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Introduction
The purpose of this document is to outline the necessary guidelines of laser plastic welding in order to equip designers and engineers with the knowledge they require during the concept and design phase of new products.

Please understand these are only guidelines and each specific application will have its own set of nuances and variations from these guidelines. We highly recommend you consult an LPKF specialist during your design process. The sooner you involve LPKF in your design constraints the better. Please see the end of this document for contact information and details on how specifically LPKF can assist you.

A Growing Array of Options
As the popularity of laser plastic welding grows, it is natural to see strides in its innovation as well. One of the most important such innovation is the introduction of higher wavelength lasers for welding clear plastics without using absorbing additives. For those readers who are somewhat familiar with standard through-transmission laser welding, but not this new process, this is quite an important step forward. This is mainly due to the fact that higher wavelength lasers open up many new doors for color and design possibilities.

Due to the potential of clear-to-clear welding, but also the stark differences in the process compared with standard through-transmission laser welding (TTLW), this document will be broken into two sections. The first section of this updated guide will cover through-transmission laser welding, with some additional content and clarification available since the first version of LPKF’s design Guidelines. The second section will cover the clear-to-clear plastic welding process, also referred to by LPKF as ClearJoining technology.
Section 1: TTLW Laser Welding Process

Through-transmission laser welding (TTLW) is a method of bonding two or more thermoplastic components using laser radiation. Although there are many methods for joining thermoplastics, laser plastic welding has a few clear advantages: higher joining quality, minimal resulting flash or particulates, higher quality control, less stress to the component and the ability to weld complex and intricate shapes. Such advantages make laser plastic welding a standout option for many applications. Most specifically you will find laser welding most prevalent within the automotive, medical, and consumer electronics industries.

The process relies on passing laser energy through an upper transmissive layer down to the surface of the lower layer where the energy is absorbed, hence the name “through-transmission.” Unlike laser metal welding, which is a seam welding process, TTLW is intended to generate heat inside at the lapped interface of the mating components. The transmitted laser radiation is then absorbed by the lower component which creates heat and causes the plastic to become molten.

There are four important requirements for the laser welding process to occur. These four points will be detailed in the following section.

The Big Four

1. Laser Transparent Top Layer

Most thermoplastic resins in their natural state will transmit all or most of a near infrared beam within specific wavelength ranges. The upper joining partner must be designed transparent for wave lengths in the range of 808nm – 1064nm, which are the most common wavelengths for through-transmission laser welding. LPKF laser welding systems most commonly use 980nm direct diode laser sources

Note that “laser transparent” should not be mistaken for “optically transparent” since laser welding radiation sources are outside of the visible light spectrum for the human eye. In fact, many laser welding applications today utilize a laser transparent top layer which is opaque to the human eye. Image 1 is an example of a completely black/opaque upper layer that is still transmissive to a 980nm laser. This will be discussed further in the section titled Materials and Colors.
There are several influences on laser transmission that include but are not limited to: colorants, additives (UV stabilizers, flame retardants and heat stabilizers), fillers (glass fiber, carbon fiber, blowing agents) and lastly the part thickness.

Only a small percentage of the laser energy needs to transmit through the top layer for the welding process to occur, the rest of the energy will be absorbed, reflected, and scattered before it reaches the weld joint. A minimum transmission rate of 3% is required, although higher transmission rates will result in a better and more flexible process window.

2. Laser Absorbing Bottom Layer

The laser absorbent layer is responsible for turning the remaining laser energy, once it has passed through the transmissive top layer, into heat at the surface of the absorbing layer.

Many factors can play into what makes plastic absorbent to laser energy, as mentioned previously additives, colorants and fillers all play a role in this. The most effective method is fortunately also one of the most economical, carbon black soot. Most major resin manufacturers use carbon black to make black resins economically, and at an amount usually between 0.2 and 0.4% by volume it provides excellent absorbing properties to any thermoplastic.

Ideally, the transmission rate of the absorbing partner should read absolute zero. In this way all of the energy would stay at the surface of the absorptive layer, or just below, where it is required to create a weld. Darker colors will absorb more effectively than lighter colors, but welds can be created with a variety of colors on the top and bottom joining partners, including translucent colors.

3. Material compatibility

The two polymers which are to be joined can, but are not required to, be the same type of thermoplastic. That being the case, the plastics must share similar properties to be good candidates for the process. The most critical factors are the chemical make-up of the polymer chains, the melt-temperature, and the surface energy of the plastics. The more similar the plastics are in these characteristics the better bond you can expect.

The most common thermoplastics are easily weldable to themselves as well as a variety of other combinations: PA 6, PA 66, POM, PBT, PC, ABS, PP, TPE and PE. Please reference the material compatibility chart in the appendix for a complete matrix of possible material combinations.

4. Contact

It is paramount that heat energy, generated on the surface of the lower layer, be transferred to the upper layer so that it may become molten as well. In order for conduction to occur the two layers need to be in intimate contact during the welding process to ensure proper heat conduction.

Contact is accomplished with various methods of clamping devices or special component designs (i.e. interference and press fits); the Clamping Overview section will cover this in detail. Clamping will help minimize any gaps caused by improper part design or tolerances, but every effort should be made to have accurate parts prior to welding.
Materials and Colors

Plastic Melt Temperature Overlap

It is important that the two pieces of plastic to be joined have similar melt temperatures. If melt temperatures do not have a large enough overlap one piece of plastic will burn before the other begins to reach plasticity. It is critical that both pieces are molten at some point during the process to achieve a true chemical bond. The larger the temperature overlap of the plastic types the better the process window, allowing for more flexibility and room for error especially in production.

Laser Radiation Interaction with Plastic

There are four possible results when laser energy interacts with a thermoplastic: reflection, absorption, transmission and scattering. It is important to understand what plastic characteristics will affect the laser radiation and how. Please keep in mind these reactions will vary based on not only the factors discussed in this section, but also the wavelength of the laser in use.

Reflection

Not all laser energy is transmitted or absorbed; some laser energy can also be reflected. This is an important aspect as it does affect the amount of laser energy transmitted to the interface, a critical parameter to understand.

All plastic will reflect some laser light. However, lighter colored plastics are known for causing higher amounts of reflection. Most notable white colored plastics containing Titanium dioxide (TiO₂). Until recently white plastics were difficult if not impossible to weld through or absorb laser energy into. Innovations in specific types of colorants and specialized process controls have increased the viability of welding white plastics. It is now possible to weld white plastics, including combinations of white-to-white.

Absorption

Most virgin thermoplastic material is typically highly transmissive to laser energy. Therefore, additives are required to cause absorption in most instances. These additives can be anything from colorants to glass and fiber fills.

Here is a complete list of factors:

- Colorants - most notably carbon black soot, but any colorant will affect the absorption of the light to some degree.
- Additives - flame retardants, stabilizers, mold release agents, etc. These can all have an effect on absorption and light interaction.
- Fills - glass, fiber, carbon, etc.
- Molding gates - plastic tends to be denser at the site of a molding gate, this added density can cause increased laser absorption in these areas. It is recommended to keep molding gates out of the path of the laser.

- Plastic type - some thermoplastics do have higher/lower transmission values, naturally without considering any additives

**Transmission**

Essentially a direct opposite of absorption the same characteristics that affect absorption also affect transmission with an added exception, material thickness. All thermoplastics will have some amount of innate absorption without even considering absorbers. The thicker the plastic, the more an absorbing effect is compounded.

The thicker a piece of plastic, the lower the transmission value compared to a plastic of the same type, color, fills and additives that is thinner. Common thickness in the laser plastic welded part can vary between the thinnest films all the way up to 3mm. It is very possible to complete welds through upper layers that are thicker than 3mm, but this is the most common thickness. As the thickness increases keep in mind the other factors that influence absorption. Plastic parts with colorants, filler and additives will require a thinner profile to get enough laser energy through to the joint.

As there are no hard and fast rules for this the best method for determining the transmission and weld viability of a part is to test it. LPKF has this capability in multiple labs around the globe. Please see the contact section at the end of this document.

**Scattering**

Light scattering in a thermoplastic is caused by plastic characteristics that force the light to move through the plastic in an uneven manner, eventually absorbing, although not uniformly. The end result is a larger heat affected zone in plastics that scatter light, whereas, plastics with less scattering will have a tighter and more uniform heat affect zone.

The main two factors affecting scattering are the crystalline/amorphous properties of plastic and glass fills. Semi-crystalline plastics tend to fracture the light coming through the part more than an amorphous plastic would. This is due to the crystalline shape made up by the polymer chains in the plastic. These crystalline shapes act like light guides, channeling the light and scattering it out before it is absorbed finally. For this reason amorphous plastics tend to absorb more uniformly, whereas semi-crystalline plastics will often create a molten pool that is less uniform and potentially deeper into the plastic itself. In certain instances both outcomes can have benefits or drawbacks.

Secondly, glass fills can act in a similar manner to the crystalline features of certain plastics, creating tunnels for the laser light to scatter through.

**Refraction**

Also worth noting is the lensing effect plastic has on light. Just like a glass lens, plastic can cause laser radiation to bend and refract. The laser entry angle, as well as the shape of the plastic itself, can affect the refraction of the laser.

It is recommended that the upper transmissive layer be consistent in thickness, and if it all possible avoid having the laser enter in an area that is heavily radiused as it can cause refraction that is difficult to overcome.
Colors and Additives

Transparent to Black
The simplest and most obvious color combination is clear (or natural) to black. This combination is not only the simplest to explain the concept of through-transmission welding, but also provides for the largest process flexibility and therefore is the easiest combination.

This is simply due to the fact that it is more forgiving with a larger process window. Excellent transmissivity is realized with clear or natural upper layers and the black lower layer (compounded with carbon black) makes for the best absorbing color.

Black to Black
Although seemingly impossible, it is actually only slightly more difficult to employ a black upper layer. This is accomplished through using dyes in the upper layer rather than organic compounds like carbon black that make excellent absorbers. In most instances the part is actually dyed a very dark red, green or blue which looks black to the human eye. The transmissivity of the black upper part is significantly lower than a natural colored counterpart would be, but still transmissive enough for laser welding.

Do keep in mind this requires the use of two separate resin compounds and therefore the parts must be shot on separate mold tools.
Color Variations
A variety of colors can be welded including fully opaque and translucent colors. Higher translucency will always result in better transmissivity, but worse absorption and vice versa. Colors add in an extra variable due to the fact that compounding a color or set of colors that can transmit or absorb the correct amounts of laser energy and matching it to the customer-specified color requirement can be a little tricky unless you are working with a compounder familiar with laser welding. However, it is very much achievable in most cases.

Color matched lower and upper layers again add an extra layer of difficulty as you must find colors that appear the same but react differently to the laser. Again this can be accomplished as seen in images 3 to 5 but it requires a savvy compounder.

Transparent to Transparent
Welding clear plastic to one another used to be difficult, but now due to higher-wavelength lasers this has become much simpler. However, this section is intended for discussion on through-transmission laser welding only. In this respect clear-to-clear welds can cause some significant issues.
First of all a specialized absorbing compound is required to make the lower layer absorptive. There are a few different options for such absorbers, but the most notable is Clearweld© a compound designed specifically to help plastics retain their transmissivity optically while adding laser absorbing characteristics for lasers in certain wavelengths. Such absorbers can be compounded into the plastic or applied at the surface; both options have benefits and drawbacks. Applied topically the absorber tends to be difficult to spread evenly and consistently, especially in high-volume and it also limits the processing window as you can only make one or two passes with a laser before the absorber is evaporated. Alternatively, Clearweld can be doped into the plastic, making it much more stable, but this can be quite expensive.

**White Plastics**

White plastic is most often created using Titanium dioxide, a highly reflective substance. Because it is reflecting and not transmitting or absorbing this makes white less than ideal for laser welding. However, recent developments in the types of Titanium dioxide, the loading amount, laser wavelength used and specialized process controls the welding of white plastics has also become much more viable. This includes the welding of white-to-white a seemingly impossible weld.

**Surface finish**

Although, there is not a specific surface finish requirement on laser welded parts it is worth noting that some finishes can cause complications. Any injection molded part should have an adequate surface finish. Where there is cause for concern is with machined and rapid prototyped parts. Laser welding does require consistent contact in the weld joint, and surface finishes with too much roughness or tool marks can cause non-uniform and varying contact.
Process Methods

LPKF systems utilize four main process types of laser plastic welding: quasi-simultaneous, contour, simultaneous, and hybrid welding. Each process type has its own set of advantages and types of applications it is suited to.

Quasi-Simultaneous Welding

Quasi-simultaneous welding is a combination of contour and simultaneous welding. A single, focused laser beam is guided by galvo-scanning mirrors, as it traces the weld path multiple times at very high speeds. In this way the entire joint line is effectively heated simultaneously. Simultaneous heating of the joint is ideal for realizing collapse and for overall process stability. Quasi-simultaneous welding is LPKF’s method of choice for most applications based on its flexibility and robust nature in serial production.

Quasi-Simultaneous Welding Video

- **Pros:** fast cycle time; excellent process monitoring; most flexible method.
- **Cons:** primarily for two dimensional parts or parts with shallow z-axis height changes.

Contour Welding

In this process the laser beam, focused into a point, moves relative to the component making a single pass over the joint. Contour welding is especially suited to large parts, three dimensional parts and radial welding welded parts. The laser motion control can be done by robotic arm, galvo-scanners or even CNC units.

Contour Welding Video

- **Pros:** very flexible and good for large, free-form parts
- **Pros:** fast cycle times
- **Cons:** expensive and inflexible; multiple laser sources are typically required; tooling is expensive and dedicated to a single application; maintenance intensive.
Hybrid Welding

Hybrid welding is technically another type of contour welding with some added features and benefits. Hybrid welding uses high-powered halogen lamp energy to assist the laser in the welding process. The halogen lamps pre-heat an 8mm zone around the joint the plastic around the joint line, in effect requiring less laser energy to melt the plastic. The benefits of pre-heating are faster cycle times as well as reduced part stress from temperature shock. The halogen light is polychromatic so it will be absorbed by, and heat, both the upper and lower layers.

Hybrid welding was originally designed to handle the large tolerances of the automotive lighting industry, but has since been used in other applications with large freeform and three dimensional curvatures. There is a separate design guidelines document specifically for hybrid laser welding of automotive lighting. [Click here](#) to download the Hybrid Welding Design Guidelines.

Hybrid Welding Video

- **Advantages:** excellent process monitoring, increased cycle times, uses less laser energy, improved gap bridging, increased seam strength
Part Design and Joint Configuration

Specific design constraints need to be considered when developing an application for laser plastic welding. This section will the most common recommendations, however, please keep in mind each application is unique and should be reviewed by an LPKF sales engineer or specialist as early in the design phase as possible.

Overall Component Size

Unfortunately it is not quite as simple as listing a single envelope range. That being said, the majority of parts welded by LPKF systems are less than four inches square, but parts up to 55” have been welded and every size in-between. The list of factors below all influence the overall part sizes that can be handled:

- Optical configuration: function of the beam size requirement, working field, laser power and a few other factors
- The process: quasi-simultaneous, simultaneous, contour, hybrid
- Laser wavelength: TTLW range or ClearJoining range
- Part requirements: joint/weld seam size, clamp force requirement, type of plastic
- The machine: part volumes, cycle time, automation or manual loading

Each type of application will have other factors and nuances that can affect the overall working field. The main factors to pay attention to will be the optical configuration and process type, these specifics are quite easily handled by an LPKF representative.

3D and Large, Free-Form Applications

With typical laser welding processes the laser source has a fixed height above the component, because of this it is difficult or impossible to weld parts with large height variations, like you see in tail lamps, because the laser would move in and out of focus throughout the entire contour. The breakthrough TwinWeld 3D, robotic-arm-assisted welding system, moves the entire laser source in relation to the component. Height changes are not an issue, because the laser source moves at a constant height in relation to the weld joint regardless of z axis changes in the component.

Optical Consideration

Beam spot sizes for TTLW can vary from 100µ to nearly 4mm in size. Multiple passes or raster effects can also be used to cover larger areas if necessary. The resulting weld seam is relative to the beam spot and weld seam width will be determined based on your part requirements and design constraints.
A Basic Guide to Joint Types

Common Joint Types

Laser plastic welding deals with three main types of joints: lap joints, T joints and radial joints. There are many variations of each, but these are the three joints most commonly used in laser plastic welding.

Lap Joints

Lap joints (Diagram 6) are the most simple of joints and are exactly how they sound, two areas that overlap to create the joint. The main defining factor is that the entire joint width, and very often the entire part, is on a single plane.

This type of joint is seen often in microfluidic plaques, small screens or covers and textile-like applications.
T Joint (Collapse Rib)

Very similar to what you would see in ultrasonic welding, a T joint makes use of a protruding collapse rib, but on the bottom layer only and unlike ultrasonic welding the collapse rib is flat on the top rather than pointed. The purpose of the collapse rib is two-fold:

1) Overcome any part tolerances (warping, gaps, etc.) and also
2) Process monitoring and closed loop feedback.

The melt-collapse (letter E in diagram 7), also referred to as melt-travel or joint path, is the distance the joining partners travel as they move together under clamping pressure. For many parts the collapse will fall in the range of 0.15mm to 0.5mm. Each application will require its own unique collapse distance based primarily on the part tolerances it is designed to overcome, but also the component size, weld rib width and requirements for weld strength.

Collapse control is a robust process monitoring technique that is used to ensure good weld quality and can measure collapse to a resolution of 0.001mm. A welding system can constantly monitor parameters such as laser time on and laser wattage and then compare it with the physical collapse of the rib to ensure that the plastic is not only properly heated, but has collapsed to overcome the part’s tolerances. This can also be setup as a closed loop process that can adjust in real time.

![Diagram 5: Basic Joint Design Concept](Diagram)

**Diagram 5: Basic Joint Design Concept**

**Joint Design Legend**

- A - Beam accessibility
- B - Clamp tool spacing
- C - Top layer depth
- D - Melt cover width
- E - Melt collapse
Special Part Features to Consider

Weld Flash
Weld flash (or melt blow-out) results from expanded material that leaks from the weld seam, most often seen as a result of the weld rib collapse, see letter F of diagram 6.

If weld flash is not acceptable for aesthetic or functional reasons, it is recommended that melt covers or a melt blow-out reservoir be designed into the part to keep flash from escaping or entering the component where it is not wanted, see letter G of diagram 6 for example.

Mechanical Limiting Stops
Although pictured in image 9 as an optional feature, hard stops are not commonly recommended as they may lead to internal stress after the parts cool and can also interfere with collapse control. Such stops have been implemented successfully in many cases, however, and if designed correctly can be a viable feature for controlling collapse.

Locating Features
If precise alignment of the cover and lower mating partner is required then locating features built into the part are recommended. Such features can come in the form of centering lugs or pins, or can be integrated into the flash traps as seen in image 6 below.

Radial Joint
Radial welds require a slightly different approach from lap and T joints in that the contact is created via interference or press fits designed into the part rather than clamp tooling.

The laser can be introduced straight down onto a part that is rotated using an indexing unit. The part can also be introduced vertically under a galvo-scanning laser head, with the laser
being redirected into the radial joint using a conical-shaped mirror.

It is important to note that radial joints do not, and should not be designed for any type of collapse. This means radial joints should never be designed with weld ribs. The interference fit should be uniform and consistent, either completely vertical or slightly angled.

The amount of interference depends on the overall size of the part and the tolerances. The interference amount should overcome all part tolerances and still have interference to spare. For the sake of laser welding a part can rarely have too much interference.

A Note on Butt joints
Butt joints, although theoretically possible, should be avoided. Handling of the parts, clamping and beam angle all result in a near impossible weld even in ideal lab settings.
Beam Accessibility

The component and clamp tooling should be designed to allow adequate access of the laser beam to the weld seam. Avoid any channels, large z-axis height changes, occlusions, molding gates or depth changes in the weld area. This includes radiused edges in most cases.

Beam accessibility dimensions can be calculated as follows: weld seam width (rib width) + positional tolerances + dimensional tolerances. Where positional tolerance is the allotted movement of the component during clamping and dimensional tolerance is the allotted size difference for variations in sizes from component to component.

Beam accessibility should also consider the cone-shape of the laser beam and the beam angle. Because the beam is projected off of a set of mirrors it can enter the plastic at an angle of 90° +/- 15° depending on where the beam is at in the working field. These calculations can be handled by the LPKF engineering team to ensure proper beam access. In the image below you can see a tapered side-wall, which had to be adjusted to account for beam shape and angle.

Diagram 8: Drafted side-wall for beam accessibility

Transparent Upper Layer Thickness

The main factor in determining proper thickness of your upper joining partner is the transmissivity of the part. If you recall from the Materials & Colors section of this document the rate of transmission is affected by many different factors, one of which being the thickness of the part.

Technically there is no minimum thickness, but we typically see most part thicknesses at a maximum of 3mm, although it is quite possible to weld through thicker parts depending on other transmission affecting characteristics.

It is recommended that the transmissive layer have a consistent thickness. Fluctuations in thickness will affect the amount of laser energy transmitted along the interface resulting in burning or underdeveloped seam spots.

Clamping Overview

Clamping pressure is necessary to ensure intimate contact of the joining partners. Conduction of energy from the absorptive partner to the transmissive partner is extremely important to ensure both parts are receiving enough energy to melt. Clamping also helps overcome part tolerances, warping and gaps. All-in-all clamping and mechanical handling of parts is often the most overlooked, yet important, part of laser plastic welding.

Each application will have customized clamp tooling which typically involves an upper clamp tool and a lower nest (this depends on the process and machines used). There are multiple types of upper clamp tooling that can be employed. This section will cover each in detail.
Glass & Acrylic Clamp Tools

Glass and acrylic clamp tools are a very simple form of clamp tool and yield very good results as they provide excellent force distribution and force directly on to the joint. They are relatively cheap and quick to build and work very well for low-volume production and prototypes.

However, glass tools are not ideal in high-volume production as they tend to contaminate and wear frequently, resulting in downtown and maintenance issues.

- Pros: simplest method, good for prototyping and small runs
- Cons: component surface must be almost flat (simple reliefs can be machined into the tool in most occasions, especially on acrylic), tooling is easily contaminated by dust or particles which can result in burning of the component.

Peripheral Clamp Tool

Peripheral clamp tools are also quite simple and effective for many applications. The main benefit here is that the tool is all metal, which allows for a more robust process and lower maintenance. The tool will not wear or contaminate like glass tooling.

The major drawback to peripheral tools is the force distribution. Force is applied only to the outer edges, usually a flange designed to handle the clamp tool. This works quite well for smaller parts or parts built from sturdy materials, but can cause bowing of the cover and side walls in certain instances. This bowing results in latent stress in the joint that can cause failures.
Hybrid Clamp Tool

Hybrid metal-acrylic tools create some added benefits in terms of force distribution and wear from repeated contact with the part cover, but the drawback is that the acrylic part of the tool is still susceptible to contamination from dust particles and off gassing.
Dual Clamp Device (DCD) Tooling

DCD technology is an LPKF patented tool concept designed to provide the most robust clamping process. It’s a low-maintenance option, and has excellent force distribution. The tool is made of all metal (no glass or acrylic to wear or contaminate), but also has inner tooling islands to help apply force evenly across the part surface and alleviate latent part stress after welding. The inner and outer clamp sections are connected by thin metal ribs as shown below in Image 14.
General Notes on Clamping

Clamping needs to be applied as close to the weld area as possible without obstructing the laser. Depending on the tool type this will require a certain amount of space be left for the tool to land. The amount of space will be part and requirement dependent, but we recommend a minimum of 0.5mm of land. This area is noted in Diagram 20, label.

Clamp tool comparison

<table>
<thead>
<tr>
<th>Tooltype</th>
<th>Force Distribution &amp; Stress</th>
<th>Contamination</th>
<th>Tool Wear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic/glass</td>
<td>Excellent</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Peripheral</td>
<td>Poor</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Hybrid</td>
<td>Good</td>
<td>Poor</td>
<td>Excellent</td>
</tr>
<tr>
<td>DCD</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

Nests/Bottom Clamp Tooling

Clamping pressure can vary from a few Newtons up to thousands of Newtons, depending on the part size and tolerances. This pressure will be supported by a part-specific nest or workpiece carrier.

Nests are custom designed to fit the component dimensions, and it is crucial the nest provides support along the entire length of the weld seam. Nests also have the critical task of accurately locating the part underneath the laser welding head.

Warping and Tolerances

It is recommended that measures be taken during the design and injection molding phase to ensure that warping is minimized, and that the joining parts fit together well, without gaps. If gaps are present, burns, or loss of energy can occur at the interface resulting in poor weld quality. Clamping can cut down on such part defects, but not in severe circumstances.
SECTION 2: ClearJoining Technology

In the past laser welding of clear components to other clear components was difficult, unreliable, and expensive due to the fact that specialized absorbers were required. The absorbers were difficult to apply, costly, and required further paperwork such as a medical validation process. But with the demand for welding clear plastics continuing to grow, new and more reliable methods were sought after.

Higher wavelength lasers (1500nm-2200nm) have been around for some time, used in surgical and other applications, but lasers were too low-powered for industrial use until recently. Now that these higher-wavelength lasers can reach outputs of 100+ Watts the doors for industrial uses have opened, including that of laser plastic welding.

Materials and Colors

The goal of welding clear plastics to themselves without additives is now achievable due to the inherent absorption of such wavelengths in thermoplastics. The specific process referred to here as ClearJoining makes use of laser near the 2µm range, specifically 1940nm. You may hear the terms two micron, 2µm or clear-to-clear welding used to describe this process.

Goldilocks Zone

At 1940nm you can see from chart 4 that the inherent absorption of laser energy in a 1mm thick piece of clear polycarbonate is about 25% at a 2 micron wavelength. A similar profile will hold true for most other thermoplastics. At roughly ¼ rate of absorption you have the ability to pass laser energy through multiple pieces of plastic while retaining a portion of that energy in the plastic as heat. Because of this phenomenon it is now possible to weld plastics without any absorbing compounds in them by volumetrically heating multiple layers simultaneously.
Colors

The main use for the 2 micron laser technology is for welding clear plastics to themselves, but the technology is not limited to just clear plastics. Translucent plastics and even opaque plastics with some transmissivity can be welded using this method as well.

It can also be noted that a 2 micron laser can be used to weld plastics in a through-transmission welding style, in other words you can potentially weld clear-to-black or a similar color combination as discussed in section 1 of this document.

Material Compatibility

Because material compatibility relies entirely on melt temperature, polymer chain length, and surface energy - factors that are exclusive of color - then it is safe to say that 2 micron welding has the ability to weld any thermoplastic combination that could be realized from a TTLW (~1 micron) process. Please see Chart 7 in the appendix for a complete list of materials combinations.

Process Considerations

The Big 3

Unlike TTLW you do not need an absorbing lower layer, so there are only three main factors required to weld using ClearJoining technology.

1. Semi-Transmissive Transmissive Plastic

Either one, both or multiple layers need to be semi-transmissive to the 1940nm laser.

2. Contact

Like TTLW intimate contact of the joining partners is still a must. This is often achieved through clamping or press fit.

3. Material Compatibility

This factor also holds true as it would for TTLW.

Process Differentiators

The ClearJoining process comes with its own set of limitations as well as added flexibility, all of which stems from the primary difference between ClearJoining and TTLW:

In TTLW the laser energy is contained at the joint interface between the two parts, where in ClearJoining the laser energy is volumetrically heating both (or all, if more than two parts are welded at once) pieces of plastic and even passing out the back of the joint.
Multi-Layer Welding

Because the laser energy is not being “blocked” by an absorbing layer it can pass through into multiple layers while still causing the plastic to melt up. This allows for welding of multi-layer stack-ups as shown here.

Energy Containment Consideration

Since the laser energy is not contained at the joint interface, understanding where that energy goes past the weld is very important. Features behind or underneath the weld can be susceptible to this laser energy.

Features that react to laser energy can potentially be damaged, degraded, or melted. It is important that placement of features behind the weld which provide structural support or features that must retain certain tolerance or shape be considered. This is especially true of liquid-containing devices as 2 micron laser radiation is highly reactive with water and will vaporize it instantly.

New Joint Entry Options

The application you see here is comprised of two pieces of PC one clear and the other a laser-transmissive black (technically dyed a very dark red). Because both parts are transmissive a laser could enter from either side to create this weld. In this case the laser was first passed through the black plastic, where it acted as the upper layer.
Part Design Considerations

**Beam Spot Sizes**

The lasers used for 2 micron welding are true fiber lasers, not fiber coupled, but true fiber lasers where the lasing chamber itself is actually a fiber-optic cable. Because of this the laser sources have the ability to produce very small and very high-quality beam spots. Beams can range from spot sizes as low as 56µm up to 1.5 or 2mm depending on how defocused the beam is.

**Overall Part Sizes**

Working fields for parts with small beam spot sizes (i.e. 56µm) are very small, under 2 inches square in fact, but by combining a typical galvo-scanning welding head with an X/Y table it is possible to hatch together multiple working fields to achieve a cumulative working area of up to 12 inches square. This is excellent for welding multiple micro or macrofluidic cartridges.

*Image 11: Welded Microfluidic Channels*

*Image 12: ClearJoining Welded Micro-Channels*
Joint Types

Lap Joint
The most common joint you will see in clear-to-clear welding is a simple lap joint. Very simple to weld and can also be done in multi-layer as displayed previously.

Radial Joint
The second most common joint, and one that has seen a lot of success with ClearJoining, would be a radial joint. Most commonly utilized with tubes and catheters, but also larger cylindrical objects like vials or bottles.

T Joints
Although possible, you must take into consideration the beam exit path. In this case the entire vertical sidewall would be affected by the laser energy which could result in an adverse structural effect.
Clamping Overview

Clamping for 2 micron welding can take advantage of many of the same tools seen in TTLW, but more often than not glass clamp tools are used. The reason being is that the glass clamp tools sit directly on top of the joint and can help contain any plastic expansion on the upper surface of the joining partner.

Diagram 23: Clamp on Lap Joint

Differential Pressure Clamping

Another tooling type developed specifically for ClearJoining by LPKF is the differential clamping technique. This technique uses a specialized tool that sits atop the part and seals itself off around the parts outer edges. The chamber is then pressurized, and the resulting force is then transferred to the entire part.

The main advantage here is that the force can be evenly distributed even if the part has raised edges or bumps. This type of tooling is most often employed when welding thin films to microfluidic plaques.

Diagram 24: Differential Pressure Clamping Concept
Consultation and Contact Information

Please remember that this document is intended purely as a cursory guide to laser plastic welding design. It is an excellent jumping starting point for companies and teams to begin exploring laser welding, however, we highly recommend you contact and LPKF Sales Engineer early in your development process to complete a full design review. Every application is sure to have nuances that would not be covered in the scope of this document.

Still not sure if laser plastic welding is the answer for your application? Let LPKF help you find out. LPKF Sales Engineers can help you with any request from general information about the technology, to in-depth design reviews and prototype welding to prove feasibility. LPKF is a global company with fully equipped applications labs in the US, Europe and China.

Contact Information and Inquiries

LPKF Laser & Electronics NA
12555 SW Leveton Drive, Tualatin, OR 97062
Phone 1.800.345.LPKF | Fax 503.682.7151
sales@lpkfusa.com
www.lpkfusa.com/lw

Recommended Information

To best serve your requests the following information is recommended, but not required.

- Application summary and function
- Images, PDF drawings or CAD (STEP or Solid files preferred)
- Materials
  - Plastic types
  - Colors
  - Other additives or fills
- Component details and requirements
  - Weld length
  - Weld strength or testing requirements
  - Hermetic seal or no?
- Production considerations
  - Cycle time
  - Annual quantities
  - Fully automated or manually loaded production environment?
  - Timeline or project milestones
Appendix

### LPKF Laser Welding Material Compatibility Chart

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