Using Additive Manufacturing to Aid the Fabrication of Complex 3D Microtargets

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Introduction

Additive manufacturing (AM), also called 3D printing, is an advanced and highly versatile manufacturing process that does not have some of the limitations inherent in other 'top down' processes such as lithography and micromachining in which sophisticated geometries are not always achievable due to the directional or optical limitations of the processes. The 'bottom up' nature of AM allows complex and sometimes interlocking geometries to be produced.

The use of additive manufacturing within the Target Fabrication (TF) group is not a new development; 3D printing has been used for many years to print parts on the millimeter scale such as alignment components for targets and target posts, and large scale parts such as target delivery boxes and support structures. However, the limiting factor for TF to extend its printing capabilities was the resolution of the existing AM system that used a Polyjet [1] process which, while more accurate than SLA (16um layer thickness to approx. 50um), does not give the required lateral resolutions for actual microtarget parts. Such parts have historically been produced by precision micro-machining which has <10um tolerances. It is desirable to use 3D printing to replace some of the micromachined target components to reduce costs and shorten turnaround times on design iterations, however, sufficiently high resolution must be achieved.

This article will discuss the recent upgrades to the TF suite of 3D printers with the purchase and commissioning of a new micro additive manufacturing system and will give examples of where it has been used for target production.

Projection Micro-Stereolithography Printer

The TF 3D printing capabilities were enhanced recently with the purchase of a BMF (Boston Micro Fabrication) S240 micro printer. Micro printing is a process that allows for high precision manufacturing of microscale components and the new system uses projection micro-stereolithography (PµSL) - a form of stereolithography (SLA) which, rather than using a spot to cure the resin, exposes the full or a section of the image. The technique produces small parts with 2-micron resolution and +/- 10-micron accuracy. A test part is shown in Figure 1.

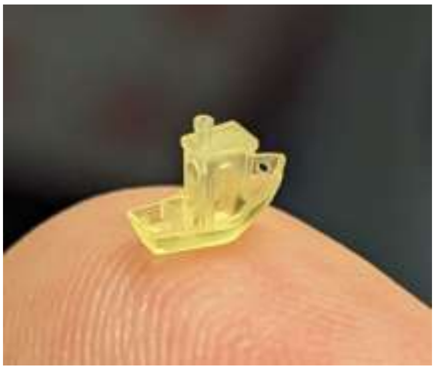

Figure 1. Example of a test print. 3DBenchy is a widely-used test object designed to evaluate accuracy of 3D printers.

In the technology (See Figure 2) a flash of UV light causes the rapid photopolymerisation of selected areas of an entire layer of resin. When the area is cured with the light the polymer hardens; the platform is then re-submerged to produce another thin layer of resin which again is selectively cured to become the next layer of component. Each layer has a Z axis height of 10um. The process is repeated until the full part is built up using cured individual layers.

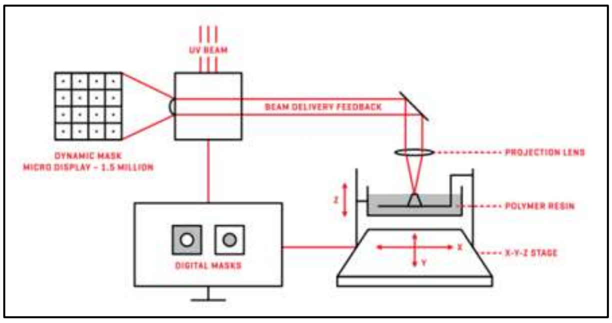

Figure 2. Schematic of a PµSL system.

When referring to the S240 as a 10µm system, the 10µm refers to the pixel size. A pixel is the basic building block of a 2D digital image: a collection of pixels are combined to create a full image or set of data. Each pixel has a unique geometric coordinate. In the PµSL method pixel size defines the resolution of the printer in the XY plane. What makes the pixel so important in projection-based printing is that it is the smallest element that can be used to create a feature. [2]

Figure 3. The BMF S240 printer and finished parts on the print bed.

Examples of AM Components in High Power Laser Targets

The capability to print components with high resolution has opened many opportunities in target design (enabling more complex and simultaneously more flexible geometries to be made) often reducing or eliminating the need for assembly fixtures by producing multi-component assemblies in one print. In some cases a sub-set of components (See Figure 3) or even a complete laser microtarget have been printed. This section will detail some of the components the TF group has worked on since the purchase of the high-resolution printer.

Micro-Ring Supports

Figures 4 and 5 show a target design that consists of two rings separated by a distance of a few mm with both rings positioned at a specified angle to their base. The design is to enable the mounting of two opposing foils at 45 degrees from the axis of the chamber in a colliding foil geometry. Previous versions of the target were manufactured using up to 6 pieces with the foils being supported on carbon fibres and subsequently needing to be manually positioned at 45 degrees. In the AM design it is possible to print the vertical support bars, the struts that hold the foil and a small ring to position the foil at 45 degrees in one print. It is also possible to print the holders accurately at the required offsets and easy to modify the target to have a range of separations.

It is noted that due to the geometry of some components it was necessary to build support structures to hold them during printing. The supports are incorporated at the design stage and great effort goes into designing them such that they do not affect the final target and also can be removed without damaging the part.

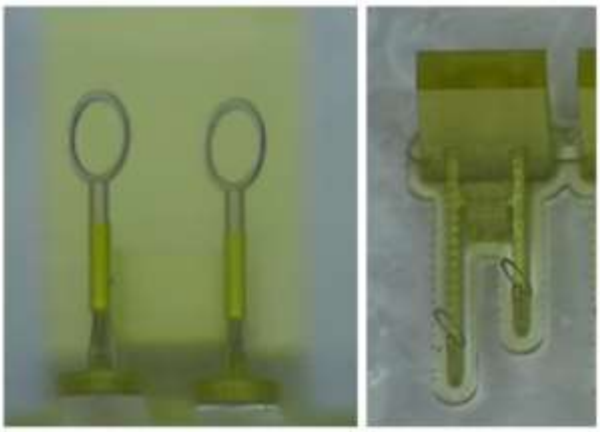

Figure 4. Colliding foil target support rings (left) and the full target with mounting supports on the print bed (right).

Figure 5. Final colliding Foil target assembly

Thin Foil Supports

In some experiments it is beneficial to have plastic rather than metal supports to reduce the effects of EMP on the experiment [3]. When producing foils of the order of a few microns thickness there is usually a bend or curvature in the foil, and they are not self-supporting. It is standard practice to support such foils on a photo etched metal frame. Figure 6 (left) shows a plastic version of a support frames made on the BMF printer. The mount is only 50um thick corresponding to 5 layers of printed material.

The foil support was a difficult component to make because the process of peeling the support from the base plate of the printer introduces some bend to the component. In this case foil flatness is paramount and consequently any curvature on the mount would not produce good targets. Therefore, to create supports within flatness specification, great care needs to be taken when removing them from the printer base.

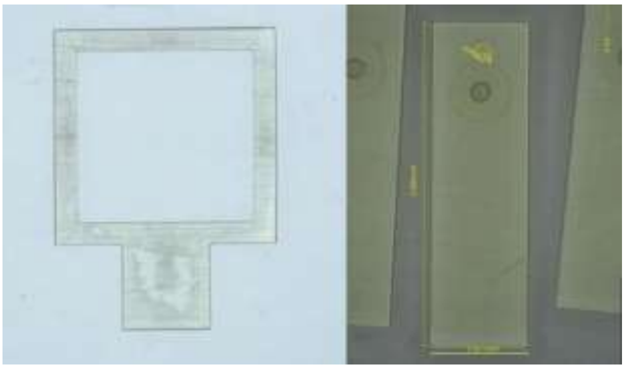

Figure 6. A 3D printed Square thin foil support that is 5 x 5mm (external) and 50um thick (left), and a 3D printed Round thin foil mount (right).

Another type of mount for sub-micron thick foil targets (shown right in Figure 6) incorporates a raised ring (approximately 20um high) around the edge of the mounting hole. The ridge is used to ensure that foils are held flat and such mounts have previously only been possible to make cost effectively (in copper) by photo etching them in larger numbers. Due to the high resolution of the BMF printer it is possible to print such mounts in plastic. The figure shows a 50um thick mount with an aperture of 500 µm diameter over which an ultra-thin film would be positioned. The target mount was initially, due to the thinness the component, not robust enough to release, however, by curing under a strong UV light, the strength could be improved which reduced the bendiness it initially displayed and allowed it to be fielded on experiments.

Full Target Assemblies

In cases where the geometries and the materials are compatible with the experiment it is possible to print (almost) complete target assemblies in one print run. In the example in figure 7 it is possible to print up to 90% of the target assembly including the spacer block, the foil mounts, and the shield on the rear of the target.

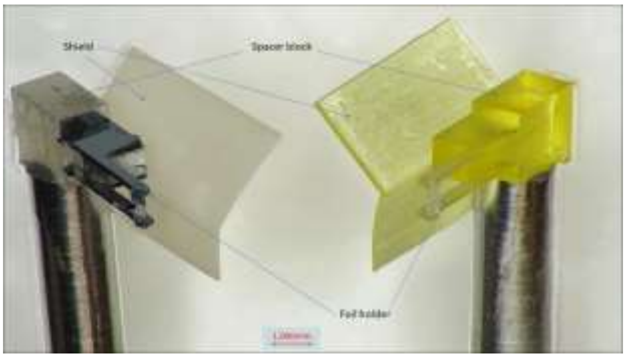

Figure 7. Traditionally made (multi-component) experimental target (left) and proof of concept 3D printed target (right).

To assess the applicability of PµSL for target fabrication a complex microtarget assembly was selected for high resolution AM printing as a proof of concept trial. The target (shown in Figure 7) is a multicomponent assembly which included a pair of foil holders with a 200x200µm aperture to hold a thin film, as well as a 100µm pinhole assembly suspended between the foil holders. Using established fabrication methods producing the target is an intensive process with weeks of design, laser micromachining, MEMS production and micro assembly required. In contrast the designed-for-AM target was printed overnight, and was well within the tolerances set by the user. The pinhole between the foil holders was also within the tolerance, however, in this case, the material was not correct for a pinhole and so could not have been used. None the less the printed assembly is a clear demonstration of how AM and conventional machining can be combined to produce high specification targets at much reduced timescales and lower cost.

Effects of Build Orientation and Set-Up

When producing AM parts it is crucial to consider a) the build orientation, b) the way in which the target is supported, c) how the target integrates into an assembly, and d) the way that printed parts will be cleaned. An example of build orientation artifacts can be seen on the foil holder in the proof of concept target described in the previous section. The image in Figure 8 shows the foil holder part of the target which has the 200x200um aperture. It is clearly visible that the resin layers which are cured to form the component had an effect on the smoothness of the internal edges of the aperture. Such inconsistency could adversely affect the experimental results because edge effects can impact the propagating plasma produced by the thin foil that is held over the aperture. To improve the surface finish and improve foil flatness the orientation of the component with respect to the print stage can be changed prior to the print.

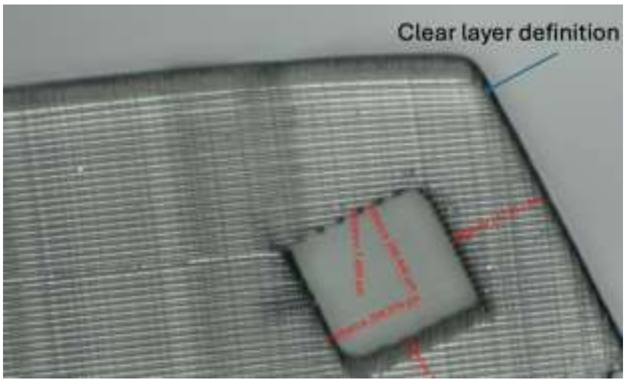

Figure 8. Target component that shows layer curing steps which can influence the edge quality.

Conclusions

The examples described show initial results integrating the newest capabilities of AM into the target fabrication research and production streams. Whilst there are some targets that are not suitable for AM production there are many geometries that can be produced which could not be fabricated in any other way. It is also critical to understand the limits of the AM systems when designing targets, specifically i) the complexities of supporting structures, ii) the consequences of removing support pillars, iii) build orientation, and iv) the strength of small components.

TF will use AM techniques moving forward to increase productivity, reduce development times and to aid assembly and production. Future targets will be more complex and larger numbers will be needed – in response AM will enable TF to meet demand, keep costs down and exploit resources better.

References

1. https://www.stratasys.com/uk/guide-to-3d-printing/technologies-and-materials/polyjet-technology/
2. BMF User Guide S240 Ver 1.1 20230918
3. Bradford, P. et al. (2018) 'EMP control and characterization on high-power laser systems', High Power Laser Science and Engineering, 6. doi:10.1017/hpl.2018.21.