HIGH POWER DIODE LASERS FOR INDUSTRIAL APPLICATIONS

Paper 502

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Abstract

New wavelengths, high brightness and increasing reliability are breaking new ground for diode lasers. The higher brightness allows direct fibre coupling of several 100 W in 200 µm and 400 µm fibres and therefore the pumping of fibre lasers. Such high power fibre 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 or selective soldering. But also as customized modules diode lasers offer competitive solutions for example in medical device manufacturing. Available as modules or as turn-key systems, featuring the laser module and all its supply and control units in one 19” rack mountable chassis, such devices become more compact and easy to integrate. New markets like solar modules production benefit from this technology.

The usage of conduction cooled laser diodes increases the typical lifetimes significantly. Life tests in pulsed and cw mode show over 16 Mega shots respectively over 14.000 h with minimal degradation. Depending on the operating conditions, such diode lasers have proven to run for several years in production nearly free of maintenance. 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 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 cooper 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 fibre coupling where the size of the laser module is not as important as for direct beam applications.

Fig 1: Air cooled turn-key diode laser in 19” chassis with integrated power supply and controller. The optical fiber exits on the backside.

Besides all other aspects reliability and availability are most important issues for production. During the last years diode lasers improved to fulfil the demands of industrial standards. Micro-channel and conduction cooled diodes both show lifetimes of more than 14.000 h cw operation and 16 million cycles in pulsed mode with minimal degradation. By extrapolating these data the estimated chip lifetime is more than 40.000 hours. Depending on the operating conditions, such diode lasers have already proven to run for several years in production.

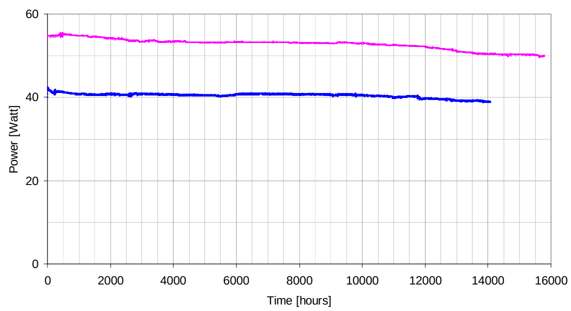

Fig 2: Life test at 40 W cw and 55W cw [3]

Higher Output Power and New Wavelength

New semiconductor material delivers more laser power per bar. InGaAlAs based chip material at a wavelength of 808nm has shown up to 120 W laser power. Compared with diodes used today the efficiency increased from about 55 % (60 W output power) to more than 62 % [1].

With InGaAs based semiconductor material at 940nm optical power of up to 170 W seems to be achievable [1]. Such highly efficient chips allow the increase of output power of diode stacks and modules without design changes. With high beam quality an efficient coupling into 200 µm and 400 µm fibres is possible [2]. Fibre coupled diode lasers are mainly used for materials processing (MP) are diode pumped solid state lasers (DPSSL).

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

Table 1: Laser power per bar and wavelength for different semiconductors [3]

Material / Wafer	λ [nm]	P/ bar [W]
InGaAlP / GaAs	630..690	> 5
InGaAlAs / GaAs	790..830	50 .. >100
InGaAs / GaAs	880..980	50 .. >100
InGaAs / GaAs	1060	~ 30..40
InGaAs /InP	1400..1550	~ 20
AlGaIn-AsSb / GaSb	1900..2100	~ 10

Examples are direct medical or aesthetic applications like photodynamic therapy and hair removal. Printing industry and defense technology take also advantage of dedicated wavelengths. Besides various medical applications diodes with 1470 nm – 1550 nm are a promising tool for polymer welding where laser transparent and laser absorbing parts need to have the same colour. First trials already showed auspicious results.

Table 2: Diode laser applications

λ [nm]	Application	Industry
630 – 635	Photodynamic Therapy	Medical
652	Photodynamic Therapy	Medical
668	Photodynamic Therapy	Medical
670	$Cr^{3+:}$ LiSAF – fs-Laser	DPSSL
689	age-related macular degeneration	Medical
730	Photodynamic Therapy	Medical
780, Δλ<<1	Diode Pumped Gas Laser (Rb Vapour)	Defense
785	$TM^{3+:}$ YAG => 2µm	DPSSL
792 / 797	Nd^{3+} : YLF	DPSSL
795,Δλ<1	Rb^{3+} / Xe^{139}/ -pumping	Instrumentation
805 / 808	Nd:YAG	DPSSL
810± 10	Hair removal, plastic welding, soldering	Medical, MP
830	Pre-Press, Computer to plate (CTP), Direct on press (DOP)	Printing
852, Δλ<<1	Diode Pumped Gas Laser (Cs- Vapour)	Defense
868 – 885	Nd^{3+} : XXX	DPSSL
901	Yb^{3+} : SFAB	DPSSL
905	Rangefinder direct	Instrumentation

λ [nm]	Application	Industry
915	Yb: Glass, Fiber Laser, Medical	DPSSL, Medical
940	Yb^{3+} : YAG, Disk	DPSSL
968, $\Delta\lambda<1$	Yb^{3+} : YAG, Disk	DPSSL
973 – 976	Yb^{3+} : Glass, Fibre Laser	DPSSL
980± 10	Medical, plastic welding, soldering	Medical MP
1064	Medical	Medical
1330–1380	Medical	Medical
1450 – 1470	Acne, Turbulence Detect., Er^{3+} pumping	Medical, MP various others
1530	Rangefinder	Defense
1700	Missile Defense	Defense
1850	Turbulence Detection, Plastic welding	Defense, MP

Polymer welding in Medical Device Manufacturing

Since several years polymer welding with lasers is a well know technology. Four different welding methods can be named depending on the relative movement between work piece and laser beam: contour, simultaneous, mask and quasi-simultaneous welding. Due to the increasing beam quality of the fibre coupled diode lasers and the availability of several hundred Watts laser power with fibre diameters $\leq$ 400 µm quasi-simultaneous welding with galvo scanners is gaining importance. If focus dimensions $\geq$ 1 mm are required the diode laser substitutes Nd:YAG lasers in more and more applications.

Beside these highly flexible solutions the modular design of diode lasers allows the implementation of customized solutions for simultaneous welding. The main disadvantage of this method is that any changes in the geometry of the parts are not possible. Especially the long-cycle products lifetime in medical device manufacturing ask less for flexible but for very stable solutions. The equipment has to be used in production for years with high reliability and low maintenance costs. Also the demands for quality welding and repetitive solutions with coloured polymers are rather high. Compared to the often used ultrasonic welding laser technology avoids pollution of the product and the often used clean room surrounding due to process emissions like dust.

Exemplarily the production of one-way needles for drug injectors is described. To join thread and needle carrier two welding spots or seams are needed. Both parts are made of polypropylene. The clear thread is transparent for laser radiation whereas the laser absorbing needle carrier is white coloured with titanium dioxide. To achieve a high production volume of several ten million parts per year the chassis carrying the parts are moved with more than 35 m/min. During the loading process the chassis is in rest for about 1s. Per cycle 20 parts have to be welded with 2 joints in 180 degree on the circumference.

Two Methods has been examined to fulfill the requirements: Passing the parts through a laser beam while moving the chassis and simultaneous welding of 40 spots with direct diode laser modules while loading the chassis. For simultaneous welding 10 diode lasers are mounted on a water cooled heat sink in an encapsulated housing. 2 rows with 2 modules get aligned to weld all parts with a single shot.

Fig. 3: Customized diode laser set up for simultaneous welding of 10 welding spots. Each laser module contains 10 conduction cooled laser diodes with maximum output power of 50 W each on a water-cooled heat sink.

The moving method achieves good results with a carrier speed up to 19 m/min. Exceeding this velocity the results were no longer reproducible. The simultaneous welding has a wide process window and beats the mechanical demands of minimum 50 N pull force for the welding joint by a factor of 3. The required laser power around 30 W per spot allows welding times of about 0.6 s. [4]

Laser Soldering in Photovoltaic Module Manufacturing

Lasers are already well established in solar cell production. Edge isolation with qs-Nd:YAG or qs-Nd:Vanadate lasers is used to obtain high efficiency solar cells. Reverse contacting and separating the silicon wafers by drilling and cutting are typical laser applications in solar cell production. All these technology have in common that pulsed lasers with high peak power and very good beam quality are used. High power diode lasers can't compete with these features but have advantages when compact beam sources for cw applications with spot sizes up to millimetres are needed.

In photovoltaic module (PV) manufacturing the solar cells get interconnected by joining cell and ribbons using soldering methods. Most common are non-contact technologies like induction-, hot air-, lamp or micro flame soldering. To get a high yield it is essential to minimize the thermal and mechanical stress for the cell and therefore tactile methods like soldering iron become less important. It is also necessary for the solder joints to exceed certain dimensions to get both good electrical contact and mechanical strength. The present trend in silicon solar cell production towards thinner (<200 µm) and therefore cheaper layers demands for gentle production methods to reduce wafer breakage during module manufacturing. [5]

Laser soldering with high power diode lasers has all properties for contacting thin film solar cells. The solder joints which can be achieved by using cw diode lasers have several square millimetres. Laser soldering is a non-contact technology with an accurate and locally limited thermal input. This limits the thermal stress for the cell. The high level of automation results in a very repetitive process. To increase the process stability a closed loop temperature control of the solder joint by pyrometer is also possible. The pyrometer is integrated in the processing head and aligned in the optical path of the laser beam.

Usually Si solar cells are interconnected to strings which then get laminated into the modules. This technology requires handling for the long and fragile strings with additional equipment. Using laser the string handling can be completely avoided by soldering directly through the laminate layers. The typical sequence for these modules is glass, polymerized Ethylene Vinyl Acetate (EVA), tinned ribbons, solar cell, tinned ribbons and transparent TEDLAR® back sheet. Front and rear side of the PV module are transparent for laser radiation. Soldering can be done either before or after lamination. This method is named In-Laminate Laser Soldering (ILLS).

Fig. 6: With In-Laminate Laser Soldering (ILLS) manufactured solar cell module

The contacts of the cell are evaporated metal stacks with 15 µm Al and 1-3 µm Ag. The ribbons are tin coated and have a typical thickness between 50 µm and 150 µm. Lead free ribbons (Sn96.5Ag3.5) could be soldered with the same parameters and comparable results as Sn60Pb40 coated ribbons.

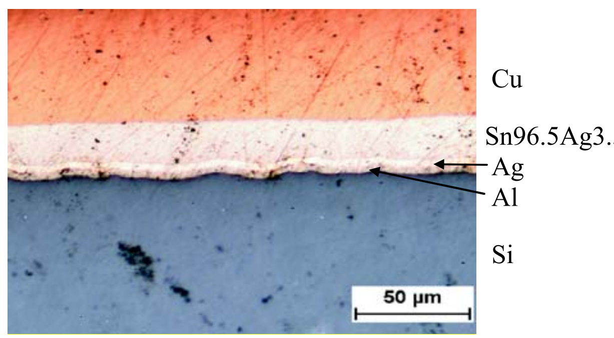

Fig. 7: Metallurgic prepared cross section of lead free copper ribbon on silicon wafer with Al(5µm)/Ag(5µm) stacks [5]

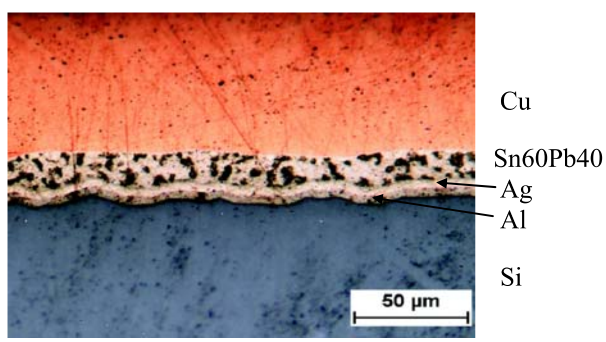

Fig. 8: Metallurgic prepared cross section of tinned copper ribbon on silicon wafer with Al(5µm)/Ag(5µm) stacks. The sinkholes in the solder layer are caused

from cross section preparation and not by the laser process itself [5]

The criteria for evaluating the soldering joints are peel force and contact resistance. The minimum peel force needed for handling the strings is 10 N/cm. This could be exceeded with an energy input between 20 and 40 J with a power density of about 5×10^3 W/cm^2. The maximum measured peel force was 30 N/cm. An energy input of more than 200 J destroys the ribbon. The contact resistance for laser soldered joints is about 0.1 mΩcm^2 which is only 14 % of a contact solder joint. [5]

Outlook

Diode laser bars and modules have become a reliable and long living product. Conduction cooled diode lasers can be operated with simple cooling devices. This will influence the development of new diode laser systems for industrial applications where additional featured for e.g. process control and easy integration in assembly lines become more important.

High-brightness fiber coupled diode lasers have the potential to offer technical and commercial solutions in applications which are now dominated by other technologies like for example lamp pumped Nd:YAG lasers. The availability of diode lasers with wavelengths > 1300 nm may offer new possibilities in polymer welding and medical applications.

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Meet the author

Wolfgang Horn, studied physics at TU Darmstadt (Germany). In 1995 he joined the German Welding Institute (SLV) Mannheim where he managed the process development department from 1997 - 2002. Since 2002 he is responsible for diode laser applications and systems at DILAS Diodenlaser GmbH.