Scaling up—The high potential of additive manufacturing for the ceramics industry

Credit: Lithoz

Figure 1. Johannes Benedikt (left) and Johannes Homa (right) with their CeraFab system.

By Monika Homa

Formerly used to create rapid prototypes, additive manufacturing has come into its own for production-scale manufacture. As the technology has grown, so has one small Austria-based company.

Lithoz GmbH (Vienna, Austria)—built on the strength of a decade of research—developed an additive manufacturing (AM) process that allows, for the first time, production of dense, finely structured, high-performance ceramic parts. Lithoz manufactures ceramic parts using lithography-based ceramic manufacturing (LCM) technology to enable creation of complex, strong, and high-resolution objects from various ceramics for industrial and medical applications. This article gives a portrait of a young company that navigated through the start-up phase and now is establishing itself as a world market leader of AM systems for high-performance ceramics. The rapid rise of the company shows the huge growth potential of the technology and gives first insights about developments as well as economical and technological perspectives of AM for advanced ceramics.

Since its beginnings in the 1980s, AM, often also referred to as rapid prototyping or 3-D printing, has developed into one of the most dynamic and most promising areas of innovation in the manufacturing industry worldwide. The market value of AM, estimated at €1.7 billion in 2012, is expected to quadruple by 2022.[1] AM technologies already are established successfully in various industries (e.g., hearing aids) and various materials, including metals or plastics.

AM also has been gaining more importance in the ceramics industry recently. In addition to opening up new markets and the creation of improved applications, the technology has the potential to create radical innovations in the future and, thus, can change the market significantly.

Capsule summary

THE CHALLENGE

Additive manufacturing techniques that worked well for plastics and metal are not suitable for making dense, high-strength ceramic parts.

A SOLUTION FOR CERAMICS

Two Viennese graduate students parlayed their doctoral research into a spin-off company specializing in development of AM specifically for ceramics.

NEW VISTAS

The ability to fabricate dense, high-strength parts with complex geometries allows engineers to design parts based on functional requirements rather than design systems around available parts.

AM often is put on a level with “rapid prototyping.” This refers to the early days of AM, when the technology was used only for prototype production. The tool-less production method enabled companies to make full-function prototypes quickly and inexpensively compared to conventional prototyping methods. Even now, companies looking for an inexpensive way to make single pieces and small production runs find AM is an efficient pathway. In addition, AM is getting more and more important for the industry on larger scales, too, for mass customization and individualization of ceramic products.

AM opens up limitless opportunities in terms of design and geometrical freedom, because it eliminates problems related to the demolding process, because parts are fabricated tool-free. Engineers use new design rules to create entirely new geometries that would not be possible with conventional manufacturing methods. For the first time, designers can implement highly complex geometries containing undercuts, cavities, or defined cellular structures. Thus, they are changing from production toward function-oriented designs.

AM also is particularly suitable for a comprehensive integration of functions by combining different parts into one. Functional integration aims to combine as many technical functions as possible with the fewest components. Often, functional integration leads to highly complex geometries, which cannot be realized with conventional manufacturing processes. Manufacturers can save high assembly costs and produce more functional products using functional integration.

Lithoz—A university spin-off

Lithoz founders, Johannes Homa and Johannes Benedikt (Figure 1), have been involved with AM since 2006, when they were graduate research associates at the Vienna University of Technology (VUT) in Austria in the working group of Juergen Stampfl.

At that time, no technology was commercially available for AM of ceramics. When Homa and Benedikt recognized the unique potential of AM for this class of materials, they decided to develop the technology themselves. It began with development of the material, but it soon became apparent that state-of-the-art AM machines were not able to process the newly developed ceramic slurries. Thus, they also began research on new concepts for AM machines and software.

The challenge was to achieve, by AM, the same density and strength achieved via conventional ceramic forming technologies. Other research groups failed at this point. After four years of intense research, the team solved a number of tenacious problems along the process chain. Finally, in 2010, they achieved, for the first time, the same material properties as with other ceramic molding methods—the proof of concept was realized!

Homa and Benedikt already were thinking of establishing a business while conducting R&D at VUT. Encouraged by their success, they followed their vision to build up a company based on this technology. Spin-off of Lithoz from VUT finally took place in 2011. Homa assumed responsibility for commercial aspects of starting up a business, and Benedikt devoted himself to production and R&D. Lithoz benefited from jumpstart funding from various national and international programs and supporting organizations.

The young team was first challenged to transfer the previously established research prototype to a series of products. The founders realized that continuous progress of their technology and production of high-quality products would be key to the company's success.

Therefore, Homa and Benedikt transferred production of their LCM technology machines to the experienced, specialized engineering company Wild GmbH (Völkermarkt, Austria). The company possesses long-term expertise in mechanical engineering and specializes in manufacturing products to specific

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Figure 2. New Lithoz shareholders from left to right: Johann Oberhofer, Johannes Benedikt, Johannes Homa, and Hans J. Langer.

customer requirements. By working with Wild, Lithoz also eliminated scaling-up issues with regard to possible production bottlenecks for the machine.

Lithoz/Wild delivered the first production-ready machine a year later, and, from that time on, the company grew. Two years later, the company achieved an important milestone by extending its ownership. Hans J. Langer, CEO and founder of EOS GmbH (Krailling, Germany)—one of the first commercially successful AM enterprises—joined the company in 2014 (Figure 2). EOS specializes in laser sintering and micro laser sintering AM. With the announcement of Langer's participation, Homa said, "Through our partnership with Dr. Langer our work finds special recognition, and our future growth opportunities will increase significantly."

The Lithoz management team, despite this achievement, realized that it was important to keep its feet on the ground. The team kept its focus on moderate, healthy growth of the company and did not take the usual route for high-tech start-ups via huge amounts of venture capital. Benedikt explains, "Lithoz prefers a rather conservative approach. We try to realistically estimate our sales potential and adapt our strategic product planning and development precisely to the needs of our customers."

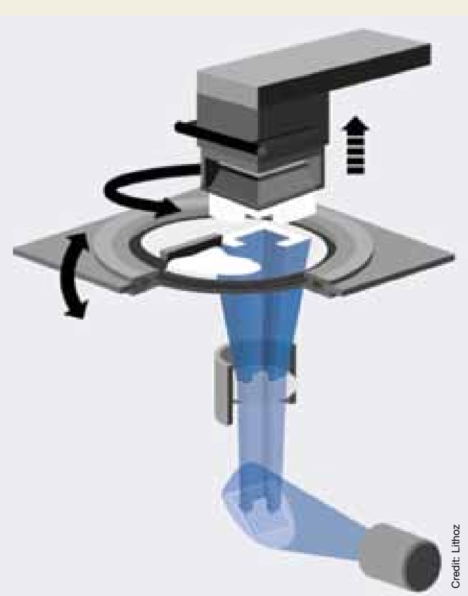
Lithoz established from the very beginning an agenda to fulfill high expectations of the ceramic industry with a clear focus on customer requirements and needs. Thus, Lithoz was inspired to earn ISO 9001:2015 certification in February 2016.

LCM technology

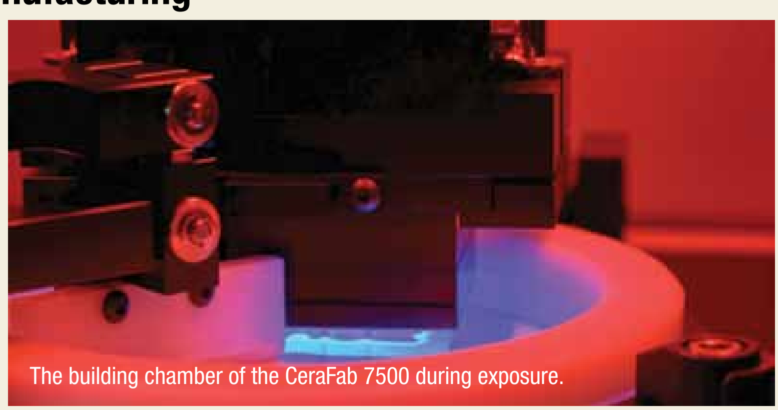
The company developed a portfolio that now ranges from machines and materials to software and applications. The LCM technology process precisely fabricates strong ceramic objects layer-by-layer (see sidebar below). A high-resolution optical system controls production of very precise and complex geometries with minimum feature sizes down to 100 µm. The outstanding properties of this process are high-resolution and isotropic microstructure and mechanical properties at the level of conventionally formed ceramics.

LCM technology fabricates parts with standard compositions, such as alumina and zirconia, which are achieving material properties comparable to conventionally formed ceramics. For example, alumina parts show values of >99.4% theoretical density (>3.96 g/cm^3) and four-point bending strength of 430 MPa. Zirconia components show theoretical density of 99.6% and strength of 650 MPa.

Lithography-based ceramic manufacturing



Schematic shows the projection system, slurry in a transparent vat, building platform, and recoater.



The building chamber of the CeraFab 7500 during exposure.

Lithoz offers a process for the additive manufacturing of high-performance ceramics that is called lithography-based ceramic manufacturing (LCM) technology. LCM technology allows production of high-performance ceramic parts with the same material properties as conventionally formed parts.

LCM technology is a slurry-based process, where ceramic powder is homogenously dispersed in a photocurable monomer system and selectively polymerized through mask exposure to produce initially the green part. These green parts are basically composites of ceramic particles within a photopolymer matrix, which acts as a binder for ceramic particles. During thermal posttreatment, processors remove the organic matrix via pyrolysis, and particles densify during sintering to give the dense ceramic body. These two process steps are typically applied in conventional ceramic forming technologies. ■

Manufactured components also have an excellent surface quality. Unfinished surface roughness for alumina is R_a of ~0.4 µm and for zirconia R_a of ~0.6 µm. Figure 3 shows a few of the complex geometries achievable with LCM technology.

To be able to ensure growth and success of the company, Lithoz has a strong orientation toward R&D and focusing on development of new materials and production systems.

The company developed its first product, the CeraFab 7500 printer, for the powder injection molding industry. The printer has a building envelope of 76 mm x 43 mm x 150 mm and a resolution of 40 µm. The system is designed to manufacture small, precise components. Lithoz currently is developing machines with larger building envelopes. For example, the CeraFab 8500 prints in a 115 mm x 64 mm x 150 mm envelope.

Besides designing next-generation LCM machines, Lithoz researchers have expanded the portfolio of ceramic compositions. Lithoz has developed silicon nitride-, cordierite-, tricalcium phosphate-, magnesia-, and silica-based powders for casting cores. These are in addition to existing alumina and zirconia materials. Because Lithoz broadened the available range of materials, lithographic AM of high-performance ceramics should see growing demand for widespread applications. High precision and accuracy of the LCM technology process offers interesting and unique opportunities in fields such as biomedical applications, catalysis, or refractories.

Lithoz scales up

To date, the company has installed more than 20 systems for customers at leading international research institutions, including the Fraunhofer Institute IKTS in Dresden (Germany) and Fraunhofer HTL in Bayreuth (Germany). In addition, several successful companies, including Robert Bosch GmbH (Germany) and Lapp GmbH (Germany), have invested in LCM technology.

Ceramco Inc., a new customer in the U.S., will install a CeraFab 7500 this summer. Thomas Hendriksen, CEO of Ceramco Inc. (Center Conway, N.H.), states, "Ceramic components made by AM methods have always had problems due to the layered structure and related anisotropy. Thus, the materials lacked the high density typical for fine ceramics—until the Lithoz machine came along. The high resolution of the Lithoz CeraFab 7500 demonstrates surface quality that is competitive with traditional forming methods, and it achieves full density in high-purity alumina and Y-TZP-type zirconia by industry standards, both of which are the main materials Ceramco makes parts from. So this machine will complement our ability to manufacture ceramic parts with complex geometry, and enable us to provide new parts to customers in short order with a quality we can stand behind; it's not just a 3-D rendering of a part that has no utility anymore."

Ceramco is Lithoz's second American customer. Lithoz sold a unit in April 2015 to an undisclosed buyer.

Sales drive growth, and growth demands space. After moving into a new building in 2014—and expanding it in summer 2015—the company is again on the verge of expanding its business premises. Lithoz requires more space

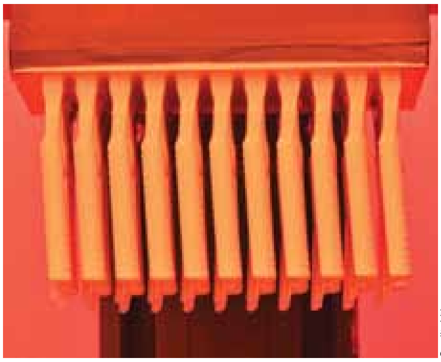

Credit: Lithoz

Figure 3. Alumina parts made by LCM technology. Applications include sensor mountings, impellers, and gears.

to meet increasing demand for customized materials and orders for LCM technology.

"This is a challenge which will be solved quickly and easily", says Homa. He is convinced that this will not be the last time that the company will need more space.

According to Homa, growth affects many departments in a small company. For example, from his point of view, it is more difficult to adapt necessary communication structures to the company's rapid growth because of the increasing facility size and



Credit: Lithoz

Figure 4. Casting cores made by the LCM process. The image shows 22 cores made on the CeraFab 8500 in 11 hours. Each core is approximately 40 x 100 mm.

number of employees. The company plans to introduce a CRM system to improve its service management. Therefore, the company will provide its growing customer base the best quality of services.

Homa is convinced the company will continue to grow. "Today, we are only at the beginning for the introduction of additive manufacturing systems in the ceramic sector," says Homa. Homa believes there is a growing need for AM because of new conditions and challenges imposed on the ceramic industry. Shorter product life cycles, need for mass customization of products, and need for resource-efficient manufacturing technologies for production of small scale series and individual pieces will continue to drive demand for AM.

High-tech solutions for high-tech markets

The possible applications of LCM technology already are diversified, and Lithoz provides the necessary components for industry and research institutes.

For example, Lithoz is developing its own material for AM of casting cores for the aviation sector. Benedikt explains, "Turbine blades are regularly used in temperature ranges that are above their melting point. One of the reasons this is possible is the presence of complex cooling channels inside the blade, which are made using casting cores. Up to date, these casting cores are produced by injection molding. But it is already clear that this approach will no longer be sufficient due to limited complexity of parts produced by this technique. Using LCM can help overcome these limitations and enables the production of geometries that cannot be manufactured with conventional technologies."

Because of its tool-free manufacturing technology, the LCM approach enables fabrication of highly complex structures and more casting cores at the same time (Figure 4).

Other industries, such as the medical sector, benefit from this new production technology. Biocompatible materials, such as alumina and zirconia, are suitable because of their good mechanical properties and their bioinert behavior, especially for permanent implants.

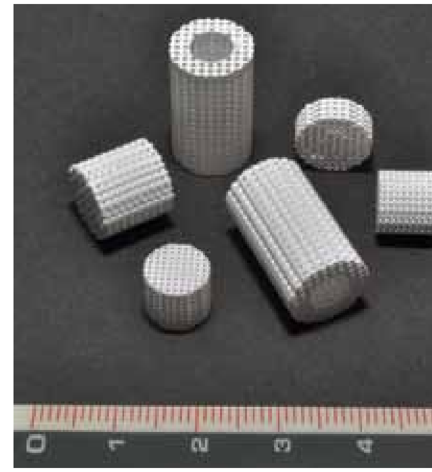
Researchers can develop completely new solutions for medical problems using LCM technology. For example, Lithoz helped develop LCM to fabricate bioresorbable ceramics as temporary implants. The body resorbs such materials and, thus, they do not require removal after the patient heals. The CeraFab system prints individual bone substitutes of tricalcium phosphate or hydroxyapatite. Figure 5 shows several bioresorbable scaffold designs.

Undiscovered potential of AM

The above-mentioned applications are not exhaustive in the least. "AM will be the driving force for innovation, and the ceramics industry can benefit in different ways by applying AM," say Homa and Benedikt. Both are convinced that the real benefits of AM have yet to be fully appreciated in the minds of industry decision-makers.

Homa and Benedikt say, that whether AM is used to produce prototypes, individualized parts, parts with higher functionality, or function-integrated parts, design always will begin with development goals. Decision makers need to have a broad view and understand that investing in new technology requires more than purchasing an equivalent or replacement system. The advantages of cutting-edge technology are achieved only by adopting new design rules and redesigning existing geometries. Companies considering AM must start with in-depth discussions of these technologies to understand how best to exploit the full potential of AM in their businesses.

Homa and Benedikt are aware of the scale of the task and are able to support companies to find their way through the advantages of adopting AM. Homa describes the clear goal for Lithoz as follows: "Our vision is to establish AM as a standard manufacturing technology. There should be no difference between manufacturing using conventional methods and AM—and we are on the way to implement this vision."



Credit: Lithoz

Figure 5. Various bioresorbable tricalcium phosphate scaffolds manufactured with the CeraFab system.

A small business grows globally

More than 98% of Lithoz business is international, and the company has built a well-functioning distribution network in China. Lithoz is working to strengthen its international presence overall and is investing resources to build up a distribution network for the United States market.

Homa explains, "In order to develop this high-potential market, we need partners with whom we act on a mutually beneficial basis. Both partners should benefit to the same extent from the opportunity that establishing our technology in the market will provide."

To ensure expansion of the company, Homa seeks ceramics specialists who are dedicated to sales to support their team abroad. By the end of the year, the company plans to employ more than 30 people along the entire process chain in Austria. ■

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References

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