Laser Welding

WHITE PAPER

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Introduction

Thermoplastic microfluidic Lab-on-a-Chip (LOAC) devices continue to emerge as high value Point-of-Care (POC) and decentralized testing options addressing multiple applications, e.g., infectious disease, critical and therapeutic care, in which a rapid testing result leads to timely diagnostics and intervention opportunities. The manufacturing of LOAC devices involves 'front-end' microchannel fabrication processes that are well-developed and adaptable to mass production, e.g., injection molding, and a number of 'back-end' microchannel bonding and assembly processes which may impact the cost effectiveness and reliability or be incompatible with the commercial product application. This paper will present available assembly methods of different polymer bonding methods and introduce a novel laser welding technology streamlining commercial introduction.

Summary

We summarize available polymer bonding methods, outline their respective advantages and disadvantages and present a case study describing Transparent Laser Plastic Welding as a process for consideration when designing and manufacturing microfluidic devices.

The selection of a polymer bonding method for scale manufacturing is a complex one and must take into consideration multiple factors including the materials, application, design, function and manufacturability and others (Table 1). Even when a method is selected the optimal process parameters can vary between different polymer lots, requiring that process settings and conditions be monitored and adjusted on an ongoing basis.

Table 1 - Considerations in the Selection of Polymer Bonding Processes

Material composition, thickness, color	Welding / bonding surface quality
Glass Transition Temp (Tg)	Physical tolerances, flatness
Temperature	Warpage and deformation
Pressure	Bond strength
Channel sealing	Optical and detection requirements
3D macro structures	Operating conditions
Welding pattern	Biocompatibility
Chemical inertness	Number of layers
Outgassing, leaching	Surface treatment, coatings
Process compatibility	Manufacturing costs

Laser Welding

Laser welding is a well-established process for medical device polymer bonding and is based on the principle of applying energy to produce melting close to the glass transition (Tg) temperature of the materials, forming a bond that is virtually as strong as the base material. Many benefits can be obtained by laser welding such as process cycle times, tight tolerances, good cosmetic properties, low residual stresses, no damage to surrounding materials or sensitive electronics and particulate-fee hygienic bonding.

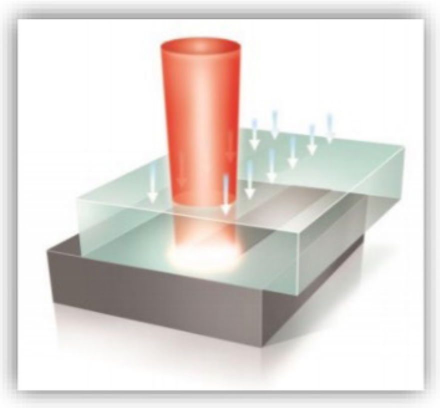

figure 1

The Through Transmission Laser Welding (TTLW) method utilizes a laser beam laser wavelength of between 0.80 μm to 1.05 μm which penetrates the transparent upper layer and heats the opaque lower layer, transferring the absorbed heat to the upper layer (Figure 1).

The Transparent Laser Plastic Welding (TLPW) method directs the laser beam with a wavelength approximating 2.0 μm along a programmed 2D (X and Y axis) contoured welding path with enough energy to heat the materials at a chosen focal point and properly weld at the joint interface, eliminating the requirement for absorber material additives (Figure 2).

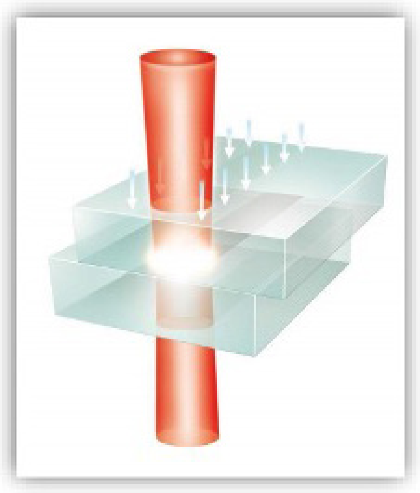

figure 2

Ultrasonic Welding

Bonding using ultrasonic welding of thermoplastics results in localized melting of the plastic due to absorption of vibrational energy along the joint to be welded. The parts are held between a custom fixture designed to concentrate the melting process and a sonotrode energy director connected to a transducer. A low-amplitude acoustic vibration is emitted creating ultrasonic energy that melts the point contact between the parts, creating a joint (Figure 3). This joint cools quickly drying time is very quick, and the assembly does not need to remain in a fixture for long periods of time for drying or curing making it much faster than conventional adhesives or solvents. Ultrasonic welding can easily be automated, making clean and precise joints; the weld site is clean and rarely requires any touch-up work. The low thermal impact on the materials involved enables a greater number of materials to be welded together.

figure 3

Solvent Bonding

Solvent bonding (also called solvent welding) is a direct joining technique bonding polymers at room or elevated temperature using a liquid or gas solvent. The process involves the application of solvent to the components being joined, which temporarily softens and dissolves the materials surfaces, fitting the pieces together usually under pressure as the surface layer molecules form entangled polymer chains. As the solvent evaporates, a solid polymer bond is formed that is clean, strong, and fluid tight. Solvent bonding differs from other bonding processes in that heating energy is generated by the chemical reaction between the solvent and thermoplastic, and cooling occurs during evaporation of the solvent. Liquid solvent processing is simple and generally has lower processing costs. Additional advantages compared to other bonding techniques include the capability to bond chemically compatible dissimilar materials and bonding that generally occurs below the glass transition temperature of the polymer.

Adhesive Film and UV-Curable Resin Bonding

The use of ‘dry’ adhesive films or tapes for bonding microfluidic devices is a straightforward, high-throughput and cost-effective approach for the sealing microchannels through lamination. Various adhesive tapes are commercially available for the mass production of microfluidic devices. With the appropriate tape selection, dry adhesive bonding exhibits good biocompatibility and good bonding capability with heterogeneous materials. Pressure sensitive adhesive (PSA) films are frequently employed but are also available in solvated liquid form. PSA films use a polymer layer which can flow at room temperature, allowing effective wetting of the bonding surface to encourage a strong bond. Another option includes the use of thermally activated adhesives whereby a polymer layer coated with an adhesive resin which is activated at elevated temperatures. UV-curable resin ‘wet’ bonding is performed by applying a thin layer, e.g., screen and contact printing, of a high viscosity liquid adhesive which forms a bond after curing by UV light irradiation. These adhesives are generally manufactured from polyester or acrylate resins containing photo initiators to enhance resin crosslinking upon exposure to specific wavelengths of light.

Thermal Fusion Bonding

Thermal fusion bonding is a common methods for sealing polymer microchannel devices in which the material substrates are heated at temperature near or above the Tg, while applying a pressure to increase contact forces. The combined temperature and pressure can generate sufficient flow of polymer at the interface to achieve direct contact, with interdiffusion of polymer chains between the surfaces leading to a strong bond which can reach the cohesive strength of the bulk material. Properly controlled temperature, pressure, and time parameters are critical to achieve high bond strength while limiting microchannels deformation due to bulk polymer flow. Surface activation may provide improved bonding strength and reduce deformation. Thermal bonding can be achieved between identical or dissimilar materials subject to the bonding temperature being to set near or above their Tgs.

Of the bonding processes summarized, each has respective advantages and disadvantages for selection consideration (Table 2):

Table 1 - Considerations in the Selection of Polymer Bonding Processes

	ADVANTAGES	**DISADVANTAGES**
Through Transmission Laser Welding	Full-surface mask welding Automation friendly Short Cycle time	Clear-to-Opaque welding requires absorbing material or additive Not optically transparent
Transparent Laser Plastic Welding	Clear-to-Clear welding, optically transparent Contour welding path Dissimilar materials Automation friendly - Vision systems Short Cycle time (100mm/s travel speed)	Warpage Weld “swelling” Custom fixturing/clamping
Ultrasonic Welding	Contour welding suitable for perimeter welding Short Cycle time Macro scale cartridge assembly	Energy director required in part design Lower precision, coarse bonding Difficult to control the plastic melt flow Custom fixture/horn for each design
Solvent Bonding	Clean full surface bonding Strong, clear bonds	Slow, difficult to control Chemical compatibility, sensitive to surface imperfections Extended drying times Environmental and safety concerns
Adhesive Film and UV Curable Resin Bonding	Wide variety of materials available Strong adhesion and flexible conformance to surface Engineered adhesive properties Compatible with dissimilar materials Automation friendly	Requires converting, adhesive thickness may be hard to control Requires precision alignment Channel depth dependent - adhesive reflow / controllability to avoid channel clogging or change dimensions Surface chemistry compatibility Losing homogeneous channel properties (different material for one side of the channel)
Thermal Fusion Bonding	Clean, full surface clear bonding Preserves optical clarity in the channel Can be dissimilar materials if Tg comparable	Long cycle time Deformation Process compatibility – heat Not automation friendly

Source Material

LPKF WeldingQuipment GmbH
Alfred-Nobel-Str. 55 – 57 90765 Fürth Germany
Phone +49 (911) 669859-0 info.laserwelding@lpkf.com
www.lpkf.com

Technical Data: LPKF PrecisionWeld 3000
Laser class 1
Laser beam source Thulium fiber laser
Laser wavelength 1940 nm
Processing field 320 mm x 320 mm (12.6” x 12.6”)
Diameter of the focused laser beam 65 µm
Positioning repeatability 30 µm

Consider impact of scale manufacturing, cost reproducibility, technique dependent parameter optimization regarding materials certain limitations, such as a long process time, the requirement of additional processing steps and facilities, and a low fabrication yield, which create problems for the commercial production of microfluidic devices.

Contact Information

Vantiva Precision BioDevices®
3601 Calle Tecate Ste 120
Camarillo, CA 93012

Email: pbd.marketing@vantiva.com
Web: https://microfluidics.vantiva.com