of up to 50%, is making it a suitable tool for portable operations. Cooling is still achieved by industrial water. Results are shown in Figure 8, together with a sketch of the module.

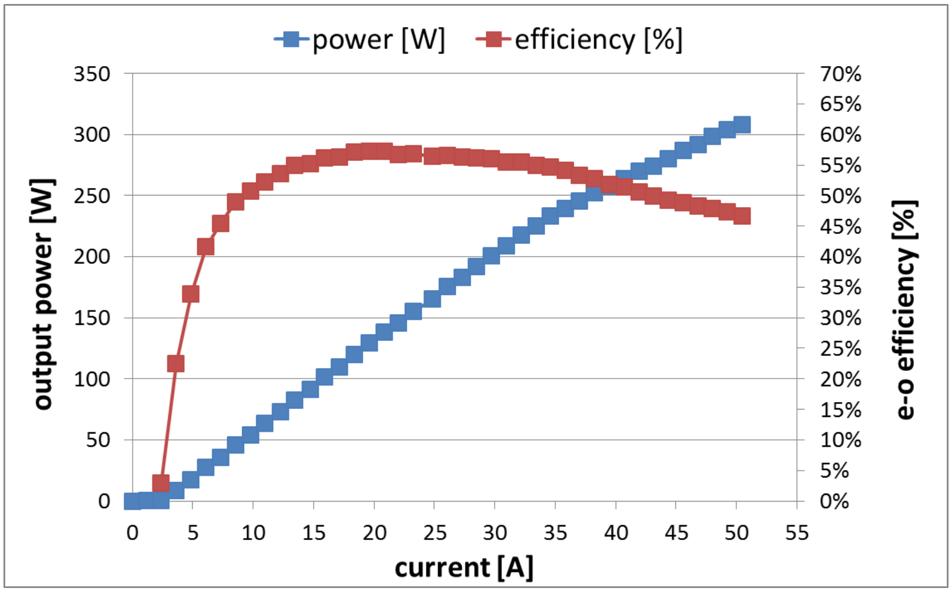

Fig. 8: P-I-E diagram for the light-weight module.

The basic data achieved are

- 308W @ 50.5A with WPE of 47%
  (200W @ 29.7A with WPE of 56%)
- 200µm core, NA0.22, mode-strip fiber
- center wavelength 975.7nm @ 49 A and 20°C
- spectral width Δλ = 4.7 nm (90%)
- weight: 278g
- power/weight ratio: > 1 kW / kg

The high output power is achieved by increased operating current, hence compromising on the lifetime of the module, which for defense applications is far more relaxed than for industrial applications.

7. SUMMARY

We have shown a variety of applications for high-power diode lasers, which are either at well-known wavelengths, but operated under high current conditions to suit the needs of pumping 100 kW class solid state lasers.
For scalable fiber laser pumping a new module based on Mini-Bars, suitable for industrial applications has been described, as well as a version which by reducing weight and increasing performance, is adapted for the use of defense applications.
Also shown are high-power results on not so common wavelength, now under consideration for diode pumped alkali lasers (DPAL), as well a variety of >1µm wavelength for applications in illumination or rare-earth-ion-pumping.

ACKNOWLEDGEMENTS

The data shown here represent a summary of the work done by many engineers and production personnel at various DILAS sites, who contributed their results and work to this overview. The support of various governmental projects (see notes in the references) is also gratefully acknowledged.

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