LIM 2013

Diode Lasers used in Plastic Welding and Selective Laser Soldering – Applications and Products

S. Reinl

DILAS Diodenlaser GmbH, Galileo-Galilei-Str. 10, 55129 Mainz, Germany

Summary

Aside from conventional welding methods, laser welding of plastics has established itself as a proven bonding method. The component-conserving and clean process offers numerous advantages and enables welding of sensitive assemblies in automotive, electronic, medical, human care, food packaging and consumer electronics markets. Diode lasers are established since years within plastic welding applications. Also, soft soldering using laser radiation is becoming more and more significant in the field of direct diode laser applications. Fast power controllability combined with a contactless temperature measurement to minimize thermal damage make the diode laser an ideal tool for this application. These advantages come in to full effect when soldering of increasingly small parts in temperature sensitive environments is necessary.

plastic welding, soldering, diode lasers
1. **Motivation / State of the Art**

Plastic components are becoming more and more delicate and sensitive and process control is becoming even more important. In conjunction with a contact-free temperature measurement, a laser process with high potential for additional plastic welding applications is available. For selective soldering applications increasingly miniaturized components and assemblies push conventional processes to their limits. For this application, the diode laser has opened up new possibilities, especially where a process control is used to monitor and regulate the non-contact soldering process. In the below paragraphs the process of selective soldering and plastic welding is described in detail.

2. **Selective Soldering**

Selective soldering of electronic components is a joining method, where the components to be joined are not melted like in conventional welding processes. Soldering is characterized by melting a filler material (solder) which fills the joint gap and the surfaces are getting connected. Up to a joining temperature of 450°C this is called soft soldering. Soldering is mainly used in the production of electronic assemblies and for connecting electronic components to circuit boards or conducting paths.

Soldering technologies are divided into two sections. First, the mass soldering processes such as soldering in a reflow oven and, secondly, selective soldering technologies. During mass soldering processes, electronic components and the PCB including the solder are heated up simultaneously inside a reflow oven. Selective soldering technology heats up the specific solder points to be soldered. Conventional selective soldering technologies require a direct mechanical contact to the solder joint, or at least the tools needs to be very close to the solder joint (Iron, inductor, wave soldering, etc.). Due to limited space this is not always possible. Furthermore, the energy input into the solder joint cannot be adjusted or affected actively. Here, laser soldering offers clear advantages.

2.1. **Process Advantages through Laser Use**

Selective soldering processes by laser are gaining more and more importance when compared to other selective soldering technologies. Amongst other reasons, the contactless energy input into the solder joint offers the greatest advantage. Due to the highly focused laser beam, this energy input is highly localized and well defined. Hence, very small components can also be soldered reliably. In addition, the narrow beam waist of the laser beam enables solder joints at poorly accessible areas. Because of these process advantages, laser soldering is used when thermal effects to close assembly elements must be prevented or when the parts to be soldered themselves is temperature sensitive. Mainly, fiber coupled diode laser systems are used for selective laser soldering processes (Figure 1).

![Image](https://example.com/image1.jpg)

**Figure 1:** Various High-power diode laser systems with different configurations provide output powers from 30W up to 500W. The units are turn-key systems and can be equipped with processing optics that suit the application. (Source: DILAS GmbH)
The laser light is guided by a flexible fiber optic cable to the working area. At the output of the fiber cable, the laser beam is focused by a focusing optic with a fixed focal length or deflected by a scanner system. An achievable spot size of 180µm shows that a very high energy input and a very selective heating of the solder joint is possible (Figure 2).

**Figure 2:** Typical measuring of a beam caustic. The slim beam waist and the sharp defined energy input which is achieved by the DILAS Diodelaser Systems, is advantageous for the soldering process. (Source: DILAS GmbH)

Flexible beam deflecting systems – so called galvo scanners – provide in addition to focusing the laser beam a fast beam deflection for positioning. Here, freely programmable mirrors deflect the beam. The speed at which the laser beam can be moved is between 7m/sec and 10m/sec. This flexible beam deflection is also able to create homogeneous temperature profiles by moving the beam continuously at high speed.

The solder material that is needed for the process can be provided by wire feeding systems or can be applied in advance by solder paste or pre-tinning (Figure 3).

**Figure 3:** Schematic illustration of solder supply. By automatic wire feeder (above) by dispensing a paste (Centre) or pre-tinning (bottom) (Source: DILAS GmbH)

### 2.2 Soldering Process Control Using Pyrometers

The soldering process is divided mainly into three phases. During the “heating phase” the parts to be soldered are heated up to process temperature. The temperature needed, depends on the solder material that is used. The following “yielding phase” is the time period in which the solder material flows to the parts to be wetted. Depending on the size of the parts, as well as on the size and condition of the soldering joint, this time needs to be adjusted accordingly.

**Figure 4:** the wetting angle as an indicator for the solder joint quality depending on a correct temperature control of the soldering process. (Source: DILAS GmbH)
Within this phase the soldering temperature must be kept on a constant level. Within the last phase, the “wetting phase”, the molten solder material is wetting the metal surface of the parts to be soldered. A high quality wetting can only be achieved if all contaminations and oxide layers are removed from the parts, as these can reduce wetting. In addition the wetting angle which should be below 30°, measured between the surface of the part to be wetted and the surface of the solidified solder (Figure 4).

An optimized temperature vs. time characteristic is crucial during selective soldering in order to reach optimized results and thus, optimized wetting. Particularly high power diode lasers provide ideal properties. Industrial high power diode laser systems are able to control the soldering temperature according to a specified temperature vs. time characteristic due to their ability to adapt the optical output power quickly.

This can be realized by using a contactless temperature measurement in combination with the diode laser system. Furthermore, this method is able to reduce damage to the components to be soldered. During the selective soldering process, the contactless temperature measurement is undertaken by a pyrometer. The pyrometer is a well-established tool for process control during soldering of miniaturized components in temperature sensitive surroundings and serves as a reliable quality control. The pyrometer is deflected into the laser beam and controls – coaxially to the laser beam – the process (Figure 5).

![Figure 5](image)

**Figure 5**: a) Processing Head with integrated pyrometer for online temperature measurement. b) Using a pyrometer, the soldering temperature can be controlled during the process in order to reach an optimized temperature vs. time characteristic (blue line). In a soldering process without temperature control, temperature fluctuations might not be compensated (red line). (Source: DILAS GmbH)

During the soldering process, the temperature of the solder joint is contactlessly measured at the laser focal point, which allows for a temperature guided process. A closed loop control between temperature (measured by the pyrometer) and laser power (diode laser system) allows for a quick and precise process control. Especially with delicate or temperature sensitive devices, this is an important issue. Defective solder joints can be detected with the pyrometer measurement and bad parts can be rejected automatically.

![Figure 6](image)

**Figure 6**: typical application examples for selective laser soldering. a) Temperature sensitive surrounding. B) bad accessibility and C) sensitive LED devices  (Source: EUTECT GmbH)
3. Plastic Welding

Generally, the laser welding of plastics is - with a few exceptions - always a so-called transmission welding process. This means that components that need to be welded must be welded in overlap joint. Hereby, the upper joining partner is irradiated by the laser radiation without affecting the components (Figure 7). The lower part to be joined absorbs laser energy and is heated and melted. The heat transfer of the melt takes place by conduction to the upper layer and also melts the upper part. With this principle, a weld between the two parts is produced.

The optical properties of the components to be welded are therefore an important parameter of this method, which is on the one hand, the transmission of the upper joining partner, and on the other hand, the absorption of laser radiation on the surface of the lower joining partner.

Figure 7: Principle of Plastic Welding (Source: DILAS GmbH)

For many thermoplastics, these optical properties have been determined by transmission measurements. These measurements show the light transmission properties, depending on the wavelength of the laser through the non-pigmented material. Typically, diode lasers used for welding of plastics emits at a wavelength between 800nm to 1000nm. Most non-colored thermoplastics have a good transmission at this wavelength range.

In order to achieve absorption of laser radiation by the lower joining partner, carbon black is often used as an absorber. Special additives can be incorporated into the plastics as well, which enable individual colors of the joining partners to be realized. At the same time the necessary optical properties are maintained. Thus, for example, color combinations are possible that appear transparent to the human eye but absorb the wavelength of the laser or appear non transparent but transmit the wavelength of the laser.

3.1 Process Advantages through Laser Use

Laser welding is competing with other conventional joining methods, yet offering process advantages that will become more and more relevant in the future because of increasingly sensitive components in the automotive, consumer or medical industry. It is clean, the energy input is well-defined and the thermal load on the components is extremely low due to the highly localized energy input. The mechanical stress on the components is reduced to the load introduced by the clamping device. The actual energy input by the laser is contactless and does not cause additional mechanical stress. In particular, the ability to control the energy input into the joining zone has been found to be a significant advantage for many assemblies.
3.2. Quality and Process Control

As with other joining methods, the issue of quality control also arises in laser welding. How can one realize during the welding process, whether a weld meets the requirements or not and separate good parts from bad parts accordingly? How can the number of parts be reduced by using an appropriate process control? One opportunity for a quality assessment, which is also used in ultrasonic welding, is measuring a set path during the welding process. Here, the welding contour is melted by the laser homogeneously and uniformly, which can be realized by using a so-called galvo scanner that deflects the laser beam in the working plane very quickly by two internal mirrors.

The laser beam is rapidly deflected over a programmable welding contour and the contour is melted almost simultaneously. By pressing the upper part with a mechanical clamping device into the molten material, a defined collapse can be measured. Given that the joining partners are compatible and weldable, it can be assumed that if a certain collapse has been reached within a predetermined time, the required weld quality has been achieved. If the predetermined time-distance curve has not been met, the welding seam quality may not be sufficient and the part can be rejected.

Another way to assess the plastic welding process qualitatively and quantitatively is by using a remote temperature measurement. A pyrometer is used, which detects the temperature of the molten material during the welding process. This detected temperature is a measure for the bonding quality. Such processing heads with an integrated pyrometer in combination with the diode laser allows a rapid control of the welding temperature and the detection of welding defects. The advantage of a temperature control during the welding process (so-called closed-loop process) is becoming clear when the components to be welded show a certain inhomogeneity with respect to their optical properties. Such inhomogeneities can occur when the components are reinforced with glass fibers, for example. Density fluctuations or various orientations of the glass fibers within the plastic lead to different transmission and absorption properties. This, again, requires adapted laser power during the welding process to achieve the required melting temperature. The pyrometer keeps the melting temperature constant within certain limits by adjusting the laser power automatically. By this online process control, the components can be processed in an optimized process window. This affects the weld strength and the stability of the process positively. A defect welding area cannot be compensated by the pyrometer control, but can be realized by a sudden increase of the temperature signal. Such a temperature increase may have several reasons. For instance, a contaminated surface can lead to higher absorption of laser radiation and burning of the material. Another reason may be poor or non-existing mechanical contact between the two welding partners. Hence the heat of the molten lower joining partner is not absorbed by the upper part which leads to overheating. This is visible in the pyrometer signal. Likewise, it is recognized when the required temperature is not achieved, e.g. by lack of laser power. If the upper and lower temperature limits, defined within the software, are exceeded, the affected components can be separated. An individual process number for each single weld allows mapping and corresponding traceability. A combination of the above described possibilities for process control is provided by a Galvo scanner with adapted pyrometer.

Such a combination combines the advantages of fast beam deflection by mirrors with fast, remote temperature measurement. Since the measurement wavelength of the pyrometer is in the range between 1800 and 2100nm, it is necessary to adapt the optical system accordingly. By using special designed and coated optics, it is ensured that laser focus and the pyrometer spot are congruent.

Figure 8: Galvo pyro combination combines the advantage of fast beam deflection and online process control (Source: DILAS GmbH)
4. Results

4.1. Selective Soldering

Selective soldering with laser radiation is well established in practice and is applied in many industrial applications. Good controllability of the output power makes the diode laser the perfect tool for this application. In combination with a pyrometer, temperature controlled soldering processes with high process stabilities lead to a constant quality. Hence, soldering inside temperature sensitive housings (e.g. plastic enclosures) or reliable soldering of temperature sensitive devices such as LED components is possible.

4.2. Plastic Welding

Laser welding of plastics is an established process that is used in more and more applications in different markets and is increasingly displacing the traditional welding methods. In medical device manufacturing, for instance, cleanliness is absolutely mandatory. Hence, laser welding is particularly well established in this market. In the automotive supply industry the parts are equipped with sensitive electronic components or guide and contain fluid - here laser beam welding is the method of choice. In combination with process control, the diode laser will make its way to a variety of future applications.
References

W. Horn – “Ein viel versprechendes Werkzeug - Hochleistungsdiodenlaser in der Materialbearbeitung” Laser Technik Journal Volume 2, Issue 1, February 12th 2007, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

S. Reinal – “Process Control Regulates Contact-Free Energy Input” Kunststoffe, January, 2011, Carl Hanser Verlag GmbH & Co. KG