Welding and Soldering with High Power Diode Lasers

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Abstract

The wide range of available wavelengths, high brightness and increasing reliability are breaking new ground for diode lasers. Material processing with high power diode lasers in industrial manufacturing is getting more and more important. In automotive, medical device and also solar cell production they are important tools for automated production. Closed-loop temperature control by integrated on-axis pyrometer and fast beam deflection units are established tools for flexible processes documentation and quality control. Depending on the operating conditions, diode lasers have proven to run for several years in production nearly free of maintenance.

High Power Diode Lasers

New semiconductor material delivers more laser power per bar. InGaAlAs based chip material at a wavelength of 808nm has shown up to 170 W laser power with an efficiency of more than 60 %. [1]
With InGaAs based semiconductor material at 940nm optical power of up to 200 W seems to be achievable. 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 fibers is possible [2]. Fiber coupled diode lasers are mainly used for materials processing (MP) and diode pumped solid state lasers (DPSSL). For industrial applications fibre coupled systems offer some significant advantages:

- Modular set-up for easy integration
- Separation between beam source and processing optics which allows plug & play exchange of the beam source during service
- Symmetric and homogeneous beam profile
- Customizing of beam size and shape at fiber end

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 with output power of 30 W. (AlGaIn)(AsSb) on GaSb substrates for >1800nm. In this wavelength range, high power means about 10-15 W per laser diode bar.
Diode lasers are highly efficient and allow fast and easy modulation of the power level. Compared to other laser types, diode lasers convert the supplied energy (current) directly and immediately into laser radiation. This, for example, allows closed-loop temperature control of a welding process by using a pyrometer. The pyrometer is detecting the thermal radiation caused by the welding process and calculates the temperature of the welding spot (Figure 1). The pyrometer can be integrated into the processing head so that laser and pyrometer detector are coaxial and have the same field of view.

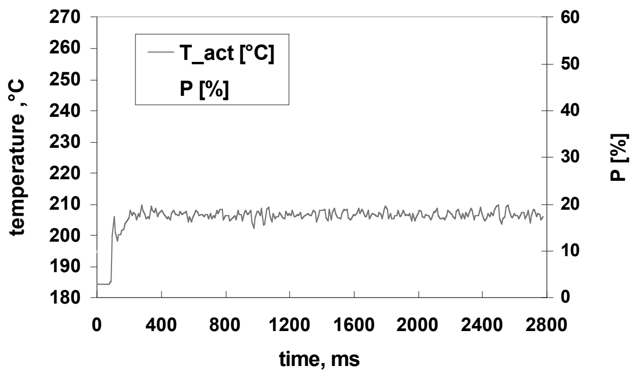

Figure 1: Closed loop contour welding of plastic housing. The temperature of the welding joint is kept constant by modulating the laser power. [5]

TABLE 1: DIODE LASER APPLICATIONS BY WAVELENGTH

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	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

λ [nm]	Application	Industry
830	Pre-Press, Computer-to-Plate (CTP), Direct on press (DOP)	Printing
852, $\Delta\lambda<<1$	Diode Pumped Gas Laser (Cs- Vapour)	Defense
868 – 885	Nd^{3+} : XXX	DPSSL
901	Yb^{3+} : SFAB	DPSSL
905	Rangefinder direct	Instrumentation
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, Fiber 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
1550	Rangefinder	Defense
1700	Missile Defence	Defense
1850	Turbulence Detection	Defense
1940	Medical, Polymer Welding	Medical MP
2200	Medical, Polymer Welding	Medical MP

Beam shaping for various applications

Fiber coupled diode lasers provide an axially symmetrical energy distribution (Figure 2). The spot size can be adapted to the application within certain limits depending on the fiber properties and the optical design of the focusing unit.
Using adapted optics even allows line and ring shaped foci as seen in figure 3 and 4. Those optics offer interesting possibilities for high volume production. Lines can be used in continuous welding or heating like a laser curtain through which the parts are moved. Combining several lines also with different geometry allows simultaneous welding of closed contours. Ring shaped foci can be used for all types of tube to plate connections. They offer an easy and cost effective solution to substitute galvo systems whenever the high flexibility they offer is not needed.

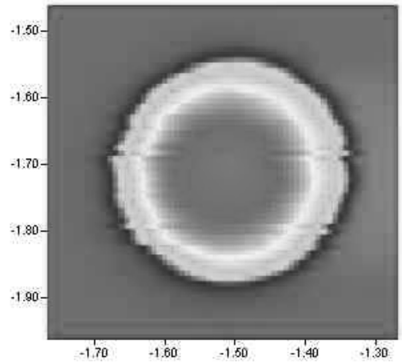

Figure 2: Energy distribution of standard fiber coupled imaging optic providing a spot diameter of 300 µm.

Figure 3: Energy distribution with fiber coupled line optic providing a laser focus of 160 x 4 mm

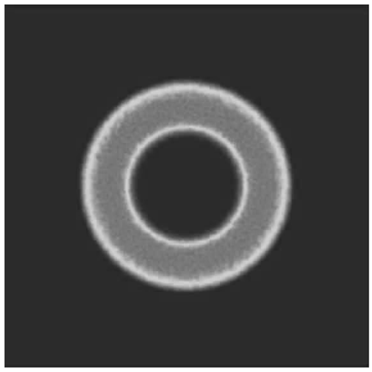

Figure 4: Energy distribution with fiber coupled ring optic providing a laser focus of 3 mm diameter

Polymer Welding

Laser beam welding of thermoplastics has advantages compared to other technologies like ultrasonic or vibration welding. Thermal and mechanical stress for the welded parts are very low. It is non-contacting, clean and offers high-quality welding seams. High flexibility and easy joint design makes laser beam welding an accepted method for industrial production.

The method is well known. The welding partners are overlapping. One is transparent for the laser (LT), the other is absorbing (LA) and melts when exposed to laser radiation through the transparent part. Due to mechanical contact which allows heat transfer between the partners the laser transparent part is melting as well. The impact on the parts from a fixture or caused by the part design results in the mixture of the melt pools and after solidification the weld is formed.

Depending on how the parts are exposed to the laser radiation, mostly four methods can be distinguished. Contour, quasi-simultaneous, simultaneous and mask welding. Contour welding is characterized by a relative movement of part and laser optics mostly with mechanical axes. If more than one lap is needed to weld the parts, the fusion zone has significantly cooled down before the laser beam heats it up again.
In quasi-simultaneous welding the laser beam is moved on a fixed work piece with mirrors on galvanometer scanners. Typically the laser beam is doing several laps on the welding contour fast enough to avoid significant cooling of the welding zone between two laser exposures. This results in a uniform heating and collapse of the welded part with high-quality and stable performance. It is also possible to implement set path measuring for quality control like used in ultrasonic welding.

Figure 5: PBT box with typical geometry for quasi simultaneous welding

Simultaneous welding means that the complete weld seam is exposed to the laser beam and no relative movement between the beam and the work piece is necessary. Due to their compact and modular design, mostly diode lasers are integrated into the fixture. It allows short cycle times with a high output volume. The disadvantage is a non-flexible tooling which needs to be adapted with each change of the parts design.
During Mask welding a mask is placed between the collimated laser beam which is mostly line shaped and the target. The mask covers all parts which should not be exposed to the laser radiation and the process is therefore capable of welding fine structures. Especially if the welding area of a work piece is small compared to the surface of the mask, the utilization of laser energy is poor.
Polymers are transparent for laser radiation in the near infrared wavelength range. To achieve the necessary absorption additives are needed. But for some applications it is not possible to add absorber due to legal regulations in food or pharmaceutical production. Using the natural absorption of polymers for wavelengths larger than 1900 nm welding of transparent foils (Figure 6) and melting of PMMA could be demonstrated.

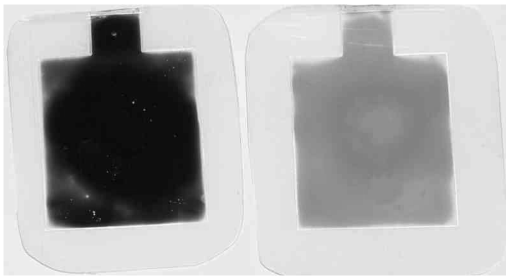

Figure 6: Welding of PE foil bags without additional absorber using wavelength of 1940 nm. The bags had been filled with colored liquid to demonstrate their tightness.

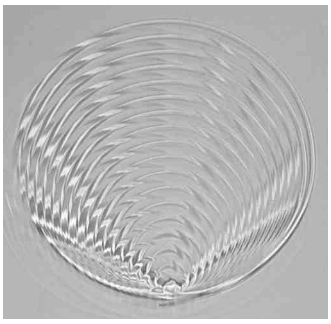

Figure 7: Melting of transparent PMMA with diode laser using wavelength of 1940 nm

Laser Soldering in Electronic Manufacturing

Laser soldering is a selective soldering technique which is used in electronics production for soldering contacts, sensors and switches. The advantages of this method are non-tactile heating, limited heat load, a highly defined, localized energy input and a good accessibility. Laser soldering is used when a thermal impact of surrounding components has to be avoided or when the components themselves are sensitive to heat. Contacting Flexible Printed Circuit boards (FPCs) with conventional methods may cause delaminating of the polymer compound and destroys the part.
The locally limited energy input allows the soldering of very small components. This can be demonstrated with a LED that has to be contacted to a thin copper wire. The diameter of the wire is 75 µm. The pads on the semiconductor are gold plated and have a size of 400 µm x 800 µm. The solder has been applied as wire with a diameter of 300 µm. Visual and x-ray inspection show no porosity or imperfections.

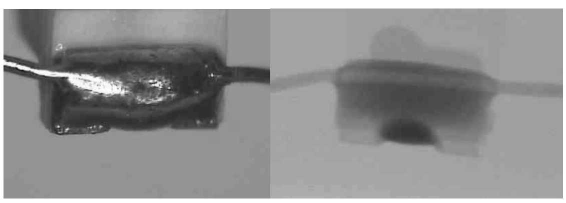

Figure 8: Laser soldered contact of a LED (left) and X-ray inspection of the joint (right)

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 technologies have in common that pulsed lasers with high peak power and very good beam quality are used. High power diode lasers cannot compete with these features but have advantages when compact beam sources for cw applications with spot sizes up to millimeters 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. [4]

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 millimeters. 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 by 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 on the laminate layers. This method is named In-Laminate Laser Soldering (ILLS).

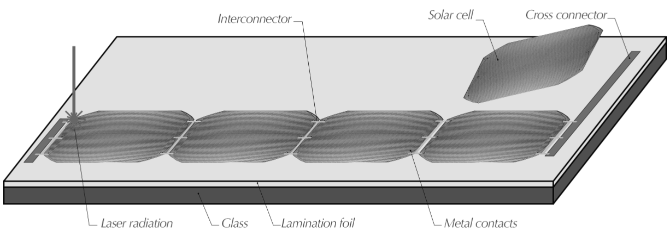

Figure 9: Soldering of a back contact solar cells with diode laser in closed loop temperature control [3]

Conclusion

Diode lasers are a flexible tool for welding and soldering processes in automotive, electronic and medical device manufacturing. Combined with adapted optics and a wide range of available wavelengths cost effective and reliable solutions for automated production are possible. Especially with wavelengths around 2 µm new applications which could not be addressed with lasers are possible now. Additional features like closed-loop temperature control with pyrometer allow the complete documentation of production processes.

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