Metal Additive Manufacturing

Tips & Best Practices for Laser Beam Melting

Foto: © Netzwerk Strahlschmelzen

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Executive summary

Additive Manufacturing (AM) – or industrial 3D printing – is gaining momentum as it graduates to serial production. Laser beam melting has emerged as a promising technology with first-movers already gaining considerable competitive advantage. More and more companies are keen to benefit from its economic and technological potential. However, many struggle to introduce additive manufacturing in the most efficient way. This white paper provides a best-practice approach to unlock the potential of AM and highlights on how to set up and run your production efficiently.

This white paper is for you, if you

→ Intend to introduce additive manufacturing - and in particular laser beam melting - in your company

→ Are interested in key learnings for the successful set-up of your production facility

→ Are looking for a best-practices in your daily operations

Abbreviations

AM	Additive Manufacturing
LBM	Laser Beam Melting (other terms often used include selective laser melting, direct metal laser sintering, laser cusing and laser metal fusion)
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CNC	Computerized Numerical Control
PLC	Programmable Logic Controller
STL	Stereolithography (file format)
VRML	Virtual Reality Modeling Language (file format)

1 Identify enterprise-specific potential for additive manufacturing

To identify potential AM applications in your company, it is important to know the AM process you want to introduce. Make use of (scientific) literature and involve experts to get an appropriate base of knowledge about the AM process.

As soon as you have a basic understanding of the AM process, the next step is to review all fields of manufacturing in your company (e.g. products, tools, jigs). To get the most out of AM, it is necessary to rethink and redesign the whole parts. If you do not redesign and simply replicate parts that are designed for other conventional manufacturing technologies (e.g. milling/machining, drilling, lathing...), you will usually miss out on the benefits of additive manufacturing. A positive example of how to achieve a reduction in weight with the new possibilities offered by AM is to integrate lattice structures in a part for lightweighting purposes. (SEE FIGURE 1).

FIGURE 2 illustrates how to enhance the functions of a part with flow-optimized channel systems for conformal cooling (BLUE) or by sensor integration (GREEN).

When potential parts are identified, an AM specific redesign should follow. The main challenge is to rethink and challenge all aspects of the design with the use of the part in mind, bring together people from different departments (e.g. production, mainte-

FIG. 1 Topology optimized lightweight skateboard axis with lattice structure inside
SOURCE: PHILIPP MANGER

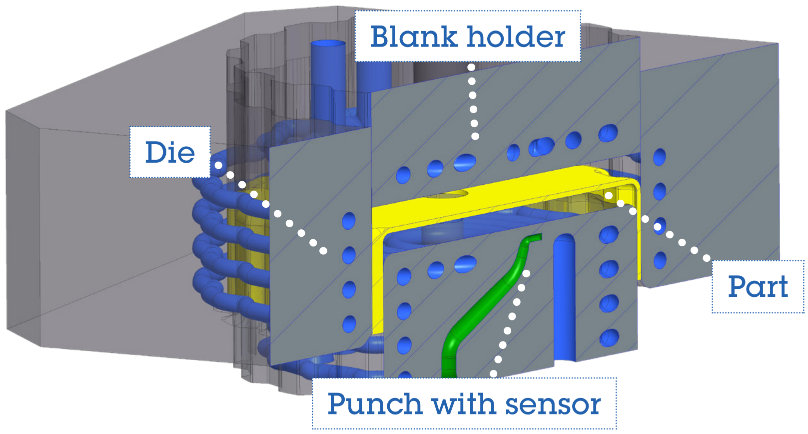

FIG. 2 Hot sheet metal forming tool with integrated conformal cooling channels and a thermocouple
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nance...) and leverage powerful calculation tools. Some companies are specialized in design and/or prototyping and therefore have special tools. If your company does not have the appropriate design capabilities and tools, it could be beneficial to cooperate with specialized companies to get the best out of your project. It can also be interesting to benefit from the know-how and tools that are quite specific depending on the competencies available in your company.

To identify AM potential in your company, think about the following points:

Can you combine parts?	→ Reduce mounting time by building only one complex product
Can you apply lightweight designs?	→ To reduce weight and costs
Can you integrate additional functions?	→ Channel systems, sensors, other features that can only be manufactured by LBM
Can you replace common workflows?	→ With LBM you can directly produce parts from the 3D-CAD data
Can you introduce new designs that can only be manufactured with LBM?	→ New products
Should you switch from buying to making certain parts?	→ Spare parts, parts with long lead times
Could you bring more value to parts that are currently standard and that could be customized to large production runs?	→ Additional customer value

2 Select the right manufacturing strategy

Based on the enterprise-specific potential for additive manufacturing, it is necessary to define a company roadmap for the implementation. This roadmap should include the planning from the idea through to manufacturing. It needs to encompass organization and team setup, employee training, change management and technology development. It pays off to engage or hire experienced professionals to monitor and facilitate this process.

An important aspect of such a roadmap is the manufacturing strategy. Even in the initial phase of prototyping, the production of parts is essential to improve the design through a number of iterations. As volumes are typically low in this stage, it may be worthwhile hiring a service provider. This limits initial investment and allows you to rely on established manufacturing know-how resulting in a fast development cycle. On the other hand, setting up an in-house laboratory scale production unit supports the development of your own expertise and may facilitate setting up in-house production at a later stage.

The question of outsourcing final part manufacturing is also pertinent for serial production. There are successful examples of companies completely relying on external service providers while in other cases, companies successfully set up their own additive manufacturing production facilities. Even hybrid forms like joint-ventures with a service provider are viable options. Ultimately such a decision needs to take into account the production volume, speed of implementation, internal resources and capabilities as well as economic criteria.

An exemplary manufacturing strategy may start by collaborating with a service bureau for the manufacturing of prototypes. At a later stage, renting a number of machine hours from the service provider is an option to gather know-how and experience in pilot production runs. Serial production is ultimately done in an in-house facility for the main materials (e.g. stainless steel) while parts made of other niche materials (e.g. titanium) are still produced by the service providers.

3 How to buy a machine

When you buy a LBM machine, there are many things to consider. The buying decision is complex because in addition to buying a machine with certain features, it is often also a decision for a particular ecosystem that may include the supply of powder and consulting.

There are also machines with very small building chambers on the market e.g. from OR Laser. These are often used for research and development purposes, but also for specific applications with small parts and a preference for short build cycles (e.g. dental). The use of multi-laser machines can significantly increase the building rate per hour. On the other hand, the hourly machine rates can be the double of a single laser machine, which reduces the cost advantage of the higher process speed (SEE FIGURE 4).

The material of the parts you want to manufacture must correlate with the machine building chamber size, because some large machines cannot process all types of powder material. For example, the typical material maraging steel (1.2709), which is very common for small and especially medium-sized machines, is not (yet) available for the large machines (e.g. Concept Laser X LINE 2000R[3] or EOS M400[4]).

And finally, let's talk about the costs. There is a wide range of small building chamber machines that cost around 500k EUR up to the large machines with big building chambers that can cost more than 1.500k EUR.

To set up a field of additive manufacturing, pre- and post-process equipment and consumables are necessary. Typically machine manufacturers offer a range of appropriate products that can span from 3D-CAD software and metal powder supply up to integrated heat treatment ovens. As such the machine manufacturers provide an eco-system that also needs to be taken into account during the purchasing process of the machine. As these peripheral aspects often do not get the attention they deserve they will be covered in more detail in TIP 6.

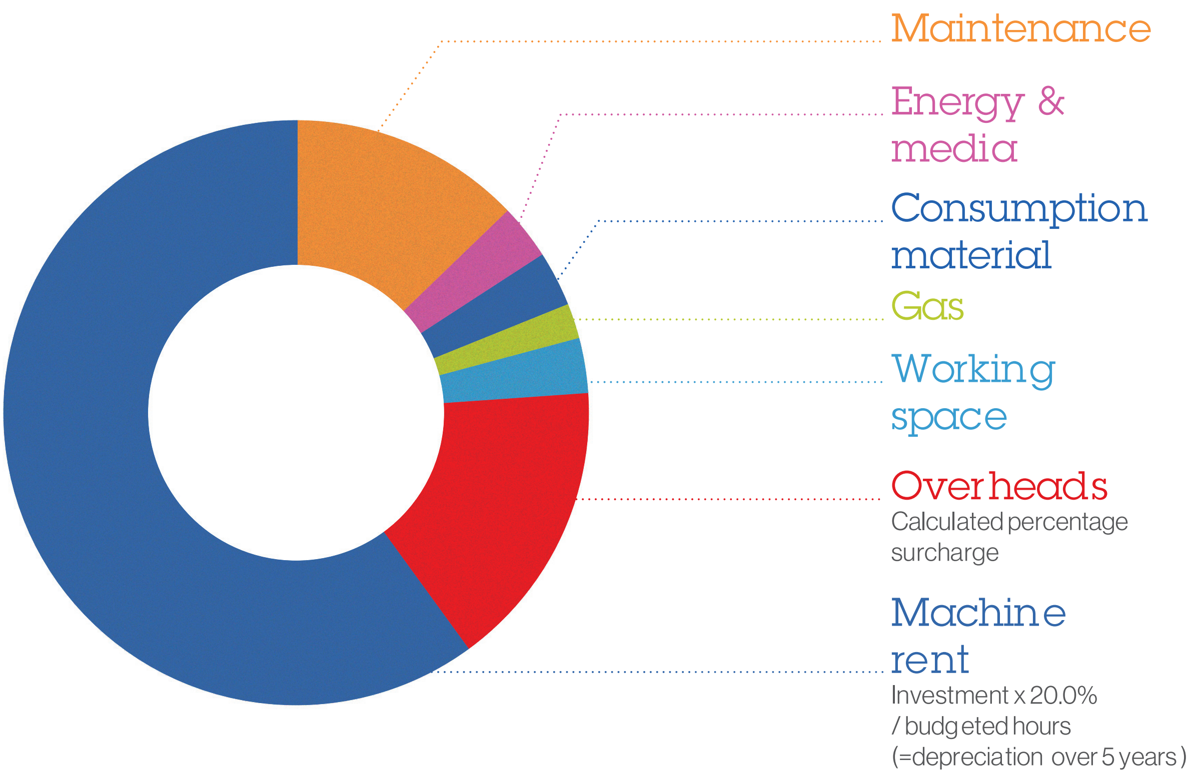
Machine manufacturers also have different approaches for transporting the powder material. Fully automated systems are mostly used for serial production runs. In a fully automated system, the powder is transported via pipes to a sieving station in order to be cleaned. Afterwards it is fed into the LBM machine again, for the next build job. It is not easy to change the powder with such a system. The most common powder transport system uses containers, where the powder is carried to the sieving station and back to the machine. This process requires manpower. With the container system, a powder change on the machine is possible, although typically avoided due to cross-contamination with powder residues and due to economic aspects (SEE TIP 5).

Based on the criteria mentioned above, a benchmarking of preselected machine candidates should be performed. It is wise to start with a design as close as possible to what you want to build, and benchmark the different machines in terms of quality (surface roughness, porosity, etc.) and economic aspects (build speed, machine cost, flexibility, etc.). As the decision process can be complex and typically includes parameters not obvious to first-time users, it usually pays off to involve an expert.

The final acceptance test at the machine manufacturer or customer site should consist of one or more pilot parts as defined in the benchmarking process, which need to fulfill certain criteria.

Hourly machine rates (2016)

SOURCE: ROLAND BERGER 2016



35-45 EUR/ H — Small single-laser

45-55 EUR/ H — Small multi-laser

90-120 EUR/ H — Large machine

Looking simply at the machine characteristics, one of the major variables is the dimension of the building chamber. This variable needs to be chosen very carefully, because it sets the limits for the part dimensions that can be manufactured with the machine. Most common are small machines with single or multi-laser and building chamber dimensions from 250x250x300 to 280x280x350 mm³. To manufacture bigger parts, there are large machines with up to four lasers and a building chamber dimension of up to 800x400x500 mm³ (SEE FIGURE 3).

Small single-laser

→ System class with **lowest investment cost**

→ **Lower productivity** countervails low system price

Sample configuration:

Investment cost	EUR > 0.5 m
Build rate (IN718)	10 - 15 cm³ / h
Build chamber	250x250x300 280x280x350 mm

M2 cusing

EOS M 290

SLM 280 Twin

M2 cusing Multilaser

Small multi-laser

→ **High productivity** due to 2 lasers at still **moderate price**

→ Well suited to **serial production of smaller parts**

Sample configuration:

Investment cost	EUR > 0.5 m
Build rate (IN718)	10 - 15 cm³ / h
Build chamber	250x250x300 280x280x350 mm

Large machines

→ **Highest productivity** when utilizing up to 4 lasers

→ Allows production of **greater parts or larger batch sizes**

→ **Automation** concepts available

Sample configuration:

Investment cost	EUR > 0.5 m
Build rate (IN718)	10 - 15 cm³ / h
Build chamber	250x250x300 280x280x350 mm

X LINE 2000R

SLM 500

EOS M 400

FIG. 3 (ABOVE) Overview of LBM machine types
SOURCE: ROLAND BERGER 2016[5)]

FIG. 4 (LEFT) Hourly machine rates for different machine types
SOURCE: ROLAND BERGER 2016

4 How to train employees

Knowledge is key. As additive manufacturing is not yet established as an everyday industrial practice, training opportunities, respective courses as well as specific vocational training for AM technicians and machine operators and college education programs are emerging. The gap that has been opened up by current demand has triggered a number of educational programs and opportunities. While they fall significantly short of satisfying the future educational needs of AM specialists in the industry, they do offer the opportunity to send selected members of the workforce with the proper background experience in comparable fields of work (e.g. CNC machining and programming, 3D CAD/CAM, laser technology or similar) to any such AM training courses and programs. In addition, a number of workshops and seminars on AM are offered, many of them with a certain focus (e.g. Aerospace or Automotive focus, material or technology specific content, design for AM, etc.).

Often content is delivered by presentations as frontal lectures with no or very limited practical aspects. They usually comprise one or two days of training (some up to four days), which is certainly not enough to gain in-depth basic knowledge and qualifications. A list of some of the most substantial training programs in Germany containing practical input and being held on a regular basis is provided on the link and may serve as a starting point[6)].

You could also use local platforms (professional associations, governmental platforms, universities...) to rent a machine for a few hours/days in order to gradually build up expertise and benefit from the know-how of local technicians. Proper training in post-processing (e.g. heat treatment, manual finishing, CNC post-machining, shot-blasting, etc.) should also be part of the training schedule.

Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik IPK:
Additive Manufacturing – Seminarreihe zur Qualifizierung von Fachkräften (Additive Wertschöpfung, AM-gerechtes Design, Expertenseminare, Summerschool und Praktikum)

LZN Laser Zentrum Nord, Light Academy:
Additive Manufacturing Trainings (Basic, Hands-on, Bionic Design, Management)

Universität Paderborn, Direct Manufacturing Research Center:
Basismodul (Grundlagen), Verfahrensmodule (Lasersintern, Laserschmelzen, FDM, AKF), Erweiterungsmodule (Konstruktion, QM, Anwendungen etc.) and Workshops

Fraunhofer ACADEMY:
Basis-Seminar, Vertiefungsseminar Laserstrahlschmelzen, Vertiefungsseminar Elektronenstrahlschmelzen, weitere Vertiefungsseminare in Vorbereitung

VDI Verein Deutscher Ingenieure, VDI-Wissensforum:
Seminar Grundlagen der Additiven Fertigung (3D-Druck), Zertifikatslehrgang Fachingenieur Additive Fertigung VDI, Additive Manufacturing Specialist VDI (4 Pflichtmodule: Metallverfahren, Kunststoffverfahren, Konstruktion, Implementierung)

FAU Friedrich-Alexander-Universität Erlangen-Nürnberg, LPT Lehrstuhl für Photonische Technologien:
Vorlesungen, Seminare, Praktika, Exkursionen, Inhouse-Schulungen, Anwendertraining, Internationale Workshops

LZH Laser Akademie GmbH:
Fachkraft für Additive Fertigungsverfahren – Metall (nach Richtlinie DVS®3602-1)

available soon also at ifw Günter-Köhler-Institut für Fügetechnik und Werkstoffprüfung

More information with an up to date list is available on our website:

https://3ddruck.airliquide.de/en/training-and-education-programs-for-additive-manufacturing-in-germany/

5 Limit the number of materials per machine

With regard to manufacturing cost, the efficient utilization of the selective laser-melting machine is crucial. This is shown by the fact that the calculated machine hour based on depreciation and amortization may represent more than 50% of the total cost.

Changing the material for a machine is typically time-consuming and requires significant manual effort. The typical duration of such a material change (e.g. aluminum to stainless steel) requires about 1.5 days of manual cleaning. During this period the machine is not available for production while labor costs still accrue. In addition, there is a risk of contamination as some powder residues will remain in the machine. For best results and most economic production, one machine should be dedicated to one material. If this is not possible, reduce the amount of material changes to as low as possible. Another option is to outsource the manufacturing of parts with rarely used materials (SEE ALSO TIP 2).

6 Pay attention to pre- and post-treatment

When establishing additive manufacturing in an organization, it is crucial to consider the entire process chain around the AM core process. Often pre- and post-processes of additive manufacturing neither get the attention nor the consideration they deserve from the very beginning (comparison of a part as built and with post-processed functional surface SEE FIGURE 5). This chapter describes the most relevant pre- and post-processes for AM.

Pre-processing focuses a lot on the proper CAD/CAM data processing chain. It begins with a powerful 3D CAD system to be used to design the parts, components and tooling to be manufactured via AM. The 3D CAD system should include an interface to export AM readable data. The most common interface format for AM is STL, a triangulated description of the 3D surface, while some 3D printers are able to import other formats like VRML (including color info) as well. There are significant differences in quality of the STL output of different 3D CAD systems – this should be tested and verified at an early stage, maybe even prior to the acquisition of 3D CAD software.

FIG. 5 MUGETO® femural hip stem as built (left) and with polished functional surface (right)[7)]

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While some 3D printers, mainly in polymer processing, include a pre-processing software to directly use STL data, most systems – especially in metal 3D printing – require an AM-specific CAM software. Within this software, STL data are being processed to place the 3D models in their build position, to generate the necessary support structure, to slice the 3D model into 2D layers, to generate printing paths (e.g. laser scan vectors or G code for print head or nozzle movement) and to finally export these data in AM-system-manufacturer-specific formats. These data are then imported into the AM machine PLC to start the build job. While many of the processes described above are semi-automatic, it is still necessary to have experienced staff to process the 3D data properly for a successful print job. This experience is required e.g. for proper build orientation, based on multiple criteria (minimal build time, local surface quality and dimensional accuracy, maximum number of parts in one build job, etc.) and for the generation of support structures (minimize required support structure, minimal contact area of support structure to part surface, maximum force of support to fixate part during build jobs, avoidance of failure and tear-off of support structure during build job).

Nowadays, more complex and advanced pre-processing steps are emerging, including process simulation (to predict and minimize internal stress and distortion) and multiple build job planning (for AM production on a larger scale – numerous parts to be produced, many AM machines running in parallel).

After the 3D print operation, AM parts usually need post treatment. Today, this still includes a lot of manual work, which also contributes significantly to the total cost for parts and production.

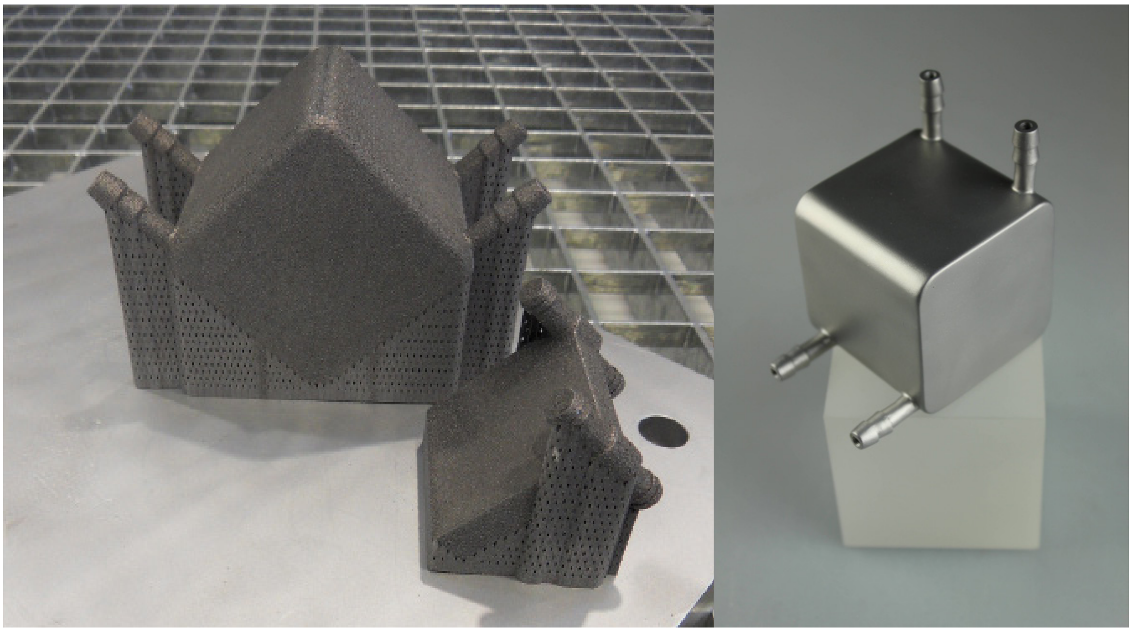

FIG. 6 Surface quality of the component after LBM (left) and after finishing (right)[8)]

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In order to highlight the complexity of the AM process chain, the most important post-processing steps are listed and briefly described below:

- → **Extraction from the build chamber and removal of unsolidified material (powder, liquid)**
- → **Cleaning of the parts to remove residual material (shot blasting, sand blasting, CO_2 snow cleaning, dry-ice blasting, washing, etc.)**
- → **Removal of part from the build plate, removal of the support structures**
- → **Heat treatment (for many metals for stress-relief and desired mechanical properties)**
- → **Surface treatment, if necessary (passivation, painting, anodizing, etc.)**
- → **Finish machining, if necessary, to locally assure high dimensional accuracy and smooth surface with low roughness, either manually or CNC controlled (drilling, milling, turning, thread cutting of functional elements, etc.)**
- → **Assembly of parts into assembly groups or complete products**

7 Ensure safety in particular for metal powder and industrial gases

In terms of safety, the metal powder represents the biggest risk. On the one hand, metal powder can create explosive atmospheres, on the other hand, it can be a health hazardous for the employees. In particular, small (nano)particles of metal powders are suspected of causing pulmonary fibrosis when inhaled - similar to asbestos. In addition, substances like Inconel 718 and Hastelloy X are even suspected to be carcinogenic. It is therefore key to manage these risks. You should carefully train your employees in the handling of hazardous materials and provide the necessary personal safety equipment. Machine and equipment manufacturers should be able to provide advice on how to assure a safe handling of the powder as well as the whole process.

Recycle and store powder in an inert gas atmosphere

In order to manage the safety risks always store your powder in dry conditions and under inert gas. Use specific powder containers provided by the machine manufacturer – these are 100% compatible with your machine and will ensure proper powder handling. An alternative is to rely on specialized equipment manufacturers with a proven track record.

Sieve your powder under inert gas just before reusing. Sieving stations are an important part of the required AM peripheral equipment, therefore the related costs and time should be taken into account from the very beginning.

Another risk to be managed is anoxia. Anoxia is a condition characterized by the absence of oxygen supply to an organ or a tissue. It can cause dizziness or even be fatal. As inert gases used in additive manufacturing are odorless and invisible, technical equipment is needed to check the surrounding atmosphere for oxygen.

In additive manufacturing the anoxia risk needs to be carefully managed as:

a) Production is indoors, often in small rooms and not large industrial premises with natural air circulation,
b) The process requires employees to open the door of the machine to take out parts and
c) The hazardous materials cannot be seen or smelled – which can lead to underestimation of the danger.

Usually the production facilities must be equipped with an oxygen detector and a valve to immediately cut the inert gas supply in case of a leakage. The oxygen analyzer has to be maintained according to the respective instructions.

8 Select the optimal process gas and supply concept

Gas supply is critical for selective laser melting. Interrupting the build process due to lack of inert gas ultimately impacts on both cost and time. The melting process will stop and the quality of the piece may be altered. Re-starting the process may negatively impact the quality of the piece and even result in a defective part. Considering that some pieces may need a high number of hours to be produced, this loss is important.

Depending on the material that you process, different inert gases can be used. For processing titanium powder, argon is the gas of choice. For other materials such as steel or aluminum, nitrogen can be a more economic alternative to argon, which, however, might influence the microstructure of the material. In some cases, machine manufacturers specify the use of a certain gas for a given parameter set.[9),10)]

When choosing the supply options for the process gas, certain factors have to be taken into account.

Process gas selection:

a) The required gas purity (often specified by the machine manufacturer)

b) The average annual gas consumption (based on machine data and individual calculations)

c) General restrictions and considerations such as availability of space, future demand development, etc.

If you are using nitrogen, you have two supply choices: On the one hand, external gas supply, which means relying on a supplier such as Air Liquide, or on the other hand, using an on-site nitrogen generator producing nitrogen from compressed air. This choice is complex and depends on factors such as gas purity requirements, future demand development, economics of compressed air supply and more. In fact, Air Liquide offers both options. To get an individual recommendation on the best supply option, please get in touch with your Air Liquide representative.

If an external gas supply is the best option for you (or a prerequisite, if you need argon), you still have the choice between bundles (12-16 cylinders as a closed system) or bulk product in a tank. Bundles are very flexible, they can be placed either in the close vicinity of your machine (respecting safety guidelines of course) or installed as part of a central gas supply system at your site usually outside of the building. A bundle typically contains 115-125 m^3 (200 bar) and 150-160 m^3 (300 bar). Usually two bundles are connected to an automatic switching manifold to ensure continuous gas availability. Once a bundle is empty, it needs to be replaced with a full one. Some manual effort is needed when switching the bundles, monitoring the remaining amount of gas and finally ordering new bundles in time.

Bulk supply is typically the most economical method of supply if you have a demand of approximately 10,000 m^3/a or more. Bulk supply requires the installation of a central gas supply system and a tank with specific safety requirements. Your Air Liquide sales representative will help in identifying a suitable location at your site.

9 Quality Management starts with the powder

9.1 Check your incoming powder

Even with the best machines and processing parameters under ideal conditions, you will fail to achieve satisfying results if the quality of the metal powder is poor. Initial quality has to match your requirements for the final mechanical properties of the part. In principle, two approaches related to powder quality management are possible.

The easiest approach is to buy prequalified powder for additive manufacturing that has undergone strict quality controls. This is typically the case when buying powder from machine manufacturers. The machine manufacturer typically guarantees that the powder can be processed on its machine as expected with the given parameter set. While this approach saves time and does not require specific equipment, it also comes at a higher cost.

For larger consumption volumes, buying powder directly on the market and doing the qualification on your own usually pays off. As powder can be contaminated or deviate from specifications, the initial powder quality needs to be monitored by checking its chemical composition as well as the physical properties.

The chemical composition such as the elements of the alloy, but also the trace elements or impurities can be determined by using X-ray fluorescence analysis. Moreover, the shape of these impurities (if detected) has to be analyzed.

Main physical characteristics of powders are particle size (granulometry) and particle shape (morphology). They determine to a large degree the flowability of the powder and other rheological properties. Quality control of physical characteristics should include granulometry, morphology and flowability analyses.

Currently there are no clear scientific criteria in which way defined powder characteristics influence the properties of the final parts. However, you can determine whether there are unusual deviations between different batches and you will be able to better assess powder that needs to be qualified.

9.2 Carefully manage and monitor the quality of your powder in use

From an economic point of view, recycling the powder is important. At the same time, it needs to be balanced with the technical requirements. During the build process agglomerated and oxidized particles (spatters) are caused by oxygen and humidity and instabilities of the melt pool. These spatters, formed by molten metal droplets that solidify in flight before impinging on the powder bed, can modify the total granulometry of the powder used and also the chemical composition[11]. They can also incorporate porosities or inclusions in the parts. Ultimately the quality of final parts can be negatively affected. While recycling by sieving aims to remove most "bad" particles, some will still remain and will accumulate over time. Based on the requirements of the final parts, a specification of quality standards on recycled powder should be established along with strict controls. If you can use recycled powder for your parts consider mixing or at least topping up the powder container with "virgin" powder which will help to reduce the degree of chemical and physical changes to the powder. In order to control this process, a system to regularly analyze and track the powder income and outtake should be implemented. This allows you to determine how much powder was added or taken out for every container.[12]

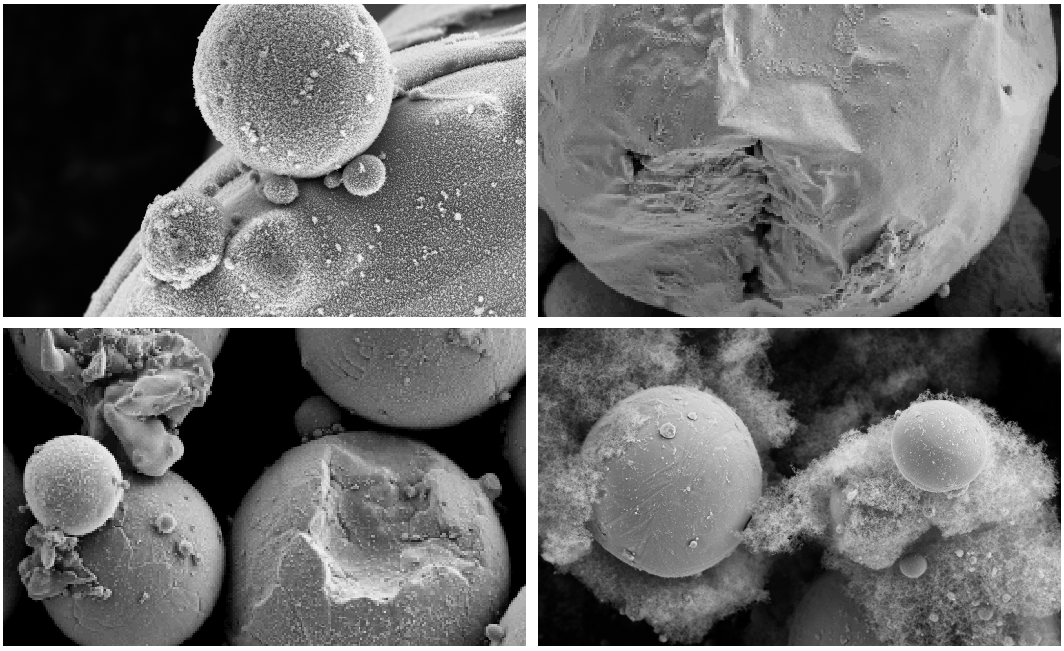

FIG. 7 Various populations of powder/spatters/generated particles after production (various materials)

SOURCE: AIR LIQUIDE

10 Manage your AM process to assure part quality

10.1 Minimize oxygen exposure and avoid moisture in the build chamber

The selective laser melting machines have been designed with an inert gas flow in the build chamber to reduce oxygen as well as humidity content and to ensure safety (SEE ALSO TIP 4). O_2 and H_2O have an immediate impact on the quality of the product and the powder recyclability, as they oxidize the metal and may increase porosity. Effects seen with an increased oxygen concentration include delamination of layers, formation of irregularly shaped inclusions and increased roughness and oxidation of down-facing surfaces.

The effect of moisture and humidity during the build process is related to the water molecule elements - oxygen and hydrogen. In contrast to oxygen as a gaseous component in the build atmosphere, the high oxygen concentration from moisture affects

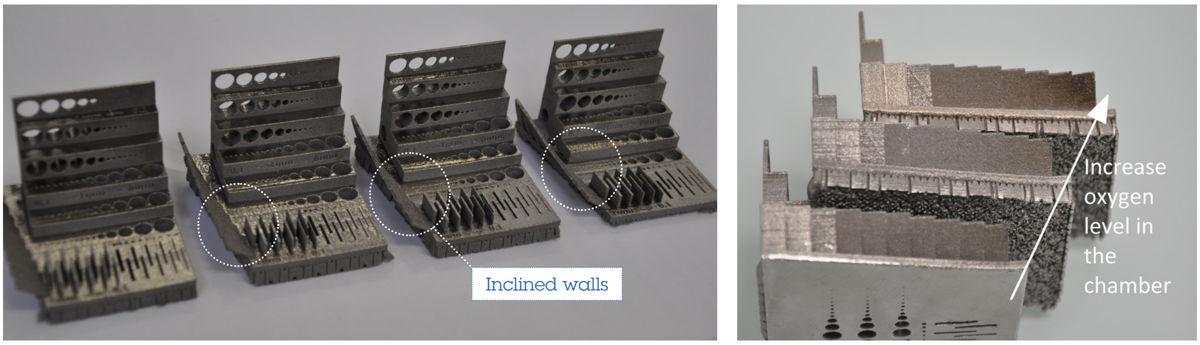

FIG. 8 Visual samples manufactured under various oxygen levels, and observation of the inclined planes
SOURCE: AIR LIQUIDE

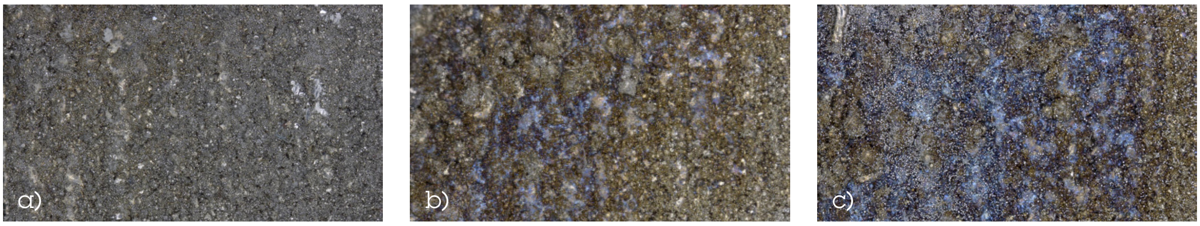

FIG. 9 Images by optical microscopy of the down-facing surface of the inclined wall manufactured at a) low oxygen level in the chamber, b) medium oxygen level and c) high oxygen level
SOURCE: AIR LIQUIDE

the stability of the melt pool and may cause pore and spatter formation as well as oxidation. Presence of hydrogen can lead to supersaturated melts, especially in aluminum alloy. This results in nucleation and growth of hydrogen pores. Hydrogen porosity finally causes inferior mechanical properties.[13)]

It is also obvious that leaks in the machine system will result in higher oxygen levels. Thus a regular check is recommended and monitoring the gas consumption helps to identify unusual deviations that may be caused by leakages.

One way to decrease the oxygen and humidity levels inside the chamber is to increase the gas flow, as shown in FIGURE 10.

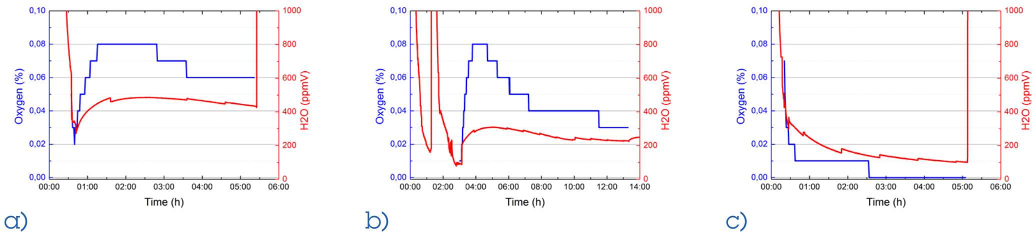

FIG 10 Oxygen and humidity level as a function of time, for production realized under (a) low gas flow, (b) medium gas flow, and (c) high gas flow SOURCE: AIR LIQUIDE

In order to minimize any adverse effects from oxygen, it is very important to

a) Control the oxygen levels in the chamber so they remain below the threshold to fulfill the quality requirements (often manufacturers specify 1000 ppm).

b) Ensure sufficient gas purity at the point of use by specifying the purity of purchased/generated inert gas and eliminating sources of contamination along the way to the machine (e.g. metal pipes instead of flexible hoses)

c) Check the sealing of the AM machines on a regular basis

Sources of moisture and humidity include (i) the metal powder itself, (ii) ambient atmosphere as machines are not perfectly sealed as well as (iii) the machine parts.

In order to reduce the moisture level, you should

a) Dry the equipment before using it in the manufacturing process.

b) Avoid the entry of humidity even during machine downtimes (e.g. by flushing the build chamber with inert gas, which is dry).

c) Also make sure your powder is dry (SEE TIP 7).

If the parts to manufacture impose a stringent quality control and materials are very sensitive (e.g. Ti6Al4V), consider installing an ambient air conditioning system to control humidity - in particular in regions that tend to have high humidity (tropics, subtropics).

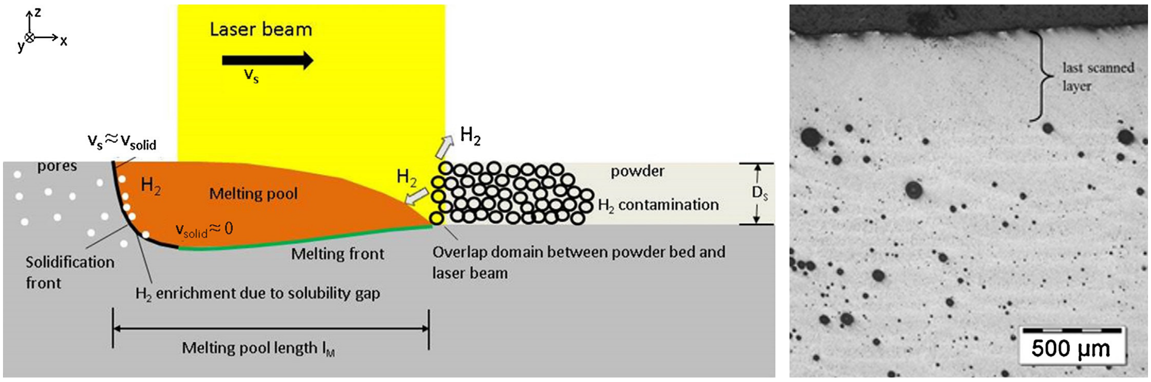

FIG. 11 (a) Schematic overview of the interaction zone between laser radiation and powder and (b) cross section of an AlSi10Mg SLM sample [POPRAWE ET AL. (2015)13)]

10.2 Incorporate relevant test specimen in your build jobs

As we have shown in the previous tips, many factors can alter the reproducibility of your production including powder supply, gas supply, quality of the machine, storage conditions of the powder and many more. Therefore it is important to check and ensure reproducibility.

For each production batch ("build job") – or at least regularly – we recommend including the build of some test samples into your build jobs, such as tensile test bars, test cubes and specimens of other shapes and sizes to regularly check the quality of the properties of the manufactured parts: mechanical properties, surface roughness and hardness (SEE FIGURE 12). To record the reproducibility of manufacturing quality, it is recommended that you place test specimen uniformly from build job to build job. A relatively simple, fast and cost-effective check consists of building a test cube in every build job and inspecting its density (microstructure, level of porosity) and dimensions. This can frequently be complemented by tensile test bars, either as retention samples or for immediate tensile tests. VDI guideline 3405 part 2 describes and recommends specific test procedures and specimen types and sizes. It is recommended that you follow the guidance provided in VDI 3405-2[14] in this matter.

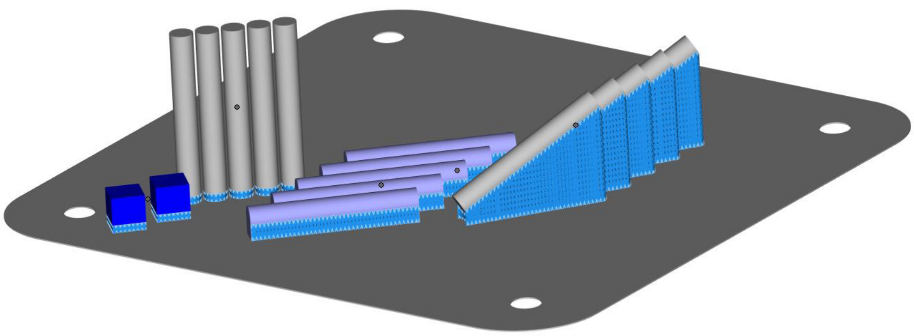

FIG. 12 Exemplary design of a build platform with different types, positioning and orientation of test specimen
SOURCE: AIR LIQUIDE

Ask the experts

Air Liquide

Air Liquide is the world leader in gases, technologies and services for Industry and Health. It is present in 80 countries with approximately 65,000 employees and serves more than 3 million customers and patients. Nitrogen, argon and oxygen are essential small molecules for life, matter and energy. They embody Air Liquide's scientific territory and have been at the core of the company's activities since its creation in 1902.

Air Liquide aims to deliver innovative gas solutions and technologies to customers, driving their performance and helping them reduce their environmental impact. Through our expertise, we enable our customers to focus on their core businesses, and we provide solutions that increase their competitiveness.

In additive manufacturing, Air Liquide has developed a strong expertise. Two R&D teams based in Paris-Saclay (France) and Chicago (US) deal with gas-related topics for additive manufacturing of metals and polymers, respectively. They investigate the role of gases in additive manufacturing in order to help customers optimize their industrial production and advise machine manufacturers on how to further improve the utilization of the gases in the process. As part of this open innovation approach, these research activities include partnerships with several academic institutions and industrial companies. In addition, Air Liquide uses the AM process to manufacture parts for its own needs - for instance to develop a new reactor-exchanger technology that allows for a more economic production of hydrogen. This strengthens Air Liquide's know-how in design, production and use of the technology.

Every day customers from powder production to build processes and post-treatments rely on Air Liquide for the supply of gases but also services and expertise. Air Liquide constantly helps them to select the optimal gas supply concept for their individual needs and to implement customized solutions for process optimization. For instance, by engineering the gas supply for powder production, advising on heat treatment or providing special equipment.

Fraunhofer Institute for Machine Tools and Forming Technology IWU

The Fraunhofer IWU is one of the most renowned research institutes for industrially-led production technology in Germany. It is part of the Fraunhofer-Gesellschaft e.V. (FhG), which connects scientific research and industrial applications. Today it is the leading organization of institutes of applied research and development in Europe. The development of intelligent production devices and the optimization of its related manufacturing processes are Fraunhofer IWU's main focus of research. As a leading institute for resource-efficient production within the Fraunhofer-Gesellschaft and with more than 530 staff members, Fraunhofer IWU is an important R&D partner for the automotive/transportation, machine tool and mechanical engineering industries. Research at Fraunhofer IWU is grouped in three scientific fields: Mechatronics and Lightweight Structures (including additive manufacturing), Forming and Joining Technologies and Machine Tools, Production Systems and Machining. Fraunhofer IWU has achieved an international reputation for developing efficient value chain and supply chain processes, particularly in the machine tool, vehicle and component production sectors. New recent research includes methods to combine manufacturing technologies and novel functional materials. The institute is a member of EFFRA, the European Factories of the Future Research Association and of EARPA, the European Automotive Research Partners Association. Fraunhofer IWU is also an active player in Saxony's smart specialization strategy via the Vanguard Initiative. Additive manufacturing (AM) has been a well-established field of research at Fraunhofer IWU for almost a decade already, focusing on powder bed, laser based metal AM and its applications. Researchers at IWU support the institute's industry partners in establishing AM as a viable manufacturing route through research projects in terms of new applications of AM, mainly in the tooling, automotive and medical sector, as well as in terms of pushing the boundaries of AM processes further in terms of new materials, quality management, process simulation and functional integration.

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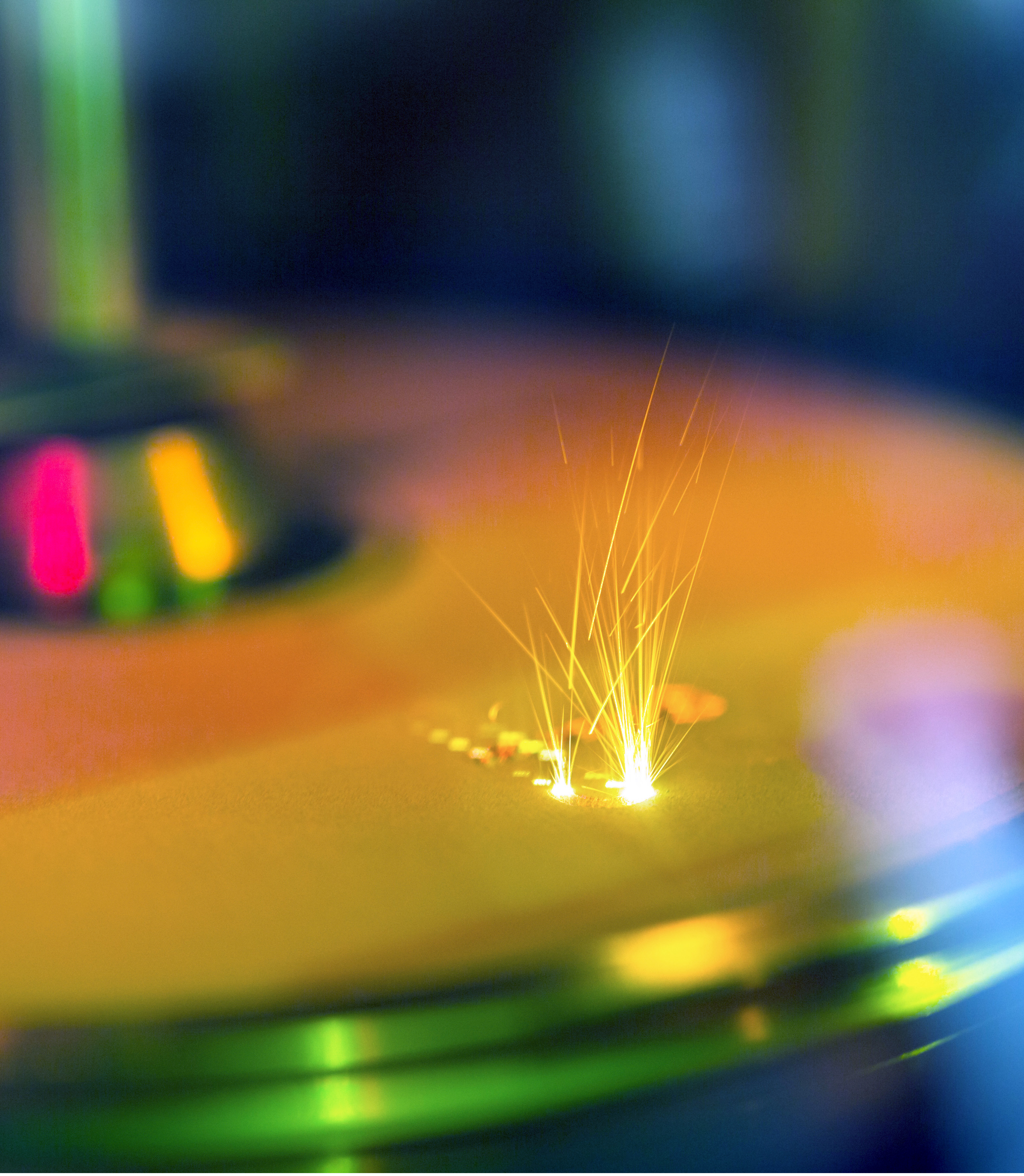

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