EXADDON

INDUSTRY OVERVIEW

ADDITIVE MANUFACTURING AT THE MICROSCALE - 2021

In 2020, we conducted an analysis of additive manufacturing (AM) companies operating within the microscale range. We conducted this appraisal of the "competitive" landscape for two reasons. First, to see what technologies existed within the space in which Exaddon operates, and how they may be used for similar applications to ours, and secondly, whether the electrochemical deposition process used within our CERES system has a truly comparable rival within the additive micromanufacturing (μAM) market.

One year on, we have surveyed the same providers from the original matrix to see what developments have been made within the world of additive micromanufacturing technology. The overview graphic of the landscape is presented on page 2, followed by a brief appraisal of each company's technology. This details their respective methods of printing, the materials used, the size range possible, the crucial dimensions involved, as well as a visual example of an object printed with their technology. For the metal printing providers, there is a note on how their capabilities compare to those of Exaddon, as we see these as the most direct competitors to our CERES technology.

The Exaddon CERES μAM Print System

Disclaimer: Whilst all companies were contacted to provide their own data, not all responded. As such, information was collected to the best of our ability, and inaccuracies may be present. Permission was requested for images, and images remain the property of their respective companies.

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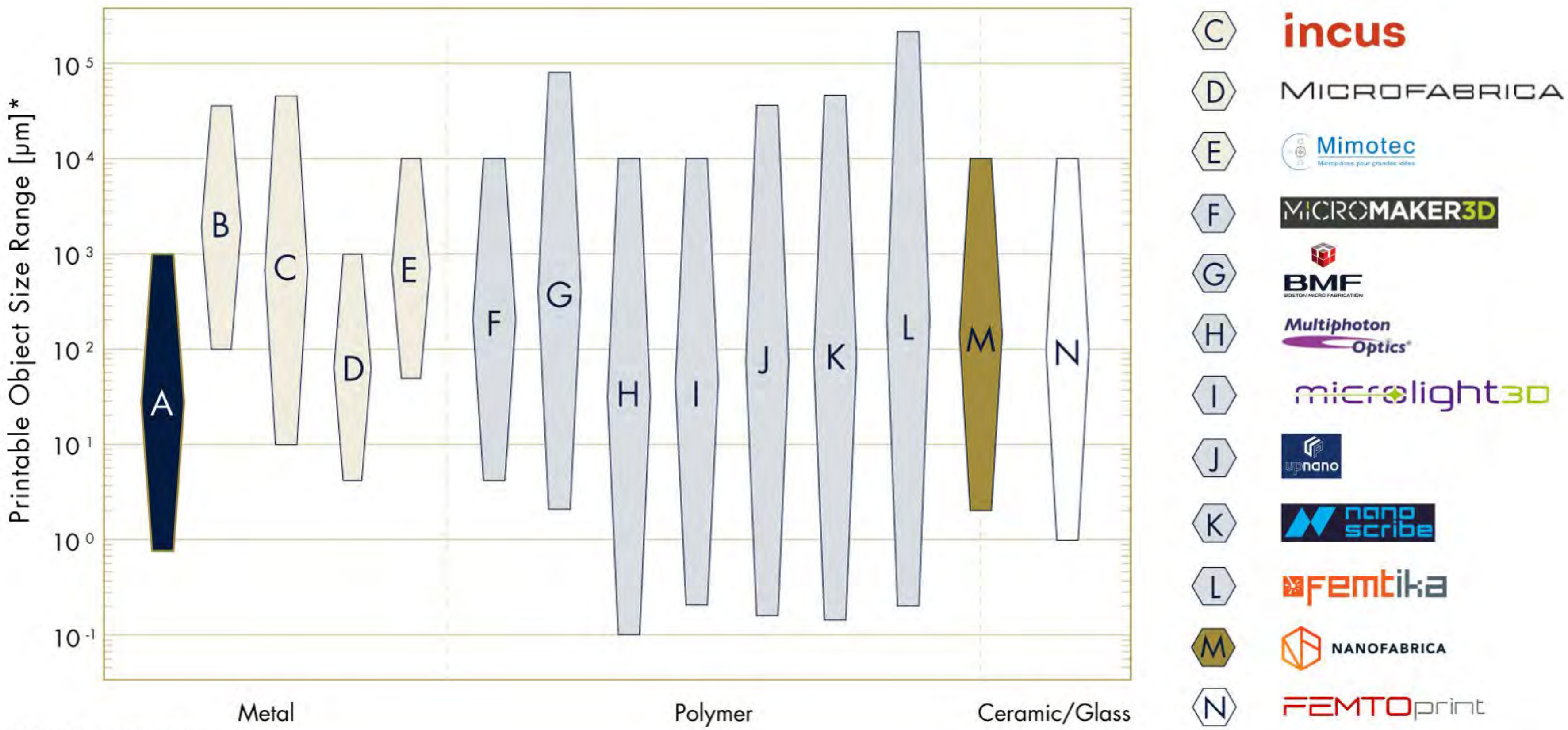
EXADDON µAM COMPETITIVE LANDSCAPE 2021



*Estimated, based on available data

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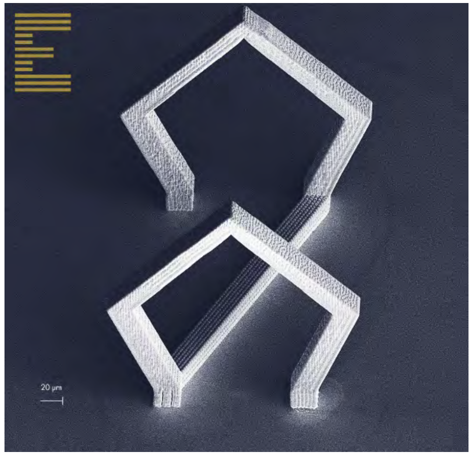
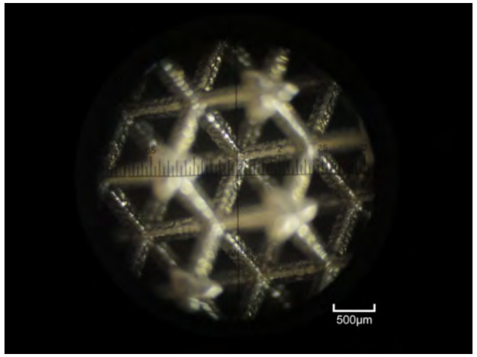
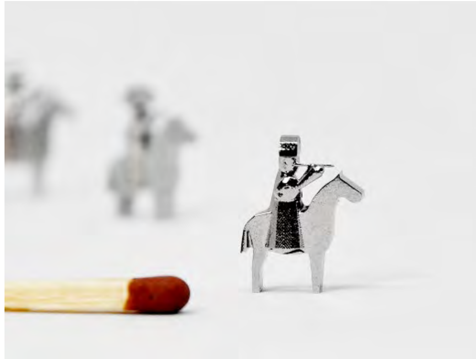
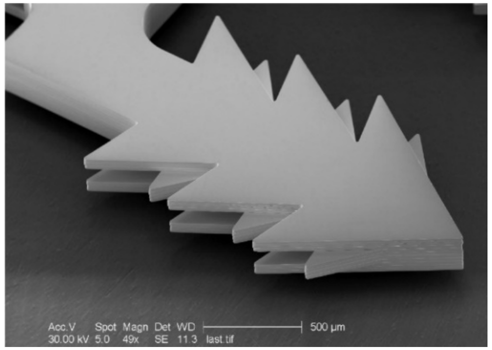
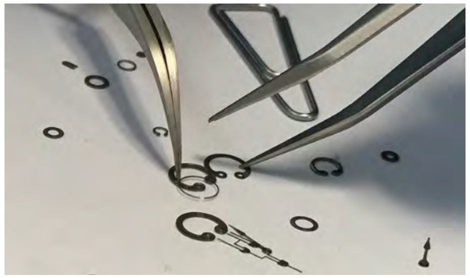
Company	Print Material	Overview	Example Object
EXADDON	Metal: -copper -gold -nickel	Exaddon's CERES µAM system prints microscale metal objects by electrodeposition. The system is optimized for printing free-standing microscale structures such as pillars, needles, coils, and lattices on existing surfaces, such as ICs or wafers. Printing occurs at room temperature, and no post-processing is necessary. Printable size range is 1 µm – 1 mm, resolution < 1 µm, and structures can be located on print surfaces with <1 µm accuracy. This makes it ideal for applications in brain-machine interfaces, semiconductor surface modification, and HF communication components.	
3D micro PRINT	Metal: stainless steel - 1.4404 (316L)	3D Microprint employ a technique they call Micro Laser Sintering, which allows wall thicknesses as low as ~100 µm. As per other sintering methods, metal powder is used, which in turn requires a post-processing step. Closest comparable structures to Exaddon's capabilities are lattice structures, yet these appear to require an external bounding wall, and have a wall thickness of 100 µm, thus placing them in a much larger size range.	 Source: 3dmicroprint.com
incus	Metals:	Incus use what they term Lithography-based Metal Molding (LMM), which uses a feedstock of metal powder dispersed among a photocurable resin	

	-iron-based alloys -titanium -copper -precious metals -hard metals	binder system. This process affords a layer thickness of 10 – 100 µm, and a lateral resolution of 35 µm. The LMM method does not require support structures as the feedstock is self-supported, though post-processing is required. Compared to CERES, the lateral resolution and layer thickness is very large, thus ruling it out for producing comparably filigree parts for fine applications, such as micropillar arrays for neural interfaces.	 Source: incus3d.com
MICROFABRICA	Metals: -Valloy 120 (nickel-cobalt) -palladium -rhodium -copper	According to Microfabrica, their MICA Freeform method involves “atomic-level deposition through patterned photoresist”. This process “provides a layer’s 2-D geometry, and planarization defines its thickness”. The layer thickness is limited by the tolerance of the planarization process, which is around 5 µm. X/Y accuracy of ±2 µm is limited by the photoresist pattern, and minimum feature size is 20 µm. Like Exaddon’s CERES system, MICA Freeform employs atomic-level electrodeposition of metal, and also has a max. object height of 1 mm. However, these are the only similarities; the minimum feature size of MICA Freeform prints is over 20x larger than that of CERES.	 Source: microfabrica.com

Mimotec Micropièces pour grandes idées	Metal alloy	Mimotec's UV-LIGA technology combines photolithography and electroforming. UV-LIGA uses UV light to alter a photoresin via a photomask pattern. Non-polymerized resin is dissolved away, before a galvanizing process creates metal parts from the polymerized objects. These are removed from the wafer substrate by another dissolution process. Accessible manufacturing range is estimated to be from 500 µm – 10 mm. The UV-LIGA system appears to be intended for batch production of new parts on a blank wafer, rather than printing *in situ* on existing structures or wafers, as is possible with CERES (e.g., printing connections between conductive traces).	 Source: mimotec.ch
CallaghanInnovation MICROMAKER3D	Polymers	Micromaker3D's Laminated Resin Printing (LRP) uses elements of microfabrication-based photolithography. X/Y resolution is 5 µm whilst Z resolution is 125 nm. Layer height is customizable from 5 µm to 100 µm, and overhangs are possible. The LRP system can print on a variety of substrates including paper, fabric, silicon wafers, and PCBs.	 Source: micromaker3d.com

BMF – BOSTON MICRO FABRICATION

Ceramic, photosensitive resin

BMF use Projection Micro Stereolithography (PµSL), which affords a printing resolution of 2 µm – 50 µm and a printing tolerance of ±10 µm - ± 25 µm, depending on the machine. As per the other providers listed here, BMF print in layers. Resolution of the pictured object is 10 µm.

Source: bmf3d.com

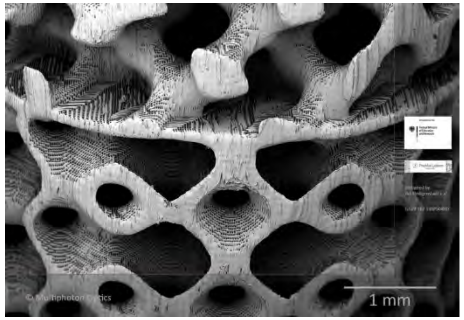
Multiphoton Optics

Polymers

Multiphoton use two photon polymerisation (2PP) with a wide range of materials and substrates. They have a printable size range of 100 nm – 10 mm, a development which was realized in Dec 2020.

Minimum X/Y feature size is 100 nm, and minimum Z feature size 270 nm.

Substrate thickness is ≤ 49 mm.



Source: multiphoton.de

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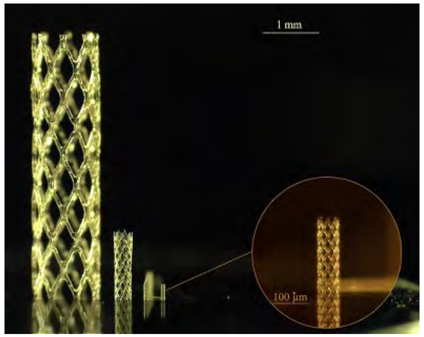
microlight3D

Biomaterials & polymers

Microlight3D's uFAB-3D system uses 2PP and is compatible with biomaterials as well as various polymers. Microlight3D claim there are no shape constraints. The X/Y resolution (voxel size) is 0.2 µm – 3 µm, and Z resolution (voxel size) is 0.6 µm – 10 µm.
Printable object range is 0.1 µm – 10 mm (max. object height).



Source: microlight.fr

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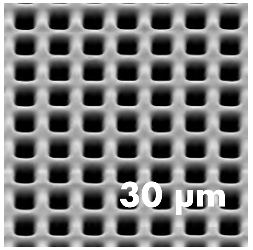
Polymers

UpNano's NanoOne system is based on multiphoton lithography and claims to combine the precision of 2PP with a throughput of up to 200 mm^3 per hour. Minimum X/Y feature size ≥170 nm, and minimum Z feature size ≥550 nm. The maximum height of printed parts is 40 mm.

Additionally, the system can print living cells.



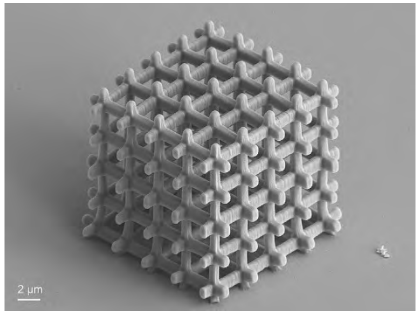
Source: upnano.at

Polymers

Silica Glass

Nanoscribe utilize layer-by-layer 2PP. Typically, highest X/Y resolution is 400 nm and highest Z resolution is 1000 nm. Specified values are slightly higher.

Typical minimum X/Y feature size is 160 nm. Maximum object height is 8 mm, and max. object size is 50 mm. Layer distance is 0.3 – 5.0 µm. Nanoscribe can print both polymers and fused silica glass.

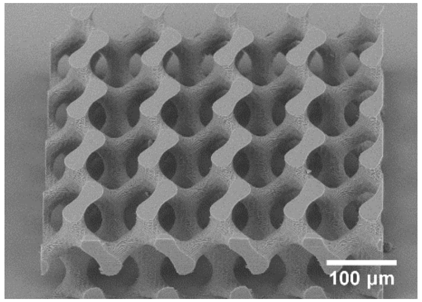


Source: nanoscribe.com

Polymers

Femtika offer a workstation which provides femtosecond laser multiphoton polymerization, selective laser etching and laser ablation processes.

Stage resolution is 1 nm for X/Y, and 2 nm for Z. Accuracy is ±300 nm for X/Y, and ±275 nm for Z.



Source: femtika.it

NANOFABRICA	Polymer Ceramic	According to Nanofabrica, their Tera 250 system "combines semiconductor lithography and advanced optics together with 3D printing." Print resolution is 1.9 µm, tolerance 1 µm, and layer thickness 1 – 5 µm. Nanofabrica work with both polymers and ceramics.	 Source: nano-fabrica.com
FEMTOprint	Glass	The Femtoprint system essentially uses light as an ink source. When the beam is focused inside glass, it locally modifies the refractive index and density of the material. Print resolution is 1 µm, with maximum object size extending to 10 mm+. Femtoprint focus on developing and manufacturing custom microsystems for industrial customers.	 Source: femtoprint.ch

Summary

Additive micromanufacturing (µAM) is an increasingly important source of innovation and disruption; one which has profound impact within both fundamental research, and global industries as diverse as medicine, microelectronics, biosensors, aerospace, and high-frequency communications.

As this overview shows, the µAM landscape is populated by truly innovative companies offering a tremendously diverse range of technologies. It is important to note that whilst this may be considered a 'competitive' landscape, these technologies all offer their own benefits to distinct applications and use cases.

From Exaddon's perspective, this analysis reaffirms that our CERES print system remains unrivalled in printing complex microscale metal objects directly on existing structures, where placement precision is crucial, and submicrometer resolution is required.