



Micro 3D Printing: Enabling Miniaturization

Additive Manufacturing has been around for 30 years – used in prototyping and now moving into production, but the biggest value of AM comes from prototyping and production of parts that are difficult to manufacture using other more traditional methods.

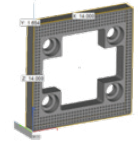
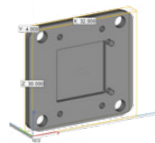
As all the noise settles concerning the benefits and drawbacks of additive manufacturing, what becomes most clear is that when fabricated parts are easy to make using standard machining methods, additive manufacturing becomes less and less necessary as a tool. Yet, when that is not the case, additive manufacturing becomes a very beneficial tool.

Additive manufacturing is an important and valuable solution when customers need to produce parts that are difficult to fabricate using standard machining methods, such as parts that include complex design features like internal cavities and geometries that cannot be machined in, and structural elements that make other machining processes too cumbersome or difficult to complete effectively (see Figure 1).

It is a common understanding that nothing is more difficult to produce — for prototypes or production

parts — than when miniaturization is critical. Because miniaturization is a continual trend in most industries, especially medical devices, electronics connectors, and micro-electro-mechanical systems (MEMS), providing a way to use additive manufacturing becomes an important alternative to other production methods. In fact, the smaller the part that needs to be produced, the more valuable it is to have a machine that can manufacture those parts quickly and accurately.

At this point in time, 3D printers have been designed to focus on printing larger parts quickly where best achievable resolutions are around 50µm and tolerances around 100µm. At the other end of the spectrum are systems that produce parts with sub-micron resolutions of smaller than 5µm. This left a huge gap between capabilities. With the idea that the market drives the technology, it was clear that a system that could print micro-sized parts at a reasonably high print speed was needed.



PARTS TOLERANCE REQUIREMENT	Simple Structure		Complex Structure	
	PRICE	TIME	PRICE	TIME
~ 50µm	~\$3,000	1-2 months	~\$30,000	Much longer
~ 25µm	~\$8,000	1-2 months	~\$70,000	Much longer
~ 10µm	~\$15,000	1-2 months	~\$150,000	Much longer

Figure 1: While demand is large for high precision parts, there are limited economical solutions. High precision molding is expensive/slow, while other 3D printing technologies lack resolution/precision.

High production costs and long lead times to market for micro-sized parts is often due to the complexity of producing such a part with high-precision equipment. Micro-machining, micro-injection molding, and diamond turning all have high setup and tooling costs that can take extended periods of time to put into place. Using these methods, the volume at which they become economical is typically in the low thousands for most parts. For small, high-precision parts that economical threshold can be significantly greater because of the high tooling costs. Additive manufacturing for microfabrication of prototypes as well as low-volume production parts can mitigate the challenges posed by traditional methods.

Producing Micro-Sized Parts

The smaller the part, the more precise the production process must be. High accuracy and resolution are necessary for items such as the connectors used in cell phones and tablets, cardiovascular stents, microfluidic devices for medical pumps, MEMS, as well as industrial sensors and edge technology components. Note that most standard additive manufacturing processing machines are not designed to provide the resolution needed for micro-sized parts. For example, note the XY resolution of the most used 3D printers on the market: SLA provides an XY resolution up to ~50µm, TPP-DLW offers resolutions of <50µm, and

MOLDING VS. 3DP • STANDARD PARTS

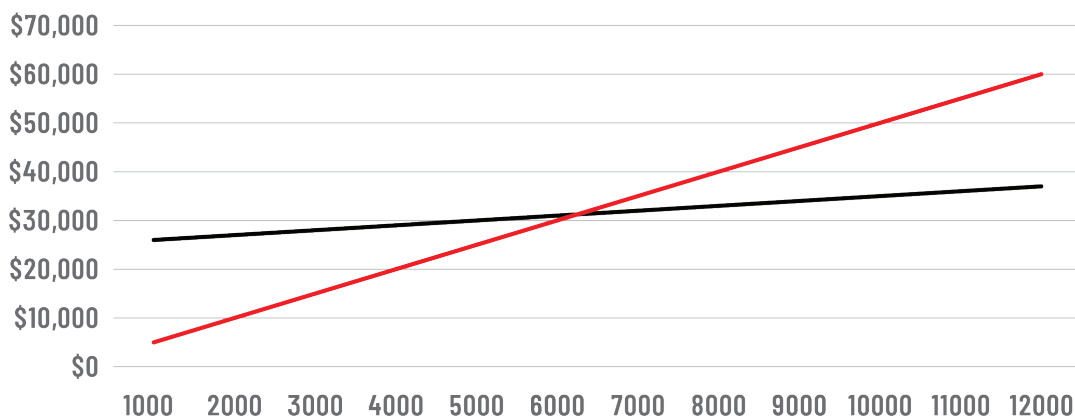


Figure 2a:

The Injection Molding/3DP Cost Volume Crossover: For standard parts, crossover volume is typically in the low thousands.

MOLDING VS. 3DP • SMALL / COMPLEX PARTS

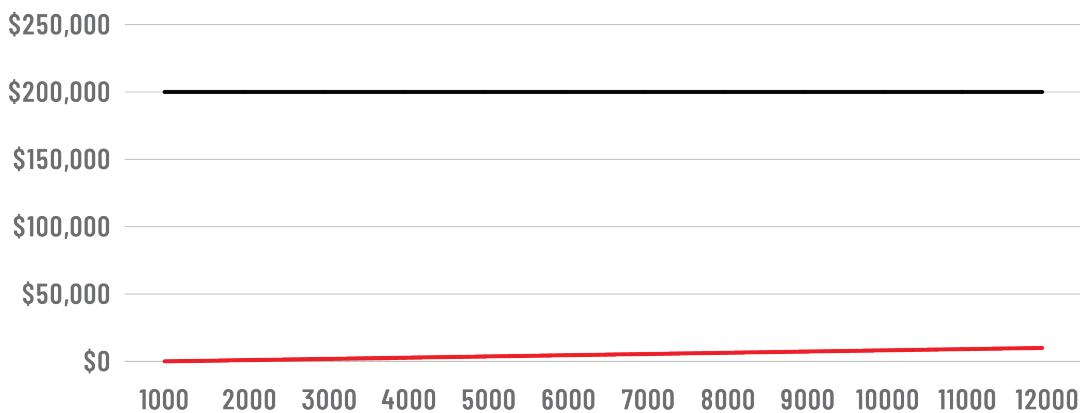


Figure 2b:

The Injection Molding/3DP Cost Volume Crossover: For small, high precision complex parts, crossover volume is much higher due to very high mold cost and low-cost contribution from material.

FDM provides resolutions up to $\sim 200\mu\text{m}$. In order to get the best results from a 3D printing system, it was necessary to rethink and redesign the system to provide accuracy, resolution, and precision.

To understand the need better, consider the specifications separately. Resolution is a function of XY feature size and Z-axis height or thickness. Both are important even though the XY value has a stronger relationship to print quality and surface finish. This is important to consider regardless of the smallness of the part, because even large parts may need tiny holes, crisp edges, or pin-like bosses. When it comes to accuracy things get clearer. If the part produced does not have the exact dimensions the user specified in, then it is not accurate enough. Precision, too, becomes an issue with small parts because no matter how precisely your part is produced, the part is unusable if elements of the design are not accurate. The technology that has emerged based on the requirements of the industry is a combination of technologies — in combination with some high-end motion control elements.

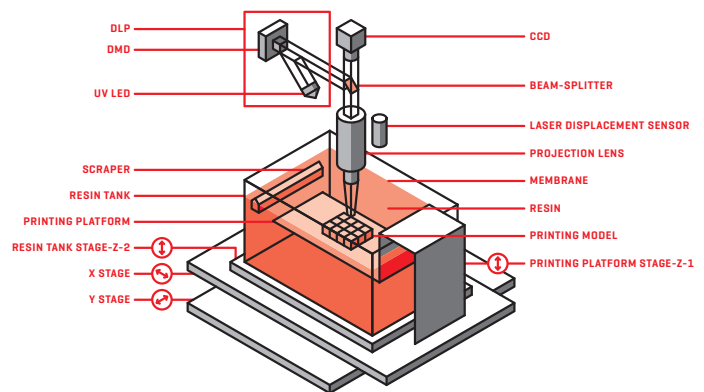
Projection Micro Stereolithography (P μ SL) technology designed and manufactured by Boston Micro Fabrication (BMF) allows customers to obtain 3D printed parts with $2\mu\text{m}$ resolution and ± 10 micrometer at scale (see Drawing 1). P μ SL printers separate themselves from other 3D printing techniques by incorporating the benefits of both digital light processing (DLP) and stereolithography (SLA) technologies.

P μ SL uses a flash of ultraviolet light at micro-scale resolution to cause a rapid photopolymerization of an entire layer of resin at ultra-high accuracy, precision, and resolution that cannot be attained with other technologies. P μ SL technology supports continuous exposure for

faster processing (see Drawing 1). By providing additional design elements, P μ SL provides added benefits to the user.

For example, standard SLA technology uses a bottom-up build method that requires the use of support structures to hold the part to the base as well as to support overhanging structures. Currently, SLA systems can typically achieve an XY resolution of $50\mu\text{m}$, a minimum feature size of $150\mu\text{m}$, and overall tolerance of $\pm 100\mu\text{m}$. Similarly, DLP also uses a bottom-up build structure and has the same needs for support structures. These systems typically provide an XY resolution of $25\text{--}50\mu\text{m}$, a minimum feature size of $50\text{--}100\mu\text{m}$, and overall tolerance of $\pm 75\mu\text{m}$.

Note that the P μ SL process is a top-down build, which first and foremost minimizes the need for support structures while also providing a way to reduce damages to small features and remove bubbles with a transparent membrane. Overall, P μ SL systems can achieve XY resolution down to $2\mu\text{m}$, minimum feature size of $10\mu\text{m}$, and dimensional



Drawing 1: Within a BMF microArch™ 3D printing system, UV light is projected onto a DLP chip according to the layer's mask pattern. By controlling the projection lens, P μ SL technology can achieve resolutions of several micrometers or hundreds of nanometers.

tolerances as high as $\pm 10\mu\text{m}$. Providing this type of quality takes every system component to be properly employed, including the resolution of the optics, the precision of the mechanical components, the control of the exposure and resulting curing, the interaction between the part and required support structures, the overall size of the part, and the ability to control the tolerances across the build.

Material Availability

When working with such a wide variety of micro-parts, the need for the right material characteristics becomes even more important. The smallest variation due to corrosion, heat damage, or caustic material damage can be high. Working with highly sensitive biological elements and chemistries for such devices as drug delivery pumps means selecting a material that won't somehow interact with the chemicals being administered. Similarly,

industrial connectors might need to be protected from environmental hazards such as extreme temperatures and washdown chemicals.

UV curable materials include plastic resins that are rigid, tough, high-temperature resistant, biocompatible, flexible, or transparent. In addition to a wide variety of engineering and biomedical plastics, P μ SL technology supports the use of hydrogels and composite resins that contain ceramic or metal particles (see Chart 1). The company also offers an open material platform and is working with a number of third-party suppliers and OEMs to add additional materials for specific applications.

Incorporating Micro Printing Capabilities

One company that is using Boston Micro Fabrication's 3D printers to great success is Isometric Micro Molding, Inc. Isometric is a micro molding and micro automated assembly strategic supplier focusing on ultra-

	GR HARD	HEK STRONG AND TOUGH	HTL HIGH TEMP, LOW VISCOSITY	UTL TOUGH	BIO BIOCOMPATIBLE	RG DURABLE
TENSILE STRENGTH ASTM D638	85 MPa	70.5 MPa	79.3 MPa	42.6 MPa	42 MPa	42 MPa
ELASTICITY MODULUS ASTM D638	3.8 GPa	2.6 GPa	4.2 GPa	2 GPa	1.8 GPa	274.3 MPa
ELONGATION AT BREAK ASTM D638	3%	14.1%	2.2%	49.4%	2.5%	11.8%
FLEXURAL STRENGTH ASTM D790	97.4 MPa	93.8 MPa	120.6 MPa	35.3 MPa	65 MPa	77.7 MPa
FLEXURAL MODULUS ASTM D790	3.2 GPa	2.5 GPa	4 GPa	1.5 GPa	2.3 GPa	2.1 GPa
IMPACT STRENGTH ASTM D256	47.5 J/m	-	30 J/m	-	-	-
HEAT DEFLECTION TEMPERATURE (0.455 MPa) ASTM D648-07	102 °C	82 °C	140.7 °C	45 °C	115 °C	56.5 °C
HARDNESS ASTM D785	86 Shore D	85 Shore D	90 Shore D	80 Shore D	80 Shore D	77 Shore D
VISCOSITY	25 cps	450-500 cps	85 cps	185 cps	20 cps	-
STANDARD COLOR	Yellow trans / Black	Yellow trans / Black	Yellow trans / Black	Yellow trans / Black	Yellow trans	Yellow trans / Black
ADDITIONAL	-	YIELD ELONGATION 5.7% YIELD STRESS 70.5 Mpa	Tg 172 °C	YIELD ELONGATION 5.6%	Cell culture survival rate in vitro = 75 %	-

Chart 1:
P μ SL technology can be used with a variety of hybrid material options.

precision products such as medical device and drug delivery applications. They are a vertically integrated company manufacturing micro-sized parts and small parts with micro features or tight tolerances. They round out their vertically integrated micro molding, micro tooling, CT scanning, micro automation, and assembly with BMF 3D micro printing capabilities.

The company's main core value is transparency, and they collaborate with customers very early in the product and process development cycle using DFM and scalability methods to produce innovative and successful micro-sized components from product conception through high volume production. Isometric Micro Molding offers 30+ years of experience and expertise in thin wall micro molding, high cavitation micro molding, bioresorbable micro molding, pharma micro molding, ophthalmic micro molding, 2-shot micro molding, and high volume micro automated assembly.

The company offers in-depth polymer material expertise to its customers since there is no substitute for experience in material selection and the understanding of material behavior while under process conditions in micro molding. The company's plastics engineering team freely and transparently applies their decades of expertise to help with applications in microfluidics, implantable products, drug delivery, and a host of thin-walled micro molding applications in the medical and pharma fields.

For micro part prototyping, the company uses 3D micro printers from Boston Micro Fabrication to produce components with 2 μ m and 10 μ m tolerance levels to support customers through their development phase. When it comes to 3D micro printing, Isometric Micro Molding's experienced team of engineers understands the correct methodology to produce the parts needed to flush out geometry and down-select

scalable micro to small part and assembly designs quickly and accurately. In most cases parts are in hand in fewer than three days, so that customers can evaluate and test critical components at their facilities — especially if mating parts are being used. Customer feedback indicates that they are pleased with Isometric Micro Molding's product resolution and quality as well as the speed at which they are able to use parts for their initial design and “show around the table” functions.

It is not uncommon for micro to small plastic components to go through an average of three rounds of prototypes before settling on a solution. These same customers often put constraints on their designs based on assumptions that are not always true or necessary and can be proven by empirical methods very quickly. Because the Isometric Micro Molding team has extended years of experience in providing design help to their customers, tiny part and feature solutions are presented that were never thought possible before. Creativity and knowledge go hand-in-hand as customers work with Isometric. Customers have exploited the company's capabilities by arranging multiple different designs to be 3D printed at once so that they can experiment with various iterations simultaneously to quickly get to a final design. As a whole, Isometric is seeing a marked increase in companies that want micro 3D printed parts to support their development journey.

Additional Application Examples

Overall, the combination of ultra-high resolution, accuracy, and precision allows customers to produce intricate and exact parts for a wide variety of industries. Medical devices (see Photo 2) from stents to prosthetics can be prototyped to optimize patient comfort and care, then produced in low quantities if needed. Additional products produced include a

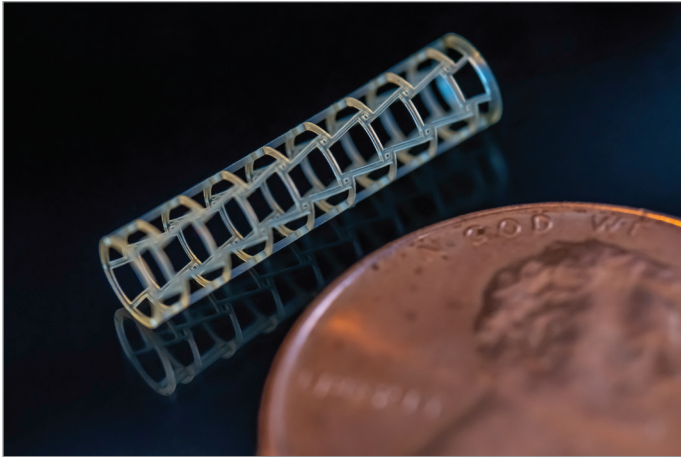


Photo 1: Small medical components can be accurately produced using micro 3D printers.

Photo 2: Connectors used in a wide variety of small electronics devices can be produced in low-volume production quantities using micro 3D printers.



Photo 3: A wide variety of valve components can be prototyped and produced in low volumes using micro 3D printers.



spiral syringe needle for minimally invasive surgery, a valve for a gene sequencer, and lab-on-a-chip (LOC) devices that integrate multiple lab functions and can filter extremely small fluid volumes. With the use of biocompatible materials, the possibilities for medical components becomes even broader.

MEMS applications span multiple industries and can include a wide variety of specialized components. Micro switches, connectors (see Photo 3), and collateral components are used on everything from cell phones to SmallSat satellites. Other parts being produced include gears and motors, valves (see Photo 4) and actuators, and a wide variety of sensors. MEMS devices are used in accelerometers for airbag deployment and electronic stability control. In the optics market, micro components are used in optical sensors, optocouplers, and fiberglass conductors.

Expanding the capabilities of micro components, P μ SL technology is used in research and development in universities in an effort to revolutionize product design, drug discovery, and microfiltration. This technology can produce anisotropic structures where a 3D printed model can have different mechanical properties in different directions. In one direction, a structure can be compressible and provide energy absorbing and dampening, while in another direction, the structure can provide stiffness for load bearing.

As advances continue to be made in 3D printing and the demand for smaller and smaller products increases, the role of additive manufacturing for complex parts will continue to grow. As production barriers for 3D printing get broken down, such as technical requirements and economics, the real value will still be reflected in the parts most difficult to make.