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High precise welding of transparent polymers

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Abstract

Since the well established classic laser plastic welding has become a favorite standard clean serial production proceeding, providing reliable strength and tight joints, its major field of application is still located in automotive and adjacent industry sectors. However, LPKF Laser & Electronics now targets the sophisticated requirements of researchers and manufactures in a modern and pioneering medical technology field. These so called BioMEMS (Bio-Microelectromechanical Systems) or Lab-on-a-chip devices are mainly based on complex systems of micrometer scale canals, enabling a rapid detection method for food safety and clinical diagnostics, chemical synthesis or biological research (Bhattacharya, Jang, Yang, Aakin, & Bashir, 2007) (Sackmann, Fulton, & Beebe, 2014).
By combining the weldability of two transparent polymers using a 2 µm fiber laser (Mingareev et al., 2012) with a high precise mechanical and optical positioning system the LPKF PrecisionWeld now provides an effective way for prototype or serial production of microfluidic devices. The heat generation for the welding process of the transparent polymers, typically polycarbonate, PMMA or COC, is based on intrinsic absorption of ~ 30 %/mm at the laser wavelength of 2 µm. The TEM_{00} shaped beam profile from the fiber laser can be focused down to ~ 60 µm spot diameter enabling the generation of extreme fine weld seams sealing the micro canals. By using a galvanometer scanner and a high precision mechanically moveable holding fixture the weld seams can be positioned with accuracy of 10 µm, besides this the treatment area can be increased by stitching scan fields based on automatic fiducial detection. With this new technique no critical absorbing additives or glue are needed for the joining procedure avoiding any toxic risk to high sensitive biological samples and it also pushes forward the existing canal diameter limits of previously known manufacturing methods.

Keywords: laser plastic welding, welding of transparent polymers, LPKF ClearJoining, fabrication of microfluidic devices, LPKF PrecisionWeld

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1. Introduction

In the following paper we describe the principles of transparent-transparent laser plastic welding using modern 2 µm fiber laser technology compared with classic transparent-absorbing laser welding. We also introduce a new developed machine, the LPKF PrecisionWeld which is designed not only to laser weld transparent polymers but also provide a high precise optical and mechanical positioning system, enabling extreme fine weld seams and micrometer accurate weld contour positioning. In the paper we show target application for this technology which are located in the medical field, particularly in fabrication of microfluidic based lab-on-a-chip devices. Actual results are discussed in detail, showing the possibilities of the system and the reached quality and precision of the welding process.

1.1. Introduction to laser plastic welding

Laser plastic welding is a well establish but still modern and fast developing technology used for joining polymers, particularly thermoplastics with great many and diverging applications in different industry sectors. However, the major field of applications is located in automotive an adjacent industry sectors but with increasing application in the consumer and medical field. From typical applications such as tight sealing of sensor housings, valves for seating comfort systems or sealing of fluidic components used in brake boosters right up to novel designed tail lamps laser plastic welding has furthered the continuous advancement in automotive support industry. The flexible applicability and outstanding optical quality of laser generated weld seams are also high attractive for consumer products with their high requirements on design aspects. Beside this, in the medical field the advantages of laser welding are, compared to other welding technologies, no particles are generated through mechanical friction and never the less no chemical additives e.g. no glue is needed to provide high quality precise and tight joints.

1.2. Introduction to transparent-transparent laser plastic welding

In classical transparent-absorbing laser plastic welding, the upper joining partner is transparent for the given laser wavelength, typically 980 nm. At the incident surface of the lower joining partner, typically carbon added thermoplastic, the laser is absorbed and heat is generated, melting the thermoplastic. Due to a given clamping force and weak but sufficient heat conductivity, the two components therefore melt along the weld seam creating a strong and reliable bond, as depicted in Fig 1 (a).

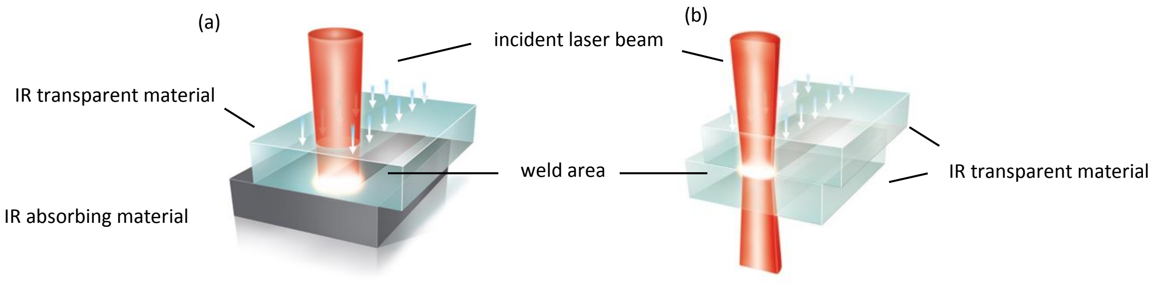

Fig 1: Principle of (a) transpararent-absorbing laser plastic welding, (b) transparent-transparent laser plastic welding

The situation changes when two, in the visible wavelength range transparent, joining partners are involved. (Fig 1 (b)) The optical absorbance properties of commonly used amorphous thermoplastics, PMMA, Cyclo-Olefin-Copolymeres (COC) or Polycarbonat (PC), vary significantly along the electromagnetic wave spectrum, UV, VIS, NIR as shown in Fig 2.

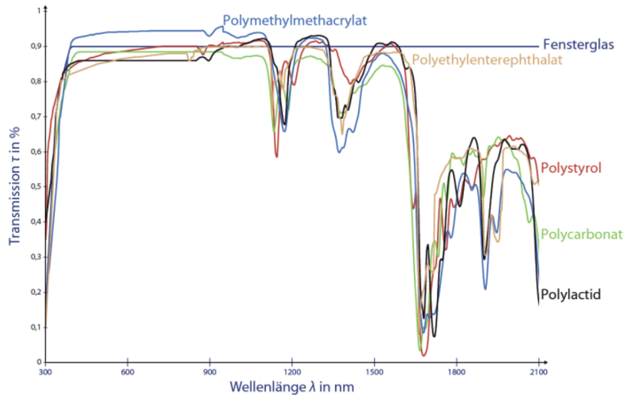

Fig 2: Transmission spectrum of different polymers. [C. Bonten (2014), *Kunststofftechnik Einführung und Grundlagen*]

While transparent in the visible spectral range, beyond 1000 nm several absorption peaks can be seen, where resonant molecule states are excited through the oscillating electromagnetic field. For the transparent-transparent polymer welding process it could be shown, that not the highest absorption rate is best but a well balanced absorption-transmission rate provides decent results. This we find at approx. 1940 nm. Due to low absorption and the focusing beam caustic, thermal effects to the upper surface are reduced to a minimum. As a consequence, welding occurs at the focus area which needs to be positioned exactly at the joining partner’s interface.

1.3. Micro-fluidics and fabrication

The major advantages of microfluidic systems are e.g. laminar flow effects enabling cell or molecule separation and detection, respectively, and the increased available optical interaction length enabling advanced biophotonic analysis.
The manufacturing of polymer microfluidic devices on modern compression molding systems allows channel sizes down to 5 µm or even less. The downscaling reduces the amount of expensive reagents and fluidics needed for analysis. Current production strategies are based on bonding processes induced by adhesive bonding, UV glue, chemical etching or ultrasonic induced thermal bonding (Tsao & DeVoe, 2009). These technologies have one disadvantage in common – the distribution of heat or chemicals is not limited to certain regions of the product. There is high risk to the channel structure to get blocked or at least to be deformed during these processes. Using laser plastic welding instead of conventional technologies the energy disposure and the weld seam position can be steered securely beside the channel edges, the risk of blocking or deformation becomes obsolete. Due to the very low heat conduction of thermoplastics even temperature sensitive bio-reagents may be pre-filled into the channel system. The high precision of the laser beam movement around the channels avoids risk of thermal or chemical detraction.

1.4. Introducing the LPKF PrecisionWeld

The LPKF PrecisionWeld, depicted in Fig 3 (a) is a compact stand-alone welding machine equipped with newest available optical and mechanical components enabling high optical and mechanical precision. Combined with the software LPKF CircuitMaster weld contours can be generated out of common CAD-data.

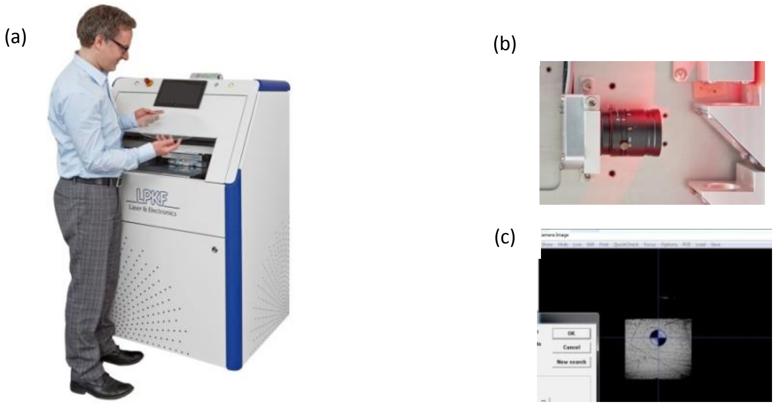

Fig 3: (a) LPKF PrecisionWeld, (b) internal vision-system, (c) fiducial detection (screen-shot)

By use of image processing algorithms fiducials (Fig 3 (b, c)) for automatic contour positioning are detected and evaluated. Also a fully 3-d calibration (± 5mm due to part thickness) is performed with a lateral accuracy of

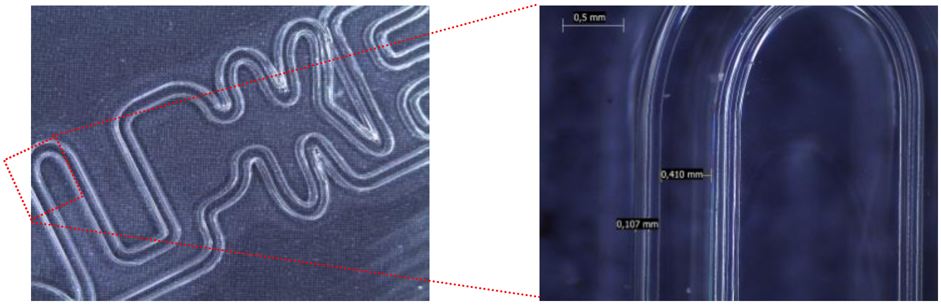

Fig 4: (a) Welded LPKF trade show demonstrator, (b) microfludic canal surrounded by very fine weld seams.

± 10 µm. The beam of a 1940 nm thulium single-mode fiber laser is guided with a galvanometer scanner and focused through a telecentric f-theta lens down to a spot diameter of ~ 60 µm @ $1/e^2$. Using an optical elevator, the focal position can be moved in z-direction in a range of ± 5 mm enabling easy adjustment to varying workpiece thicknesses. The workpiece holding fixture is attached on an axis positioning system increasing the working area by using a stitching procedure also enabled through fiducial detection. Therefore the maximum working field size scales up to 300 x 300 mm with a scan field size of 50 x 50 mm. Clamping pressure on the workpiece can be applied by air overpressure or a glass clamping device with pros and cons concerning workpiece flatness and bridging of remaining bulges from the beforehand compression molding process, respectively. The machine tooling is optimized for flat or disc shaped workpieces which are typically used in microfluidic fabrication.

1.5. Welding results

With the LKPF PrecisionWeld, using the LPKF ClearJoining process stable and precise welding of transparent polymers can be realized. One example is depicted in Fig 4. where a microfludic device is joint with approx. 100 µm thick weld seams.

The shown demonstrator device is made out a 1 mm thick PMMA substrate with a molded microfludic canal in the shape of the LPKF company logo. The entire structure, shown in Fig 4 (a) is 23 mm long and 10 mm high where in Fig 4 (b) a magnified region is shown. In this we see the 410 µm broad micro canal sealed by approx. 100 µm broad weld seams on the left and right side. The micro canal is 20 µm deep, enabling normal ink to be pulled through due to capillary action. For accurate positioning of the weld seam fiducial detection for automatic weld contour positioning were used, not shown in the picture. In Fig 4 (b) we clearly see the preciseness and very high quality of the weld seam.

Further more good welding results with amorphous polymers with higher melting points as PC and Cyclo-Olefin-Copolymeres (COC) and thin layers of semi-crystalline polymers as PP could be achieved.

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