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Putting the Lid on Microfluidics With Vantiva Precision BioDevices

EBOOK

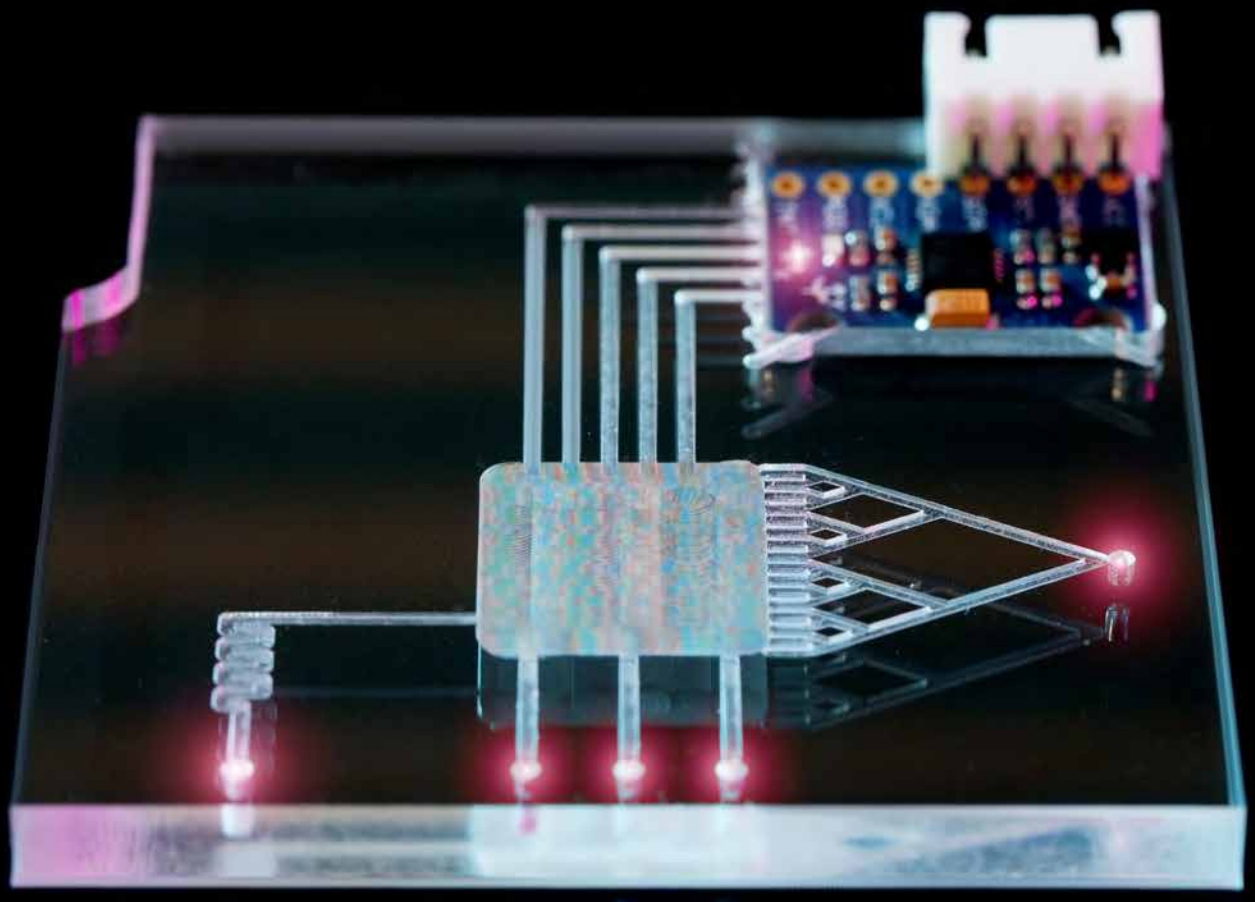
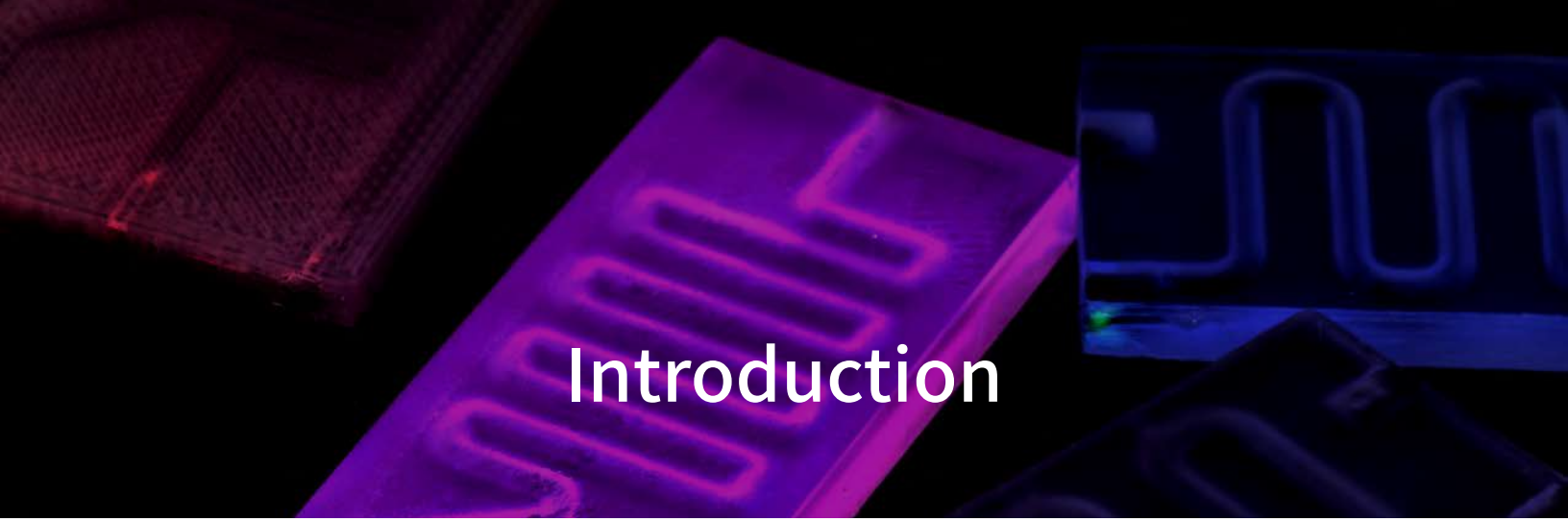


Table of Contents



Introduction

The physics, manipulation, and study of extremely small amounts of fluids—microfluidics—is an essential science to the development of lab-on-a-chip and other portable assay technologies, enabling the miniaturization of one or several laboratory functions onto a single integrated circuit that can effectively analyze biological materials such as blood or tissue samples in the field.

Functional, efficient microfluidic devices require precise manufacturing with razor-thin tolerances to fulfill their essential roles in medical diagnostics, clinical point-of-care testing, environmental and agricultural monitoring and testing, veterinary testing, drug discovery, and life sciences daily.

Highly precise polymer injection molding and effective bonding techniques are critical to controlling the flow of fluids through your lab-on-a-chip devices to ensure accurate results and reliable performance in the field.

In particular, cover layer bonding and sealing techniques are of paramount importance. In this free eBook resource, Vantiva Precision BioDevices will walk you through the critical importance of effective cover layer bonding and review common cover layer bonding and sealing techniques. This resource will also demonstrate how the right cover layer bonding and sealing techniques can make all the difference when working to overcome the challenges of manufacturing diverse microfluidic devices.

What Does Cover Layer Bonding and Sealing Do?

From home pregnancy tests and home COVID tests to point-of-care diagnostic devices in countries with limited healthcare resources or less-developed healthcare infrastructure to environmental and agricultural assays and beyond, microfluidic devices play a global role in life sciences.

The bonding technique that holds your microfluidic chip together, particularly what bonds the cover layer to the rest of your chip, is the unsung hero of the lab-on-a-chip device. The cover layer is the "lid" on your microfluidic device that enables your microfluidic device to continue to provide accurate, reliable service and performance.

When properly bonded to the chip, the cover layer on your microfluidic device provides three essential benefits:

1. **Maintains fluidic integrity, preventing leaks and delivering precise control of fluid flow through the device**

   Microfluidic devices require extremely precise control over the flow of fluid to deliver accurate and reliable testing and assay results. A well-sealed cover layer maintains pressure and prevents leakage, ensuring that the small amounts of pressurized process fluid that flow through the lab-on-a-chip device flow where they should, not where they shouldn't.

2. **Prevents contamination of the microfluidic chip by foreign materials, ensuring that testing and assay results in sensitive applications are accurate and reliable**

   Cover layer bonding and sealing not only keeps fluid in but also keeps contaminants out—an absolute necessity for lab-on-a-chip devices for use in sensitive applications such as medical diagnostics or biological assays where inaccurate results can have severe consequences downstream. This is why it's especially important that microfluidic chip assembly and cover layer bonding all occur in well-maintained cleanroom environments.

3. **Maintains the structural integrity of your microfluidic device, enabling it to withstand the rigors and stress of its operational environment without breaking**

   In addition to keeping fluid in and contaminants out, a proper cover layer bond also strengthens the structural integrity of the device overall, reducing the risk of breaking or deforming over repeated use.

Exploring the Microfluidic Device Bonding Technique Toolbox

To reap the benefits of your microfluidic chip's cover layer, choosing the right bonding technique is paramount. There are multiple types of microfluidic lab-on-a-chip device bonding techniques that can be applied to ensure a strong seal around your microfluidic chip.

Some are better for certain applications than others; misusing a bonding technique that does not suit the intended applications of your device can hamper its performance and prevent it from delivering accurate or reliable results!

Two main categories of thermoplastic polymer bonding techniques are utilized in microfluidics manufacturing: adhesive bonding and fusion (adhesive-free) bonding. Within these two categories are various bonding techniques, including lamination, resin bonding, thermal bonding, laser welding, solvent bonding, and ultrasonic bonding.

Each technique in the bonding toolbox has its own advantages and disadvantages and its own use cases, some of which we'll visit later on in our case study section.

What is Adhesive Bonding?

Adhesive bonding, the most widely used indirect bonding method in microfluidics, involves using an intermediate layer between the two substrates that connects them like glue. Adhesive bonding works best with substrates composed of two different types of materials.

The adhesive used in adhesive bonding can be categorized as either wet or dry. Wet adhesives take the form of types of waxes and epoxy, while dry adhesive bonding involves adhesive tapes and films.

Types of adhesive bonding include:

PSA Film Lamination

Pressure Sensitive Adhesive (PSA) film lamination is an adhesive cover layer bonding technique that relies on various flexible, compliant adhesive films. This dry adhesive bonding technique provides strong adhesion and conformance to surface features and dissimilar materials.

Because there is a plethora of available adhesive film materials with their own unique properties, PSA film lamination can be used on a wide range of material substrates. Film lamination does, however, require converting and precision alignment when used.

PROS

- Engineered PSA adhesive properties (low autofluorescence, no outgassing, hydrophilic/hydrophobic, good adhesion)
- Controlled PSA thickness
- Flexible film and deformable adhesive
- Scalable, as it lends itself to roll-to-roll based manufacturing methods

CONS

- Converting
- Precision alignment
- Non-homogeneous channel properties
- Channel depth dependent
- Biocompatibility of the adhesives

UV-Curable Resin Bonding

UV-curable resin bonding is a wet adhesive bonding technique that makes use of resin, a liquid polymer that hardens to a solid when exposed to UV light and cured. As an adhesive technique, resin bonding is fast and automatable, with excellent adhesion and cure properties. However, one of the major challenges associated with its use is controlling its flow to avoid channel clogging.

PROS

- Controlled thickness
- Adhesion strength

CONS

- Losing homogeneous channel properties (different material for one side of the channel)
- Channel depth dependent
- Biocompatibiltiy

What is fusion bonding?

Unlike adhesive bonding, which uses a third material to join two substrates, fusion bonding directly fuses the cover layer to your microfluidic chip without the need for any intervening material between them.

Types of fusion bonding include:

Laser Welding

Laser welding uses high-energy beams of laser light to melt and fuse two microfluidic substrates together, much like welding on a macro scale. Laser welding is fast, highly precise, scalable, and automatable, providing contour or full-surface (also known as mask) welding. Laser welding is also capable of clear-to-dark and clear-to-clear welding.

PROS

- Custom welding path (CAD file adoption)
- Cycle time (100mm/s travel speed)
- Clear-to-clear welding
- High precision alignment using vision system
- Automation friendly and tech-transferable – small-batch and prototype production can be done on commercially equivalent equipment

CONS

- Warpage
- Weld “swelling”
- Custom fixturing/clamping
- Laser entrance damage
- Geometrically limited field of view (weldable area)

Thermal Fusion Bonding

Utilizing thermal fusion bonding for microfluidic chips relies on the application of heat and pressure to fuse two surfaces. The heat and pressure required for this microfluidic cover layer bonding technique are near the transition temperature for glass. Thermal fusion bonding is typically used when the two surfaces are made from the same material.

PROS

- Clean full surface bonding
- Surface activation to improve bonding strength and reduced deformation
- Preserve optical clarity in the channel
- Scalable/High throughput feasible
- Minimal deformation

CONS

- Cycle time
- Not automation-friendly
- Tight global flatness tolerances required for integral bond

Solvent Bonding

Resulting in high bond strength with short process times, solvent bonding is a simple, versatile, and widely used method for bonding thermoplastics. As the name implies, solvent bonding applies a solvent between the two substrate layers of the microfluidic device, then uses heat and pressure to fuse the layers.

Solvent bonding is much like thermal fusion bonding, except that using a solvent encourages polymer chains to connect and form strong physical bonds without the need for high temperatures and pressures. Solvent bonding produces strong, clear bonds, but solvent use raises issues of chemical sensitivities as well as environmental and safety considerations.

PROS

- Clean full surface bonding
- Strong bonds

CONS

- Slow, difficult to control
- Process compatibility – chemical and biocompatibility
- Environmental and safety concerns
- Deformation/Sagging

Ultrasonic Welding

To create a pure bond between the layers of your microfluidic chip, ultrasonic welding uses directed, incredibly high-frequency vibrations, effectively melting and fusing them through the heat and friction generated by the ultrasonic sound waves.

Ultrasonic contour welding is suitable for lower-precision applications and perimeter welding applications.

PROS

- Cycle time
- Macro scale cartridge assembly

CONS

- Energy director required in part design
- Low precision
- Coarse bonding
- Difficult to control the plastic melt flow
- Custom fixture/horn for each design

A Brief Look at Bonding Quality Testing Methods

Quality testing is a vital component of microfluidic device cover layer bonding. Whatever method of bonding the cover layer of your microfluidic chip you use, the cover layer isn't of much use if the bond between it and the rest of the chip can't adequately guard against leakages, contamination, or structural weakness.

Vantiva Precision BioDevices performs comprehensive bonding quality testing for quality assurance, primarily utilizing three methods:

Bond Strength Testing

Comprehensive strength testing assesses the cover layer bond's ability to maintain a stable bond under the maximum pressure and tension of its intended operational conditions, making sure that the cover layer bond will hold in place over the course of normal use.

Leak Testing

Leaks and quality concerns are major issues for microfluidic devices, with even small leaks having the potential to render the results of a lab-on-a-chip device's analysis unusable. Comprehensive leak testing checks for gaps in a cover layer bond that may allow fluid to escape from the device and cause inaccurate results.

Metrology

Advanced metrology systems assess and monitor the microfluidic chip's dimensional metrics and topographical features, including surface roughness, dimensional thickness, and optical characteristics such as light transmission and fluorescence to ensure that the chip will function as intended.

Ensuring that the bond in a microfluidic device will hold firm and enable the device to fulfill its purpose best and provide faster, smarter, more accurate data requires a thorough examination:

Considerations or Checklist to select right Bonding Technology:

Materials

- Types
- Thickness
- Color

Physical Tolerances

- Deformation
- Flatness
- Warpage
- Adhesive squeeze-in

Assembly

- Channel sealing
- 3D macro structures

Detection Methods

- Optical
  - Imaging
  - Fluorescence signal
- Electrical
- Lens
- Texture

Surface Roughness

- Channel surface
- Welding/bonding surface

Operating Conditions

- Temperature
- Pressure
- Assembly with O-ring

Thermal Performance

- Thermal conductivity
- Glass Transition Temperature (Tg)

Alignment

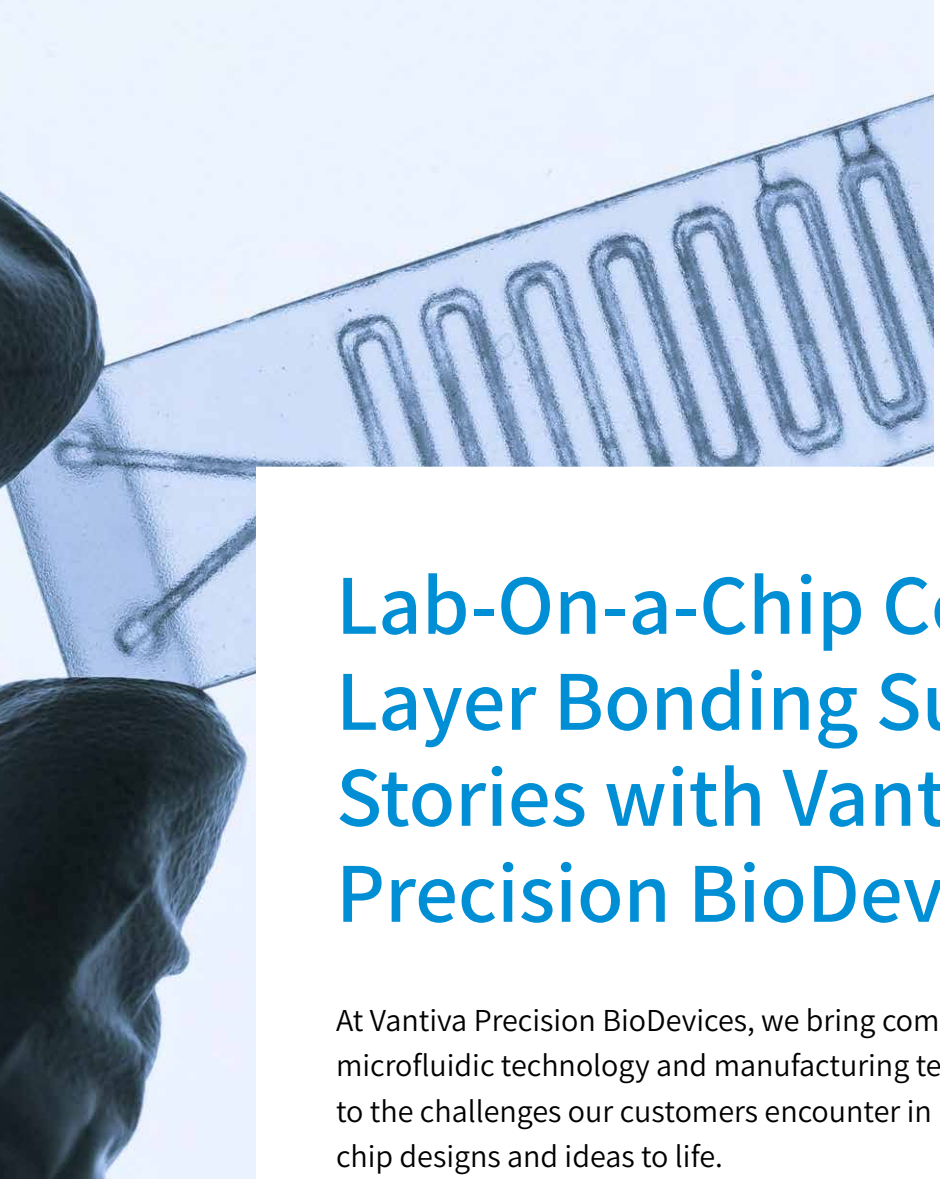
- Layer to layer
- Microchannel to welding pattern

Process-Compatibility

- Pre-reagent loading, coating, surface treatment
- Post-reagent physical alteration (dimple on film), heat-treat (annealing)

Biocompatibility

- Chemically inert
- Medical grade
- No outgassing
- No leaching

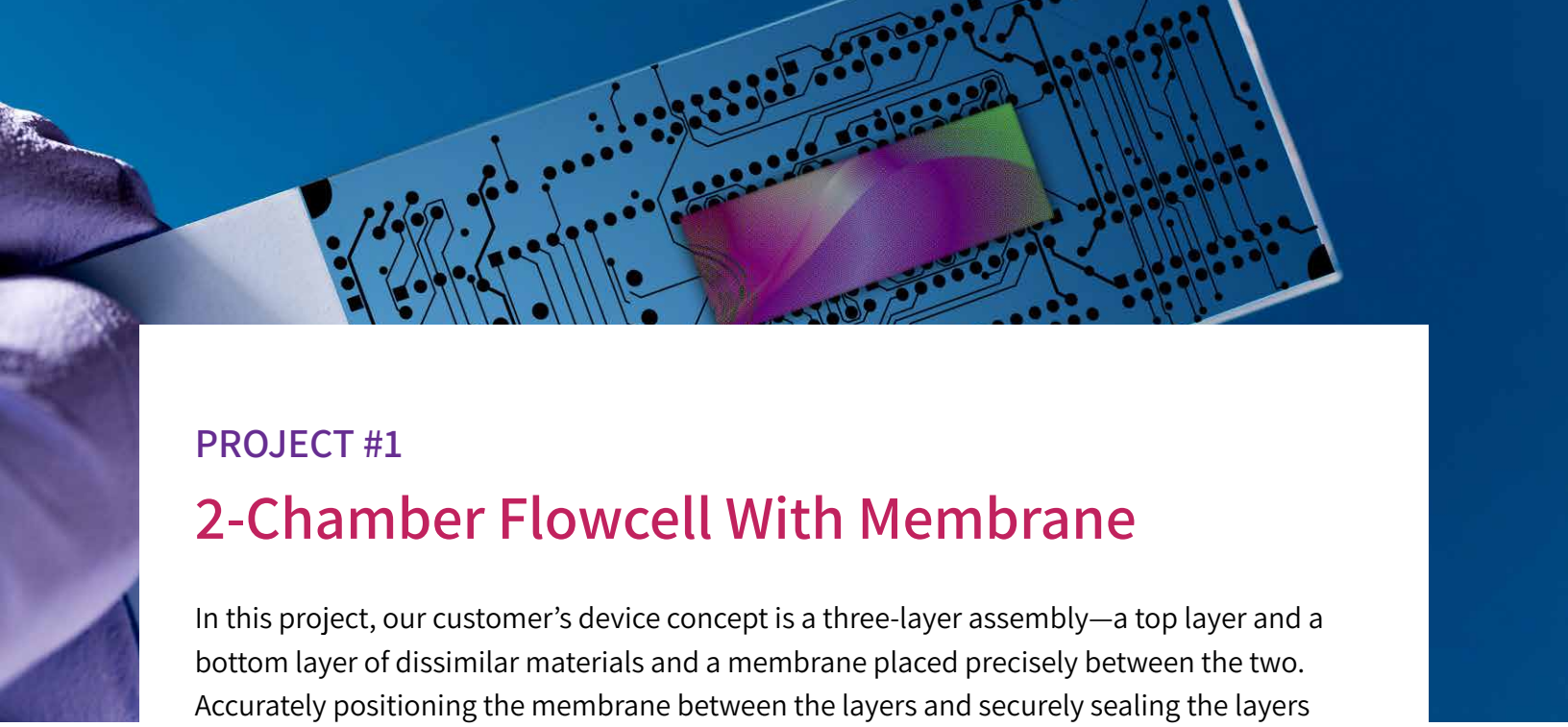


Lab-On-a-Chip Cover Layer Bonding Success Stories with Vantiva Precision BioDevices

At Vantiva Precision BioDevices, we bring comprehensive expertise in microfluidic technology and manufacturing techniques to find solutions to the challenges our customers encounter in bringing their lab-on-a-chip designs and ideas to life.

With so many diverse means of bonding microfluidic chip layers, it can be difficult to know which technique is best for you, let alone whether the proper bonding technique is within your technical capabilities.

Read on to see how our engineers helped four customers overcome their design challenges by finding just the right bonding method for their microfluidics product.



PROJECT #1

2-Chamber Flowcell With Membrane

In this project, our customer's device concept is a three-layer assembly—a top layer and a bottom layer of dissimilar materials and a membrane placed precisely between the two. Accurately positioning the membrane between the layers and securely sealing the layers together is crucial to the device's operation.

The Challenge

- Joining dissimilar materials
- Precise 3-layer alignment
- Hermetic sealing
- Chemical and mechanical sensitivity of membrane

The Solution

Due to the needs of the customer's device, laser welding is the perfect fit for cover layer bonding:

- Suitable for welding dissimilar materials
- Precise alignment
- Avoids chemical and heat sensitivity

The Results

Utilizing laser welding, we achieved process optimization with weld-to-channel spacing under 100 µm and no leakage!

- Laser power/Speed/Focus Clamping
- 2-micron (µm) clear-to-clear laser welding
- Precise alignment with vision system—fiducial recognition

PROJECT #2

3-Layer Hybrid Droplet Generator and Lens Array

Our customer's device here is a three-layer assembly with delicate nano- and micro-features to guide the flow of microfluids, including a lens and film that require precise alignment, hermetic sealing, and optical clarity.

The Challenge

- 0.5µm deep diffractive lens array—with no deformation
- 3-layer alignment and bonding—with precise lens-to-channel alignment
- Hermetic sealing for droplet generator
- Optical clarity for lens array

The Solution

The unique requirements of this project make thermal fusion bonding the perfect fit for cover layer bonding:

- Optical clarity preserved
- Hermetic sealing from full-surface bonding
- Preserves lens array feature integrity

The Results

Utilizing thermal fusion bonding, we achieved a precise microlens array that preserved all of the necessary lens features to optimize the device's performance!

- Microlens array features preserved, producing required optical efficiency and clarity
- Temperature/Time/Pressure to ensure 3-layer bond strength
- Custom fixturing for alignment

PROJECT #3

Multi-Depth Multi-Featured Cell Sorter

This project features a flowcell with various pillar and channel arrays, posing a very complex device built from multiple layers with varying topographies and requiring a hydrophilic coating for uniform flow and complete hermetic sealing of narrow fluid channels.

The Challenge

- Hermetic sealing of multiple features and topographies
- Hydrophilic coating required
- Channel height and aspect ratio preservation post-bonding

The Solution

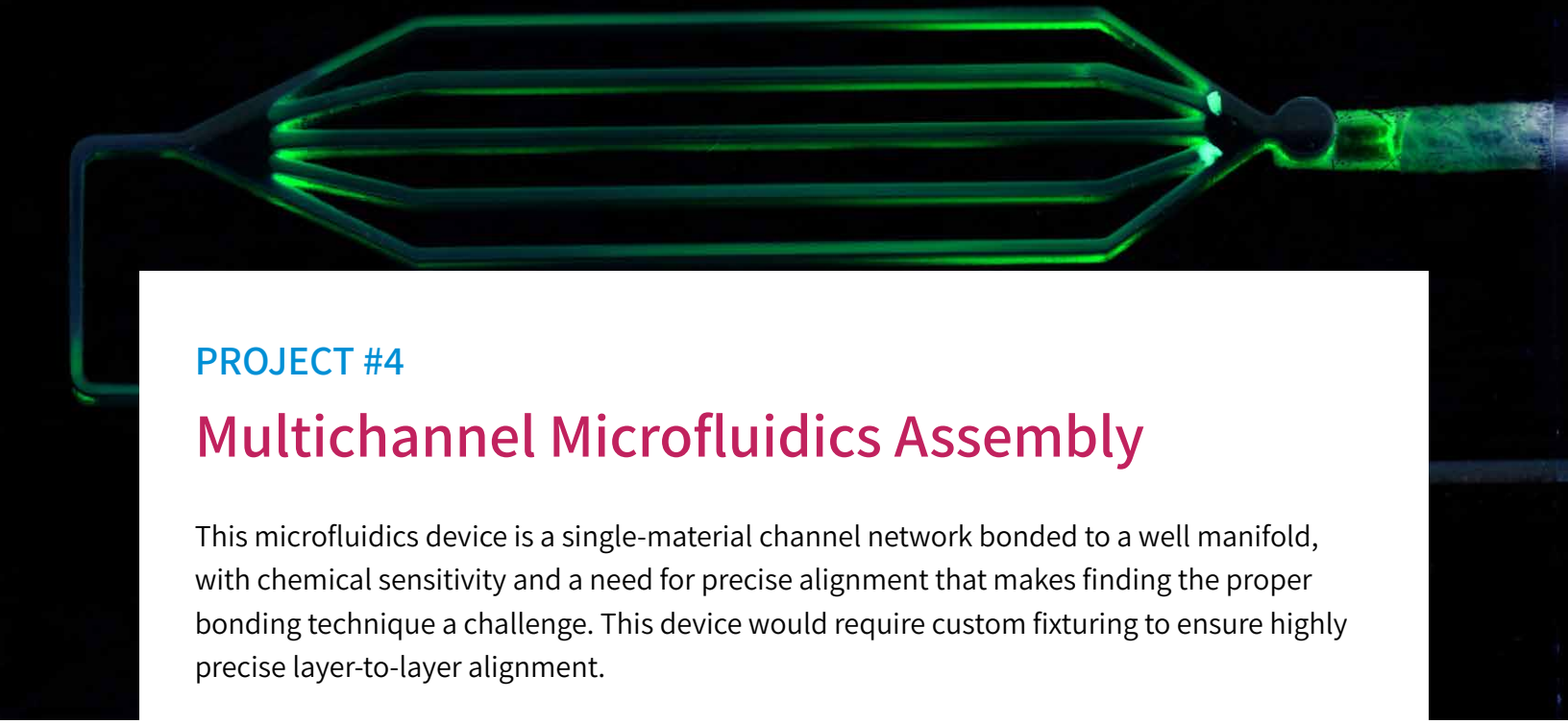
The unique requirements of this project make PSA film lamination the perfect fit for cover layer bonding. PSA film lamination offers:

- Compliant, full surface bonding of fine features
- Hydrophilic coating compatibility
- Preserves channel finish/quality

The Results

Dry adhesive bonding proves to be the best solution for process optimization in this case study. Utilizing PSA film lamination, we achieved the exact uniform channel depth and flow, hermetic sealing, and compatibility with hydrophilic coatings our customer's device needed.

- Temperature/Pressure/Time
- Uniform channel depth providing desired steady/uniform flow front profile
- Controlled adhesive thickness



PROJECT #4

Multichannel Microfluidics Assembly

This microfluidics device is a single-material channel network bonded to a well manifold, with chemical sensitivity and a need for precise alignment that makes finding the proper bonding technique a challenge. This device would require custom fixturing to ensure highly precise layer-to-layer alignment.

The Challenge

- Requires homogeneous material due to
- Chemical sensitivity
- Hermetic sealing
- Precise alignment of channel network to
- manifold
- Preserve channel surface quality for optical
- Analysis

The Solution

This project's need for precision and the properties of its chemically sensitive materials make Laser Welding the best fit for cover layer bonding:

- Fusion bonding—homogeneous bond
- Precision contour welding
- Preserves channel finish and quality
- Custom fixturing for precise alignment

The Results

Laser welding is the best solution for process optimization, providing layer-to-layer and weld-to-channel alignment within the tolerances of our client's needs, with 200 µm welds, 120 µm channels, and 150 µm channel-weld spacing in between them.

- Custom fixturing—precise alignment
- Laser power/speed/focus clamping
- 2-micron clear-to-clear laser welding

About Vantiva Precision BioDevices – Your Global Partner in Microfluidics Manufacturing

Vantiva Precision BioDevices is a global partner in microfluidics—a contract microfluidics manufacturer and Strategic Partner focused on connecting manufacturers around the world with the expertise and capabilities needed to bring their microfluidics designs to market.

With over 30 years of precision injection-molding expertise and global logistics capabilities, we offer end-to-end solutions to your design, production, and distribution challenges. Our team helps you find the best, most cost-effective solutions to produce your microfluidic product at any scale.

Our engineers are here to help you design and develop your microfluidic devices, offering rapid prototyping at industry-leading turn times, competitive pricing at scale from small batches for testing to cost-saving strategies for global distribution, and global logistics and supply chain expertise.

Our design-for-manufacturing capabilities include:

- Mastering and mold tooling, including lithography, DRIE, and ultra precision micro-machining
- Injection molding, a wide range of prototyping form factors, and a cleanroom production environment for manufacturing
- Expertise with a wide range of materials, including COC, COP, PMMA, PS, PP, PC and more
- Assembly and bonding techniques including clear-to-clear laser welding, thermal fusion bonding, PSA lamination, solvent bonding, and ultrasonic welding
- High-resolution inspection capabilities with laser confocal/optical microscopes and atomic force microscopy

Other capabilities include:

- ISO7 Cleanroom processing, assembly and packaging
- Reagent integration and specialty coatings
- Microfluidic testing lab
- Full-service, in-house logistics and distribution
- Laser cut film converting

For drug discovery, clinical diagnostics, point-of-care testing, and more, Vantiva Precision BioDevices brings you from design to rapid prototyping to production, providing expert advice and recommendations at every point to deliver the perfect microfluidic device to suit your product's needs and your budget.

Bring your device to market with the precision, accuracy, and global logistics expertise of Vantiva Precision BioDevices.

Get Started Today

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