INDUSTRY OVERVIEW

ADDITIVE MANUFACTURING AT THE MICROSCALE - 2023

In 2021, we conducted an analysis of additive manufacturing (AM) companies operating at the microscale range.

The aim was to ascertain what technologies existed within the same space as Exaddon, the printable size range of each technology, and whether the use cases were similar.

Two years on, we have surveyed the landscape again. Whilst there have been changes, with some new entrants to the market, the manufacturers are largely the same as in 2021.

Microscale AM is an increasingly potent force in fundamental research and academia, enabling unique developments in many fields. As technologies have matured, some companies are making a move beyond research or rapid prototyping, and into industrial applications.

This overview provides a graphic matrix, followed by a brief description of each company's technology, including method of printing, materials used, object size range, and other information where available. Conclusions from our analysis are on the final page.

Please note that this is a guide for general information, and inaccuracies may be present. All information was obtained from the websites and publicly accessible promotional materials of each manufacturer, and was correct at time of collection.

The Exaddon CERES µAM Print System

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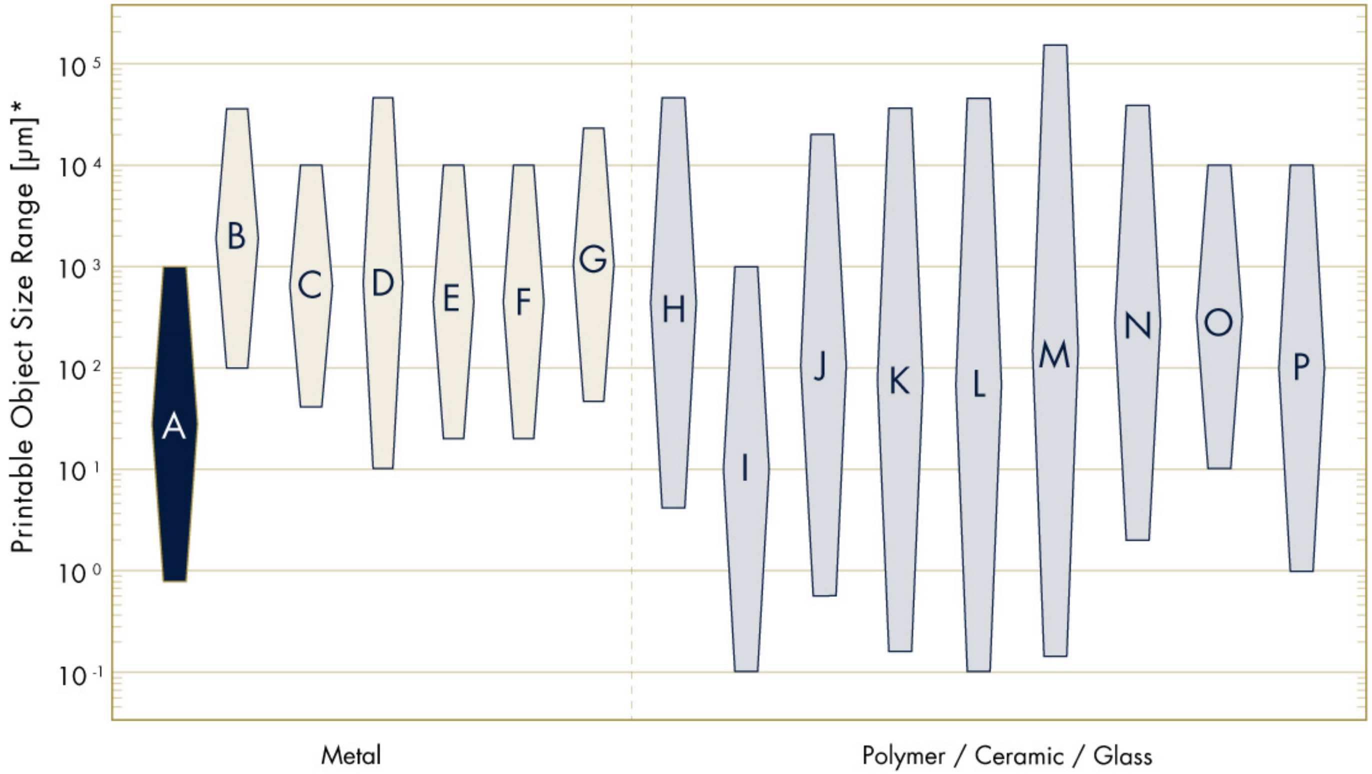
EXADDON µAM TECHNOLOGY LANDSCAPE 2023



*Estimated, based on publicly available data from manufacturer websites

- A EXADDON
- B 3D Microprint
- C Incus
- D Microfabrica
- E Mimotec
- F Nanogrande
- G Fabric8Labs
- H BMF
- I Multiphoton Optics
- J Microlight 3D
- K Upnano
- L Nanoscribe
- M Femtika
- N Nano Dimension
- O Skyphos Tech
- P Femtoprint

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Company	Print Material	Printable Size Range (est.)	Overview
EXADDON	Metal: -Copper -Gold -Others in development	<1 µm – 1000 µm	Exaddon's CERES µAM system prints highly conductive metal objects by local electrodeposition. The system prints free-standing structures such as pillars, needles, and coils directly on prepatterned chips and microPCBs. Printing occurs at room temperature, requires no post-processing, and is compatible with IC and PCB manufacturing steps. Resolution is <1 µm, and structures can be located on print surfaces with micrometer accuracy. Possible aspect ratio is 100:1. Applications include semiconductor probe testing, neural interfaces/BCIs, and mmWave/5G/THz components.
3D Microprint	Metal: -Stainless steel - 1.4404 (316L) 1.4542 (174PH) -Titanium- 3.7164 (Ti6Al4V)	100 µm – 40,000 µm	3D Microprint utilize Micro Laser Sintering, which allows wall thicknesses down to ~50 µm. A micro metal powder is melted by laser and is then post-processed. Various alloys are available as print materials. < 2 µm inner surface roughness is claimed, along with high temperature and corrosion resistance.
Incus	Metal:	35 µm – 10,000 µm	Incus use Lithography-based Metal Molding (LMM), which uses a feedstock of metal powder

	-316L stainless steel -Titanium -Copper -Tungsten -Precious metals -Carbides		dispersed among a photocurable resin 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 steps are required.
Microfabrica	Metal: -Valloy 120 (nickel-cobalt) -Palladium -Rhodium -Copper	10 µm – 50,000 µm	Microfabrica's 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.
Mimotec	Metal: -Nickel -Gold -NiFe	20 µm – 10,000 µm	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 galvanizing to create metal parts from the polymerized objects. These are removed from the wafer substrate by another dissolution process.
Nanogrande	Metal: -Titanium 6-4	20 µm – 10,000 µm	Nanogrande use metal powders with nano- to microscale particle sizes as feedstocks for their process. The method is variously listed as DMLS,

	-316L stainless steel -Copper alloys -Various others		SLA, SLS, and Polyjet. Maximum build volume is 250 cm^3. Nanogrande state a maximum resolution of 5 µm.
Fabric8Labs	Metal: -Copper -Stainless steel -Aluminium -Nickel -NiCo	50 µm – 25,000 µm	Fabric8Labs utilize an electrochemical approach with a water-based feedstock which contains metal ions. The minimum layer thickness is reported to be 30 µm whilst the build volume is 300 × 300 × 450 mm.
BMF	Ceramic, photosensitive resin	5 µm – 50,000 µm	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 many other providers listed here, BMF print in layers.
Multiphoton Optics	Polymers	100 nm – 10,000 µm	Multiphoton use two photon polymerisation (2PP) with a wide range of materials and substrates. Minimum X/Y feature size is 100 nm, and minimum Z feature size 270 nm. Substrate thickness is ≤ 49 mm.
Microlight3D	Biomaterials & polymers	600 nm – 20,000 µm	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).
UpNano	Polymers	170 nm – 40,000 µm	UpNano's NanoOne system is based on multiphoton lithography and claims 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.
Nanoscribe	Polymers Silica Glass	100 nm – 50,000 µm	Nanoscribe utilize layer-by-layer 2PP. Highest X/Y resolution is 400 nm and highest Z resolution is 1000 nm. Specified values are slightly lower. 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.
Femtika	Polymers	150 nm – 160,000 µm	The Femtika system offers a hybrid of additive multiphoton polymerization and subtractive selective laser etching. The specifications for each process differ.

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			Minimum feature size for the additive process is 150 nm.
Nano Dimension	Polymer Ceramic	1.9 µm – 45,000 µm	Nanofabrica's 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 polymers and ceramics.
Skyphos Tech	Biocompatible resin	10 µm – 10,000 µm	Skyphos use micro-DLP-3DP to create microfluidics and lab-on-a-chip devices. They report a minimum possible feature height of 10 µm, and a minimum feature width of 20 µm.
Femtoprint	Glass	1 µm – 10,000 µm	The Femtoprint system uses light to modify the density of glass. 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+.

Summary

The µAM / micro 3D printing landscape is populated by truly innovative companies offering a diverse range of technologies, each with different applications and use cases. Given the variety of printing methods employed, choosing one technology over another depends on what the customer wants to achieve, their industry/field of research, and intended end use.

For example, manufacturing tissue engineering scaffolds requires incredible detail in nanometer size ranges and would likely be best served by 2PP. On the other hand, researchers wanting highly conductive, mechanically stable metal pillars for use as neural interfaces should look to Exaddon's template-free printing, where high aspect ratio pillars can be printed directly on contact pads. Printing directly in pure metal also avoids the need to coat, etch, and process polymer structures, as may otherwise be required.

In terms of true 3D freedom of printing, the method of printing defines the geometric possibilities of printed objects. The layer-by-layer approach of lithographic methods is very different from 2PP, or Exaddon's electrodeposition, which offers great design freedom; complex and overhanging geometries with a high degree of customization are possible. Conversely, Exaddon's approach is not intended for the type of large-area planar printing needed for microfluidics devices; a lithography-based process would be more suitable.

Finally, those in the market for a microscale AM system should consider what post-processing is required before printed parts can be used. Additionally, if the system is to be used within an industrial application, it should be compatible with other fabrication processes. These considerations depend on the customer's intended use for the technology. Within industrial microelectronics, compatibility with standard IC and PCB process steps is key and is something Exaddon has demonstrated in published research.