High Power Diode Lasers for Industrial Applications

New wavelengths, high brightness and increasing reliability are breaking new ground for diode lasers. The higher brightness allows direct fiber coupling of several 100 W in 200 µm and 400 µm fibers and therefore i.e. the pumping of fiber lasers. Such high power fiber coupled laser diodes combined with fast beam deflection units (galvo scanners) have been implemented in industrial processes and used for quasi-simultaneous welding of polymers, heat treatment in the sub millimeter range or selective soldering in solar cell production. Besides pumping of solid state lasers, high power diode lasers become more and more a competitive tool for many applications in material processing.

Reliability

High power diode lasers mainly consist of a diode laser bar, a heat sink on which the bar is mounted and some micro optics. Most important for a proper function of the laser diode is an effective heat removal by the heat sink. In most laser systems two different types of heat sinks are used.

1. Micro-channel heat sinks with DI-water cooling

DI (de-ionized) water cooled micro-channel heat sinks have the most effective heat removal and can therefore operate on a high power level. Manufacturing very compact multi kilowatt laser modules by stacking the laser diodes is a big advantage for this technology.
On the other hand the cooling circuit has to fulfill high demands for water quality. Purity, conductivity, flow rate and temperature need to be set within a certain range to guarantee a maximum lifetime. For industrial production regular maintenance and stocking of consumables like particle filters and DI-cartridges has to be taken into account. But even with perfect water conditions the flow inside the micro channels causes wear and therefore the lifetime of a laser diode is in most cases limited by the lifetime of heat sink.

2. Massive copper heat sinks for conduction cooling

Conduction cooled diode modules combined with thermal electrical chillers (TEC) don't need any water at all. For higher laser power the TEC gets less efficient and has to be replaced by a water cooled plate. Compared to micro channel heat sinks the heat removal and therefore the maximum laser power is limited. Direct stacking of conduction cooled diodes is not possible.

The demands for the cooling circuit and the integration of a conduction cooled laser diode into a turn-key system are low. The temperature of the diode is measured inside the heat sink. Additional flow or temperature sensors are not needed. The lifetime is mainly limited by the semiconductor material because the heat sink is free of wear. Conduction cooled diodes are mostly used for fiber coupling where the size of the laser module is not as important as for direct beam applications.
But for some customized solutions it can be advantageous to use the direct beam. Figure 1 shows a laser module which is used for simultaneous welding of 10 welding spots. Four of these modules are integrated in a production line for syringes. The module consists of 10 conduction cooled laser diodes mounted on a common water cooled plate. [1]
Besides all other aspects reliability and availability are most important issues for production. During the last years diode lasers improved to fulfill the demands of industrial standards. Micro-channel and conduction cooled diodes both show lifetimes of more than 14,000 hours cw operation (compare Figure 2) and 16 million cycles in pulsed mode (compare Figure 3) with minimal degradation. By extrapolating these data the estimated chip lifetime is more than 40,000 hours. Depending on the operating condi-

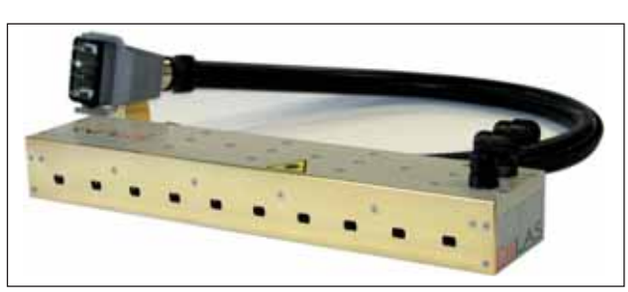

FIGURE 1: **Customized laser module for simultaneous spot welding.**

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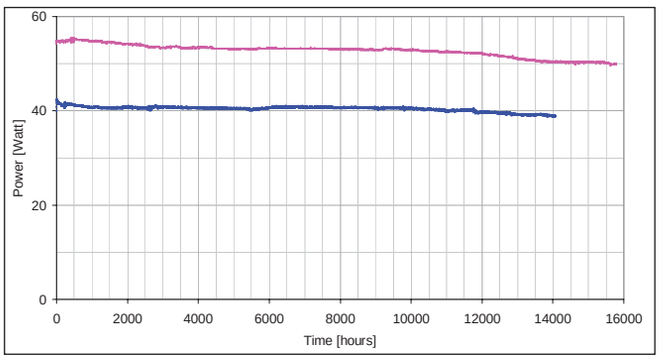

FIGURE 2: **Lifetime tests with DI-water (pink) and conduction cooled (blue) single diode laser bars in cw operation.**

tions, such diode lasers have already proven to run for several years in production.

Higher Output Power and New Wavelength

New semiconductor material delivers more laser power per bar. InGaAlAs based chip material with emission at a wavelength of 808 nm has shown up to 120 W laser power. Compared with diodes used today the efficiency increased from about 55 percent (60 W output power) to more than 62 percent (100 W output power) [2].

With InGaAs based semiconductor material at 940 nm optical power of up to 170 W can be achieved. Such highly efficient chips allow the increase of output power of diode stacks and modules without any other design changes. The ongoing lifetime tests show promising results.

With the good beam quality available, the laser radiation can be coupled into 200 µm and 400 µm fibers. Fiber coupled diode lasers are not only used for materials processing but also for pumping of solid state lasers and especially for fiber lasers.

With higher laser power also for non-standard wavelengths a large number of different applications can be addressed (table 1). Just to mention InGaAs on InP substrates for wavelengths > 1300 nm and (AlGaIn)(AsSb) on GaSb substrates for wavelengths > 1800 nm. In these wavelength ranges, high power means 10…20 W per laser diode bar.

Examples are direct medical or aesthetic applications like photodynamic therapy and hair removal. Printing industry and defence technology take also advantage of dedicated wavelengths. Table 1 gives an overview about typical application for different wavelengths.

New Applications Arising

Several years ago most integrators used direct diode lasers in their production lines. With increasing beam quality, the coupling into smaller fiber diameters with higher laser power opened new options for material processing. Due to the advantages for industrial production most of the systems today are equipped with fiber coupled diode lasers. Even if the laser module needs to be exchanged, an easy on-site replacement can be done within a short time. The possibility of a plug and play diode exchange is increasing the availability of the laser system for production. Because of the independence of laser source and processing head new teaching of the process is not necessary: the processing head stays inside the laser cell. Using conduction cooled diode laser modules the system can run nearly maintenance free. No complex and costly cooling unit is needed. Up to 100 W laser output can be generated using an air cooled Peltier-chiller without any water.

A turn-key diode laser system features the laser module and all its supply and control units in a 19" rack mountable chassis. The set up gets completed by a fiber, beam shaping and/or focusing optics with complementary features for processing control and surveillance. For example the integrated pyrometer has been established as a helpful tool

THE COMPANY

DILAS Diodenlaser GmbH

With operations in Mainz, Germany and Tucson, AZ, DILAS is the diode laser company delivering the most innovative technology and advanced products to the industrial, defence, graphic arts, and medical markets. Founded in 1994, DILAS designs, develops and manufacturers high power semiconductor lasers components, modules and systems, including fiber coupled products.

For more information about DILAS, visit our website at www.DILAS.com.

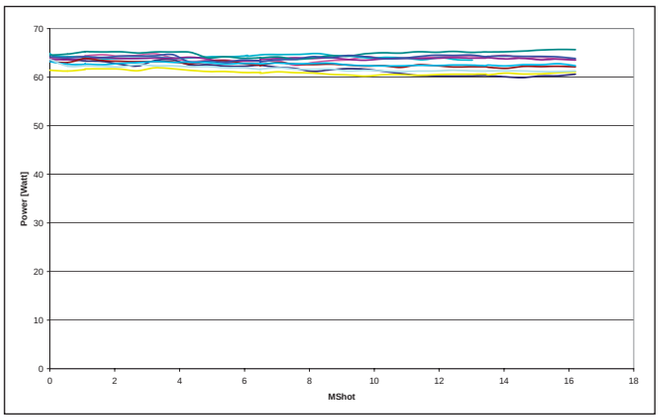

FIGURE 3: **Lifetime tests with single diode laser bars in pulsed operation (1,5 Hz with 50% duty cycle from 0 to nominal power).**

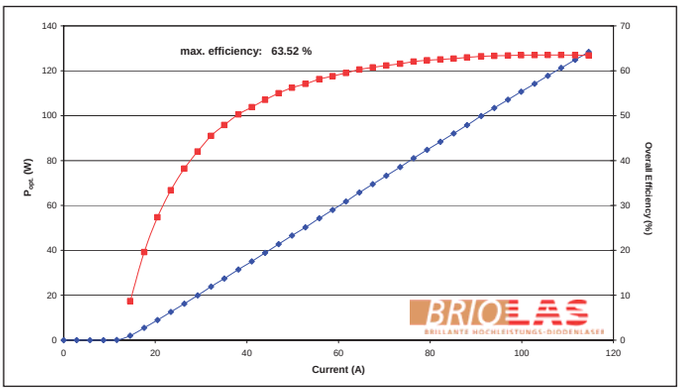

FIGURE 4: **Lifetime tests with high output power (micro channel heat sink).**

for many applications. Turn key systems become more compact and easy to integrate. Figure 5 shows the new DILAS turn key diode laser system family: The COMPACT series which fulfils all demands of a state-of-the-art production tool. It will be introduced on the LASER 2007 show in Munich and completes the DILAS product range, starting from single bars up to full featured, stand alone laser systems.

The main applications in materials processing in the power range up to several hundred Watts are soldering and polymer welding. Especially in polymer welding the diode laser has technical advantages compared with other laser types and technologies like ultrasonic welding. For typical widths of the welding seams of more than 1 mm the homogeneous energy distribution in the focal plane with a big laser spot, compared with other lasers, leads to excellent results. The usage of galvo scanners makes the highly flexible diode lasers even more flexible and allows quasi simultaneous welding of closed contours often needed for sealing all types of housings used in medical device manufacturing and automotive production. As part of the ROFIN group, DILAS can offer galvo solutions with an advanced software package used for marking systems and world wide support.

High power diode laser are also used as a flexible and precise tool in solar cell manufacturing. Most silicon solar cells are interconnected with pretinned copper ribbons to strings by conventional soldering. The soldered strings are then laminated into modules. The handling of these long and fragile strings is difficult and needs complex equipment. Using In-Laminate Laser Soldering (ILLS) technique developed by the Institute for Solar Energy Research Hameln (IFSH) the very thin solar cells are interconnected to a module by placing cell and ribbon on their final position onto the laminate. The laser beam is soldering cell with ribbon and the handling of the strings can be avoided completely.
The achieved electrical contact resistance is below 0.1 m Ω cm^2 and the peel forces exceed 10N/cm. As known from electronic production the laser is well suited for the use of lead free solder. To increase the process stability the soldering is done with a closed loop temperature control. The pyrometer is integrated in the processing head and aligned in the optical path of the laser beam. Compared to standard soldering methods laser soldering is contactless and produces no mechanical stress. The localized heating minimizes the thermal stress for the solar cells which have a thickness below 200 µm. The ILLS technology allows producing thinner and therefore cheaper silicon wafers. [3]

FIGURE 5: **Turn key diode laser system for production: DILAS COMPACT.**

Summary and Outlook

Diode laser bars and modules have become a reliable and long living product. The conduction cooled diode lasers can be operated with a simple cooling device. New semiconductors allow high efficient fiber coupling in small fibers. All these attributes put the availability of diode laser systems in an industrial production chain on a very high level.
The joint research initiative BRIOLAS of the Federal Ministry of Education and Research (BMBF) in line with the actual research program "Optical Technologies for the 21st Century" is following the increasing demands from the market to improve brilliance and reliability of high power diode lasers. With new technologies the field of technically feasible and economically reasonable applications will be expanded [4].

Wavelength	Application	Industry
630 – 635 nm	Medical Photodynamic Therapy	Medical
652 nm	Medical Photodynamic Therapy	Medical
668 nm	Medical Photodynamic Therapy	Medical
670 nm	Cr^{3+}: LiSAF – fs-Laser	DPSSL
689 nm	age-related macular degeneration	Medical
730 nm	Medical Photodynamic Therapy	Medical
780 nm, $\Delta\lambda << 1$ nm	Diode Pumped Gas Laser (Rubidium Vapor)	Defense
785 nm	TM^{3+}: YAG => 2 µm	DPSSL
792 / 797 nm	Nd^{3+} : YLF	DPSSL
795 nm, $\Delta\lambda < 1$ nm	Rb^{3+} / Xe^{139}/ - pumping	Instrumentation
805 / 808 nm	Nd:YAG	DPSSL
810 ± 10 nm	hair removal, etc.	Medical, Material Processing
830 nm	Pre-Press, Computer to plate (CTP), Direct on press (DOP)	Printing
852 nm, $\Delta\lambda << 1$ nm	Diode Pumped Gas Laser (Caesium Vapor)	Defense
868 – 885 nm	Nd^{3+} : XXX (various host crystals)	DPSSL
901 nm	Yb^{3+} : SFAB	DPSSL
905 nm	Rangefinder direct	Instrumentation
915 nm	Yb: Glas, Fiber Laser, Medical	DPSSL, Medical
940 nm	Yb^{3+} : YAG, Disk	DPSSL
968 nm $\Delta\lambda < 1$ nm	Yb^{3+} : YAG, Disk	DPSSL
973 – 976 nm	Yb^{3+} : Glass, Fiber Laser	DPSSL
980 ± 10 nm	Medical	Medical Material Processing
1064 nm	Medical	Medical
1330 – 1380 nm	Medical	Medical
1450 – 1470 nm	Acne, Turbulence Detection Er $^{3+}$ pumping	Medical, various others
1530 nm	Rangefinder	Defense
1700 nm	Missile Defense	Defense
1850 nm	Turbulence Detection, Plastic welding	Defense, Material processing

TABLE 1: **Diode laser applications.**

Literature

[1] *Wolfgang Horn,* Flexible kundenspezifische Lösungen zum Kunststoffschweißen, 6. Workshop Anwendung von Hochleistungsdiodenlasern, Dresden, Germany, 2006

[2] New generation of laser bars in the starting blocks: World record efficiency for 808 nm achieved in the laboratory, http://www.briolas.de , April 2006

[3] *Maren Gast, Marc Köntges, Rolf Brendel,* In-Laminate Laser Soldering – A Gentle Method to assemble and interconnect silicon solar cells to modules, 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, 2006

[4] http://www.briolas.de, April 2006