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Additive manufacturing in ASML lithography machines: benefits and quality assurance

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Abstract

Additive manufacturing (AM) is empowering the chip making industry to follow the Moore's law into the next decade. Higher design freedom accentuates a need in bringing ASML lithography machines to new levels of productivity and accuracy. All efforts have the ambition to manufacture faster, smaller and cheaper chips. AM technology is enabling optimization of parts by improved dynamic performance, thermal and fluid optimization, geometric fit and improved robustness. Moreover, AM is being used to shorten the lead times and lower the costs in certain applications. When each machine is built from thousands of parts, quality is crucial. To safeguard this, ASML has written an internal standard that empowers suppliers to put in place the quality measures required to produce reliable parts. Next to ASML specific requirements, this standard is making a reference to the most relevant standards already available in the industry to achieve the best compromise between the cost of quality versus the value of parts.

Keywords: Additive Manufacturing, semiconductor, lithography, ASML, chip, standards

1. Additive Manufacturing enabling progress to semiconductor industry

Semiconductors are at the heart of progress of human civilization [1]. Additive Manufacturing technology fuels the advancement of semiconductor industry. During the last 40 years Additive Manufacturing has slowly but surely evolved from a tool primarily used for prototyping plastic parts, into a class of manufacturing technologies able to produce parts in a large range of materials and for numerous applications. Some of these technologies have reached a level of maturity sufficient for use in ASML products, already resulting in more than 200 parts that are in production at this moment. These parts range from plastic cable guides to metal manifolds and heat exchangers, to ceramic mounts for optical components.

Here we showcase the advantages of using AM in our systems as well as highlight the quality control measures needed secure reliable parts.

2. AM benefits to ASML lithography systems

Most AM parts are being used in positioning stages. These positioning stages move the wafer and the reticle such that features of 5 – 10 nm are patterned as fast and as accurately as possible [2, 3]. Although some stages weigh almost 50 kg, they need to move with accelerations of up to 50 m/s^2 and with a positioning error within 0.15 nm. Achieving this requires very light and stiff parts to cope with the very high system dynamics. Additive Manufacturing is ideal to produce these parts because it enables the freedom to add material only where is needed. Titanium parts produced by Powder Bed Fusion (PBF) are the most commonly used because of the good specific stiffness of the material and because of the relatively high maturity of the technology.

2.1. AM for thermal optimization

To enable such level of positioning accuracy, thermal conditioning within mili Kelvin range is required in order to limit the differential thermal expansion of the parts between the point of measurement relative to the point of interest. A component of the wafer stage that needs tight thermal conditioning is a specific sensor. The sensor was traditionally conditioned by a Titanium ring with water flow inside. The part is conventionally manufactured by milling and welding, which restricts the shape of the water channel to a ring-like structure. Due to this limitation, the water is flowing only on the outside. The resulting thermal gradients of several mK's across the top surface area are insufficient for optimal cooling of the sensor. To solve this, additive manufacturing has been used to direct the cooling channels towards the top surface of the ring as can be seen in Figure 1. Following a thermal and flow optimization, the thermal gradients have been improved by a factor 6. This brought the sensor performance within the specifications. Figure 2 shows the results of the finite element simulation of the ring conventionally manufactured (left) and the one redesigned for AM (right). The dynamic performance is improved by 15% by lowering the mass.

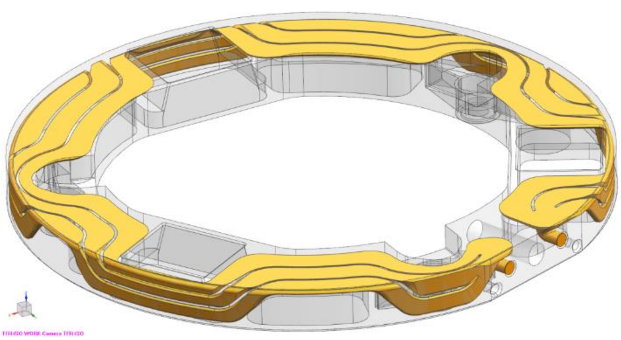

Figure 1. Thermal conditioning ring with channels redesigned for AM

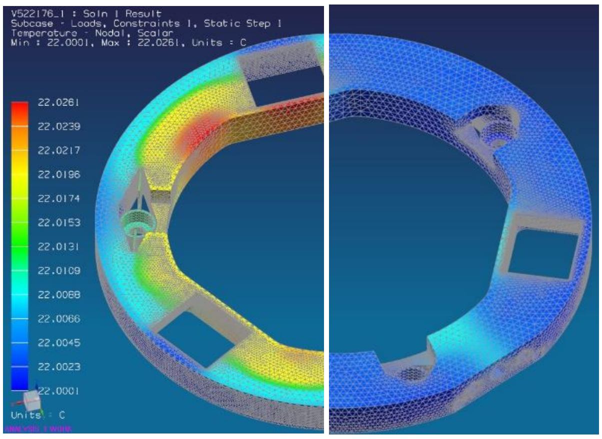

Figure 2. Thermal conditioning ring with channels redesigned for AM. Left: Temperature profile of conventionally manufactured ring. Right: Temperature uniformity achieved after AM optimization.

2.2. AM for reducing flow induced vibrations

AM is often used within our machines for water transport applications. Positioning stages contain powerful actuators which need water cooling. Many manifolds manufactured conventionally have cooling channels drilled at 90° with respect to each other. When the flow needs to change direction at a sharp corner, flow induced vibrations are introduced. This affects the positioning stability of our positioning stages. Additive manufacturing allows these corners to be redesigned into smooth transitions lowering these disturbance forces by an order of magnitude. Figure 3 shows a titanium manifold produced by Powder Bed Fusion (PBF) which has been introduced into our machines already more than 15 years ago.

Figure 3. LB-PBF Titanium manifold to reduce flow induced vibrations

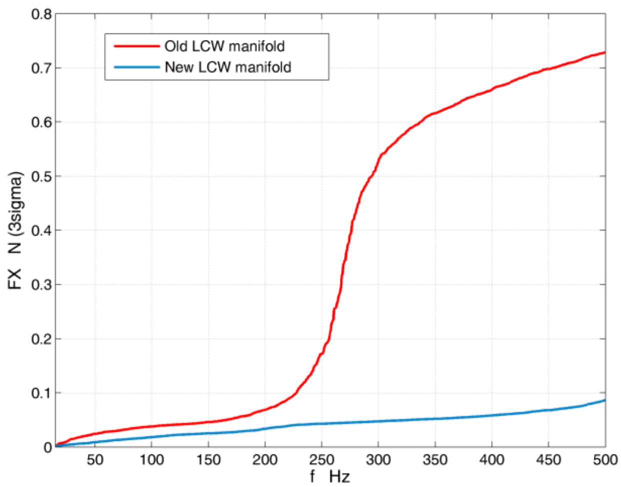

Figure 4. Thermal conditioning ring with channels redesigned for AM

The measured disturbing force caused by water flow turbulences is plotted in Figure 4 for the conventionally manufactured manifold and the new AM manifold.

2.3. AM for lead time reduction

Thanks to the recent advancements, the AM technology is not only beneficial to ASML for improving the performance of our lithography machines but also for reducing the costs and manufacturing lead time. And so it brings the triple benefit. To address the chip shortage crisis and high customer demand, ASML is committed to grow the number of machines produced each year. This puts an enormous strain on the suppliers.

One of the critical components with very long lead times is the titanium carrier for one of our wafer stages: it takes many weeks to produce it by conventional manufacturing. It is made of Titanium which is difficult to machine, while 95% of material needs to be removed to produce the part. This stresses a high demand on finding an alternative manufacturing technology. Such technology has been found in Rapid Plasma Deposition (RPD) - a branch of Direct Energy Deposition (DED).

The walls of the carrier are additively printed on a titanium substrate, leaving only 5% of material to be removed by milling to achieve the desired tolerances and roughness. Due to the smaller grain boundaries, the mechanical properties are more consistent and less tension is present in the material after the final heat treatment. A fully qualified printed carrier was completely integrated and tested inside an ASML system in which it showed equal functional behaviour and even slightly better dynamic performance compared to the conventional manufactured carriers from bulk Titanium.

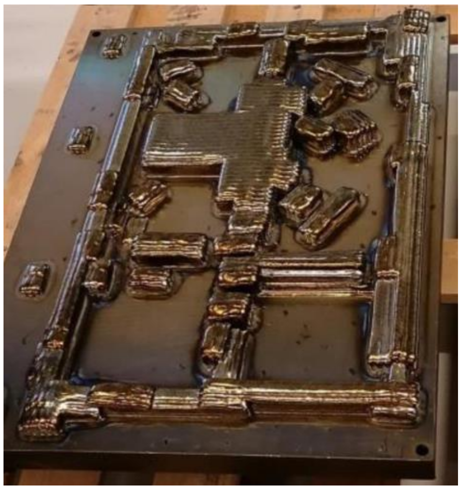

Figure 5. Titanium wafer stage carrier manufactured with DED

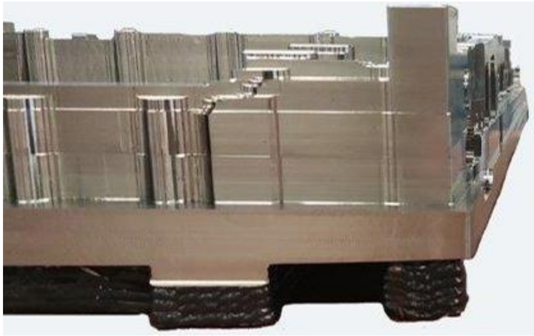

Figure 6. Partially milled wafer stage carrier manufactured with DED

Thanks to this AM technology, a lot of milling capacity is freed up at our suppliers, drastically decreasing the total lead time with almost a factor 3. With this, a lot of material, pre-milling and tool cost is being saved leading to 60% CO_2 reduction.

3. Quality assurance of AM parts

All our AM suppliers are qualified based on the requirements needed for ASML machine parts. Using this qualification, mainly the final manufactured product is verified. However, this is not sufficient as defects during the manufacturing process may occur undetected. These have negative impact on production yield and reliability of these parts during machine operation.

To assure parts quality, we have decided to introduce a Generic Standard of ASML (GSA) specifically tailored for Additive Manufacturing. At this moment it is covering only the PBF of metals. The GSA is based on international ISO and ASTM standards, the best practices known in AM industry. It describes the requirements to which the producing party needs to comply.

We have divided the quality measures into three categories to lower the costs.

3.1. Complexity level 1

First category is for Class 1 parts. This category is for the parts with lowest complexity, e.g. simple parts that do not have any critical design areas. An example of such parts are support brackets in which the application loads are well below the maximum limits of the AM material.

Even for this complexity levels the suppliers need to have their AM process in place to meet the standards DIN EN DIS ISO/ASTM 52920:2021-08 – Additive manufacturing - Qualification principles - Requirements for industrial additive manufacturing sites and processes and DIN EN ISO/ASTM 52901:2018-12 Additive manufacturing - General principles - Requirements for purchased AM parts.

3.2. Complexity level 2

Assigned to complex and/or critical parts that will be made during controlled volume production, and can be manufactured well within process variation window. The material performance is validated upfront. The design must comply with all the design rules applicable to the manufacturing technology and material. It must be robust against the maximum loads demanded by the application.

In addition to the requirements from complexity level 1, adherence to the following standards is needed as well: ISO/ASTM TS 52930:2021 Additive manufacturing — Qualification principles — Installation, operation and performance (IQ/OQ/PQ) of PBF-LB equipment; ISO/ASTM 52907:2019 Additive manufacturing — Feedstock materials — Methods to characterize metal powders and ISO/ASTM CD 52928 Additive manufacturing — Feedstock materials — Powder life cycle management.

3.3. Complexity level 3

Used for the most complex and/or critical parts that are challenging to manufacture and where controlling the volume production alone does not guarantee performance. Performance must be, therefore, validated at part level according to its own individual requirements. Such parts are parts require leak tightness, good cleanliness, corrosion resistance or resistance to high stress and fatigue loads.

For this complexity level all the requirements from the previous 2 levels are needed with the addition of standard ISO/ASTM 52904:2019 Additive manufacturing — Process characteristics and performance — Practice for metal powder bed fusion process to meet critical application.

A risk evaluation of the manufacturing workflow with and ASML specific pFMEA is needed for each specific design.

An overview of all the standards that are required to meet the quality of our parts depending on their complexity level is given in Figure 7.

Scope	Standards for the assessment of conformity
Human & AM Production Quality Standards of AM Processes Complexity Level 1, 2, 3	ISO/ASTM DIS 52920
	ISO/ASTM 52901 (Purchase AM Parts)
Build Process Quality Standards of AM Systems and Materials Complexity Level 2, 3	ISO/ASTM TS 52930 (IQ/OQ/PQ) ASTM F* (PBF material standards)
	ISO /ASTM 52907:2019 (Characterisation of metal powders) ISO /ASTM CD 52928 (Powder life cycle management)
Part specific Quality Standards for critical to quality parts Complexity Level 3 Co-developed with the supplier	Based at ISO/ASTM TS 52904 (Part specific manufacturing plan) and AM process category Risk Map, pFMEA, QS plan

Figure 7. Overview of applicable ISO/ASTM standards applied to the different complexity levels

4. Conclusions

Additive Manufacturing plays an important role in enabling the advancements of semiconductor industry. The higher design freedom of machine parts allows achieving better dynamic performance, superior temperature conditioning, lower disturbances. All together this creates faster and more accurate systems. This way the Moore's law – the number of transistors per unit area doubles every 2 years – can continue into the next decade [4]. As quality is crucial for the value of our ASML systems, a generic internal standard has been developed to assure the quality of AM parts. This standard empowers our supply base to improve their AM production centers to manufacture reliable parts in volume production.

The next steps are: pursue introduction of more AM metal parts inside ASML machines and expanding the standard to cover ceramics and plastic components as well.

The expectation is that the number for AM parts used in our machines will continue to grow. AM brings triple benefit for

ASML machine parts: improved performance, reduced lead times and higher conventional manufacturing capacity at our suppliers. The impact is more ASML machines to our customer sites to address the chip shortage.

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