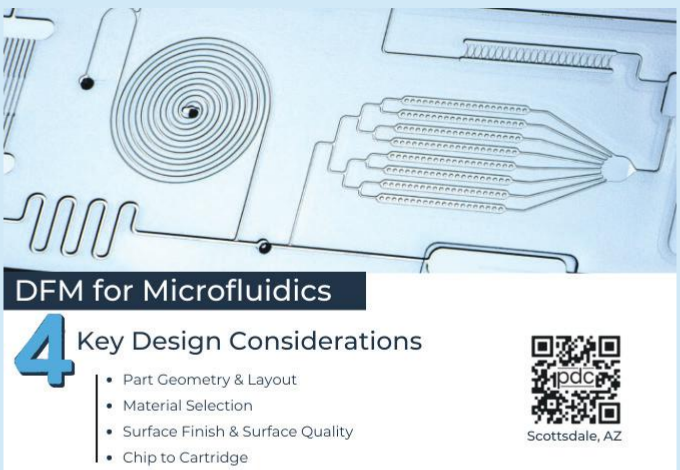
Optimizing Microfluidic Chip Design for Manufacturing:

KEY DESIGN CONSIDERATIONS FOR DFM

Microfluidic chips are complex devices integrating multiple functions such as mixing, separating, and detecting fluids at the microscale level. However, the design and fabrication of microfluidic chips are challenging due to the complexity of the device and the need for high precision and accuracy. Therefore, it is crucial to consider design for manufacturing (DFM) during the design phase to ensure that the chip can be manufactured cost-effectively and with high reliability.



DESIGN WITH THE END IN MIND

Designing a microfluidic part with the end application needs in mind during the prototype process is crucial for several reasons:

- o It helps to ensure that the prototype will meet the required specifications and functionality, saving time and resources in the long run.
- o It can help identify any potential design issues or limitations that may impact its performance.
- o It allows for optimizing the design to improve its efficiency, accuracy, and reliability.
- o It ensures that the final product will be suitable for its intended use, increasing its chances of success in the market.

"As an experienced manufacturer of microfluidics and microplates, PDC is an established partner to life science companies. Combining an ability to produce complex micro geometry with an understanding of material characteristics, PDC is well-positioned to support various applications in point-of-care (POC) testing, immunoassay, clinical chemistry, and molecular diagnostics."

- JEFF KYLE, CEO.

Key Design for Manufacturing Considerations

Several key considerations should be considered when designing microfluidic devices for Design for Manufacturability (DFM). These considerations focus on ensuring the device can be manufactured efficiently and at scale while maintaining high quality and functionality.

1. PART GEOMETRY & LAYOUT

The layout and dimensions of the cartridge and microfluidic features have a critical impact on the moldability of the part and the precision to which features can be reliably produced.

Wall Thickness

Wall thickness is critical in microfluidic manufacturing, impacting melt flow rate and pressure distribution through the mold cavity. Variations in thickness can significantly affect flow characteristics, potentially creating a variety of undesirable conditions such as non-uniform shrinkage, hesitation/backfill, air traps, and poor flatness/warp. Even when consistent, an overly thin wall thickness can challenge molding feasibility due to large pressure drops during fill and pack or premature freezing of the melt flow.

Flatness

Flatness is critical in microfluidic manufacturing as it affects how consumables interact with the equipment during microscopy or fluoroscopy, impacting optimal performance and accuracy. Therefore, ensuring the production of consumables with highly repeatable flatness is crucial for accurate results and overall equipment functionality and reliability. Lastly, part design can greatly impact the feasibility of achieving high flatness performance, where large standing structures like fill ports or ribs have the potential to lead to voids or warp if not properly accounted for in tool and process design.

Draft

Draft is crucial in all plastic injection molded parts, and microfluidics are no exception. An adequate draft ensures the part can cleanly and reliably release from the mold cavity without distorting or inducing stresses in the part during ejection. Insufficient draft angles can result in poor flatness performance, feature defects such as smearing or cracking, and in extreme cases, damage to the part or mold. Balancing draft angles with other design requirements like surface finish is essential to achieve desired device quality.

Aspect Ratio

Features on a microfluidic device less than ~200μm width become sensitive to the ratio of their height to width. Deep and thin features are formed by corresponding tall and thin steel features in the mold, which are fragile and have poor thermal conductivity. An aspect ratio of 1:1 is preferred on the micro-scale, and larger ratios need additional engineering evaluation.

2. MATERIAL SELECTION

Material selection is crucial for achieving the quality of the part and ensuring compatibility with the application's chemistry and analytical techniques. Different material families have varying levels of suitability for microfluidic applications. Collaboration between application scientists and manufacturers is essential, with the former bringing knowledge of chemistry and analytical techniques and the latter bringing experience in manufacturing and material properties.

Material selection is a fine balance between the functional requirements of the part and economic feasibility. Medical grades of commodity resin families such as polypropylene (PP), polycarbonate (PC), and polymethyl methacrylate (PMMA, acrylic) enjoy competitive pricing and supply due to their high volume and are appropriate for many applications that do not have specific functional needs of more specialized, high-performance materials such as cyclic olefin copolymer (COC) or cyclic olefin polymer (COP). The latter generally have superior performance regarding chemical resistance, optical clarity, and low autofluorescence.

3. SURFACE FINISH, QUALITY & FUNCTIONALIZATION

Microfluidic devices often require precise and uniform surface quality and finish to achieve optimal performance. Some surface finish specifications are purely cosmetic, while others serve critical functional purposes for the product. Optical features often require very high polish surfaces (SPI A1), while the main surface plane of many cartridges requires a textured media-blast surface for improved film bonding or light-scattering for contrast from fluidic channels when viewed in an optical system. Our tool build process allows for highly specific surface finish requirements.

Lastly, many applications require surface functionalization with a few key considerations detailed below:

Surface Modification Techniques: Various techniques are used to modify the surface properties of microfluidic devices, including physical adsorption, covalent bonding, plasma treatment, and self-assembled monolayers (SAMs). Each technique offers unique advantages and can be selected based on the desired surface properties and application requirements.

Biocompatibility: Functionalized surfaces in microfluidic devices should be biocompatible to ensure compatibility with biological samples and minimize interference with the desired processes. Biocompatible coatings or materials can reduce protein adsorption, cell adhesion, and potential toxicity, enhancing the performance of microfluidic devices for applications such as cell culture, tissue engineering, and diagnostic assays.

Hydrophilicity/Hydrophobicity Control: Controlling the wettability of microfluidic surfaces is crucial for efficient fluid transport and manipulation. Hydrophilic surfaces promote uniform fluid flow, reduce sample loss, and minimize bubble formation, while hydrophobic surfaces can be useful for specific applications such as droplet-based assays or oil-water separation. Surface modifications like plasma treatment or coatings can be used to achieve the desired hydrophilic or hydrophobic properties.

Surface Charge Control: Modulating the surface charge of microfluidic devices can influence the electrostatic interactions between the surface and analytes or cells, enabling selective adsorption or repulsion. Surface charge control is particularly relevant for applications involving biomolecular analysis, such as DNA or protein separation, where specific binding or repulsion characteristics are required.

Specific Functional Groups: Functionalizing surfaces with specific chemical groups allows for the attachment of biomolecules, probes, or receptors, enabling specific interactions with analytes or target molecules. These functional groups can be introduced through surface modification techniques or by using pre-functionalized materials. Examples include the immobilization of antibodies, enzymes, or DNA probes for biosensing or immunoassay applications.

Surface Stability and Longevity: Functionalized surfaces should exhibit stability and long-term performance to ensure reliable microfluidic operation. The choice of surface modification technique, material compatibility, and appropriate sealing methods play vital roles in maintaining surface functionality over time.

Multi-Functional Surfaces: In some cases, multiple functionalities may be required on a single surface to achieve complex microfluidic operations. Strategies like patterned functionalization or gradient coatings can be employed to create spatially controlled surface properties, facilitating diverse fluidic manipulations or selective interactions within a single microfluidic device.

4. CHIP TO CARTRIDGE

The resulting microfluidic chip produced by the injection molding process typically requires additional value-added processes to convert it to a functional microfluidic cartridge. Building an understanding of the required value-added steps during the design and development process will allow for a more efficient and seamless program execution. It is critically important to establish an early understanding and alignment regarding the materials and methods for bonding cover plates or films to seal microfluidic channels and the integration of additional functional elements like valves, reagents, filters, and electronics for sensing. This will enable a more informed design of parts, tooling, and process. One example is the precise component alignment is crucial to designing microfluidic devices in a chip-to-cartridge format. This results in tight dimensional tolerances for feature size and position over a relatively large footprint. In larger SBS format cartridges, maintaining these tight tolerances becomes particularly challenging due to anisotropic shrinkage characteristics that manifest from the thin wall sections and long length of fill. One of PDC's core competencies in microfluidic mold design is quantifying and adapting to this to maintain optimal precision and consistency in the molded part. Consideration for the final system or cartridge is a great example of the philosophy of "starting with the end in mind" and critically important for overall program success.