3D Printing of Large Ceramic Parts for Space and Semiconductors Industries

3D printing became an important production tool for demanding high-end applications

Current and future space and airborne optical instruments are subject to major technical and economic challenges, tending towards a high level of integration. The complexity of the components and the resulting subassemblies thus place Additive Manufacturing (AM) as a means of disruptive production. In addition, as performance requirements increase, optical systems are getting bigger and bigger, which requires the development of new manufacturing processes in order to guarantee the expected performances. Another very demanding and challenging key domain for ceramic materials is the semiconductor industry. Indeed, the whole manufacturing process flow of these devices is very aggressive and requires materials with exceptional chemical, thermal and electronic properties, that only ceramics can meet. Moreover, the need for flexible and complex shapes and a growing ambition of relocation and acceleration of the production following the recent shortages makes 3D printing as a relevant respond. Thus, we easily understand why aerospace and electronic applications represent the most significant revenue opportunities for 3D-printed ceramic technical parts over the next 10 years and are expected to reach about USD 764 million by the end of 2030.

Additive Manufacturing (AM) of optical instruments for space applications

The main technical characteristics of an optical instrument for space applications are the following:

- Stability of the line of sight
- Strength to severe mechanical and thermal environments
- High optical performances as a mission component.

Ceramic materials can meet these needs as they are very resistant and display exceptional mechanical properties (stiffness, strength, stability). Nevertheless, ceramic products often suffer from the limit of traditional manufacturing methods, limiting their uses to massive and little stressed parts. However, the need for optimized large-scale optical instruments for space application is becoming acute. Indeed, satellite mirrors must be lightened as much as possible and only AM can optimize the design and production of these new mirrors. To

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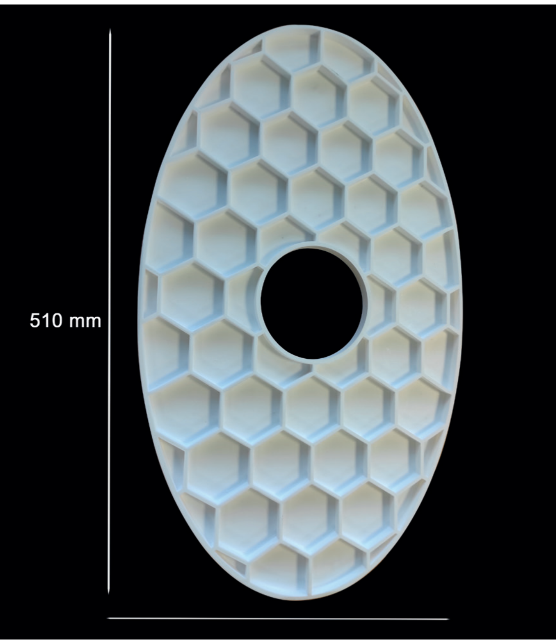

Fig. 1
Satellite mirror after sintering, printed on CERAMAKER C3600 printer in just 13 h

meet this growing demand, 3DCERAM Sinto has developed the C3600 Ultimate 3D printer with a printing platform of 600 mm x 600 mm x 300 mm (L x W x H), which is by far the largest stereolithographic printer existing on the current market.
The use of the C3600 Ultimate 3D printer for the production of optical parts has many advantages such as:

- Reduction of lead time: the traditional manufacturing process of optical parts is composed of 6 steps (production of a blank body – light weighting by machining – grinding – polishing – coating – interface integration). 3D printing allows to avoid both the machining and the grinding steps.
- Saving of ceramics: usually 90 % of the blank body's weight is removed by machining, thus resulting in an excessive generation of waste and high risk of cracks in the ceramic.
- Disruptive design: more complex designs as well as weight reduction can be considered.
- Integration of functions: like internal channels, electrical tracks and feedthroughs.
- Printing of large parts up to 600 mm x 600 mm x 300 mm (Fig. 1).

Thus, the 3DCERAM Sinto process enables the simplification and reduction of the manufacturing process. This opens a new way of developing cooled optical systems, active optical systems or freeform optical surfaces. The net shape capabilities of 3D printing also improve the quality of the integration/bonding process with increased accuracy.
So, thanks to the C3600 printer, it is now possible to produce "tailor-made" large ceramic optical substrates resulting in a reduction of risks during the manufacturing process. Moreover, new mirror designs included semi-closed back structures that allow a reduction on weight and integrated interfaces can now be explored (Fig. 2).
3DCERAM Sinto processes also open up new perspectives for the next generation of instruments such as:

- Compact solutions with integrated functions (thermal insulator, cooling channel, etc.)
- Limitation of mechanical and thermal interfaces
- Integration of the optical function as a structural device.

Thus, thanks to the new C3600 Ultimate printer, players in the space industry are now able to produce a range of large and complex optical substrates adapted to the harshest environments.

Electronics applications

In recent years, semiconductor manufacturing plants have developed increasingly complex processes that require very specific equipment to meet their expectations. Moreover, the growing need of the market in terms of microcircuit capacity has led to the use of increasingly large silicon wafers from a diameter of 1–12 inch (from 25–300 mm) and the development of equipment to handle them and to achieve the desired deposits.
To better understand the role of ceramic materials in the semiconductor industry, here is a synopsis of the main steps involved in the fabrication of integrated circuit chips:

- Wafer processing is performed to obtain a round wafer slice formed by cutting a single crystal column made of silicon or gallium arsenide.
- Oxidation step is necessary to form a protective film on the surface of the wafer.

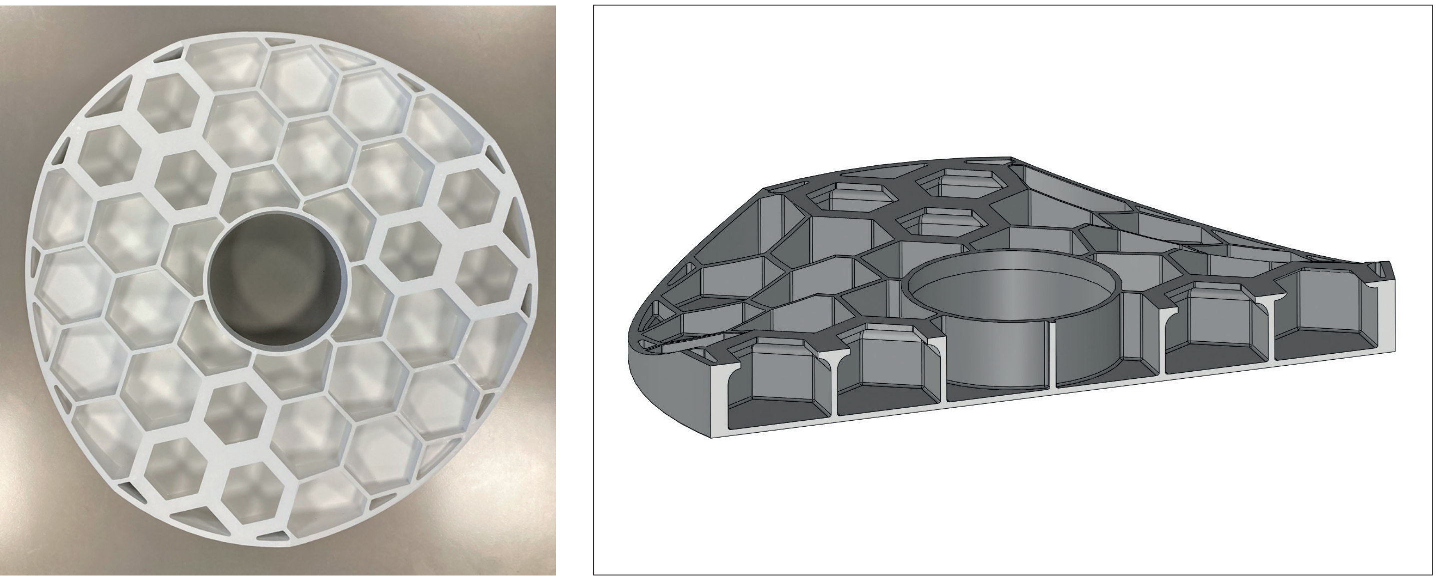

Fig. 2
500 mm diameter satellite mirror with a closeback structure printed in less than a day on CERAMAKER C3600 printer

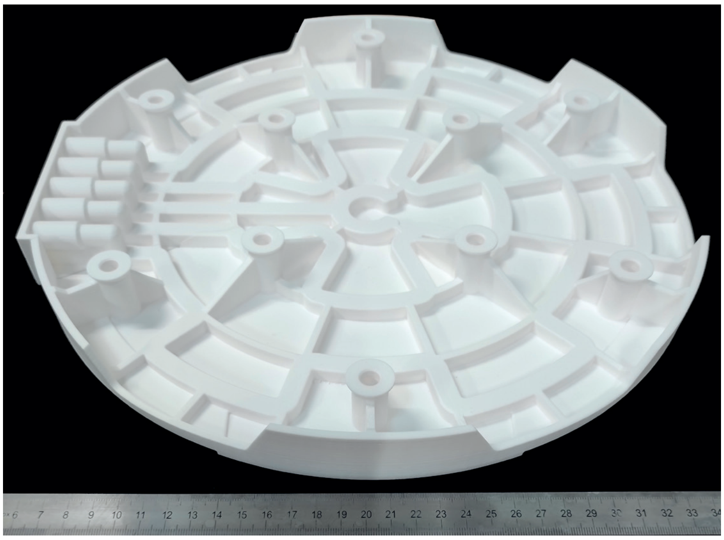

Fig. 3
21 h 49 min is the time needed to print this big part on CERAMAKER C3600 printer to address the semiconductor industry

Fig. 4
Dr Holger Wampers, Alumina Systems CEO, holding a part printed on the CERAMAKER C3600 printer

- Photolithographic process is used to “print” circuit patterns onto the wafer.
- Etching process to remove excess of oxide film and leave only the semiconductor circuit diagram.
- Film deposition is used to form a multi-stack structure composed of alternately conductive and insulating films on the surface of the wafer.
- Interconnection process to achieve power and signal transmission.
- Assembly, packaging and final tests.

For all these steps, in order to increase equipment lifetimes and reduce operating costs, manufacturers are using the remarkable properties of ceramics. Indeed, beyond the need to work in extremely clean conditions, the multiple deposition techniques used such as CVD, PECVD, ALD require materials with specific properties to obtain and maintain the perfect conditions required for the production of these high-performance products.

Among the ceramic materials, most in demand are the following:

- Common oxides such as Al_2O_3, ZrO_2, SiO_2, cordierite which represent the major part of the market, but also oxides with higher added values such as Y_2O_3.
- Aluminum and silicon nitrides: AIN and Si_3N_4
- Carbides: SiC.

Here are some examples of parts made of ceramics used for the semiconductor industry:

- In the wafer cleaning step, ceramic materials are used in wafer transport trays, chucking/suction tables (Fig. 3) and robot arms.
- In the thermal diffusion and chemical vapor deposition processes, many parts such as radiant tubes, wafer boats and gas introduction ports are made of ceramics.
- In the plasma etching process, ceramics are used for chambers, electrostatics chucks, nozzles, and rings.
- Ceramics can also be used as heaters during thermal treatments.

Furthermore, the 3D printing process, due to its flexibility and reactivity as well as its the open access given to complex geometries, appears to be a technique of choice with a bright future for the production of these high-tech parts.

An excellent success story of ceramic 3D printing for the semiconductor industry has been achieved in 2018 by Alumina Systems GmbH/DE. Indeed, this company was awarded the with Best Component Award at CERAMITEC in Munich/DE for the development of a 380 mm diameter ceramic gas distribution ring for PEALD (Plasma Enhanced Atomic Layer Deposition) processes. Thanks to its ingenious geometry, the ring can supply 2 gases concomitantly or sequentially. PEALD is an innovative process applicable for semiconductors production showing an important growth in technology with a significant economic potential.

Originally, the aluminum oxide ring was produced in many separated pieces which were joined with glass solder. But since the acquisition of a CERAMAKER C3600 printer by Alumina Systems, it can be fully printed in a single run (Fig. 4).

3DMIX slurries

3DCERAM Sinto supplies an extended portfolios of technical ceramics to print on CERAMAKER machines. Starting from oxides such as alumina, zirconia, cordierite, over non-oxides like silicon nitride, aluminum nitride. 3DCERAM Sintos also provide biocompatible materials such as HAP/TCP and silica-based slurries for the foundry cores industry. All these formulations are ready-to-use and the properties of the final materials are equivalent to those of the materials obtained using conventional ceramic processes.

3DCERAM Sinto also develops on demand-formulations based on the powders of the company´s customers to be printed using the CERAMAKER process. In that case, the experts of 3DCERAM Sinto determine the ceramic formulation and the process parameters adapted to the customer needs, according to the characteristics to be obtained.

The choice of the materials intended to be used in optical and semiconductor applications is very important. Manufacturers have to take into account the following material

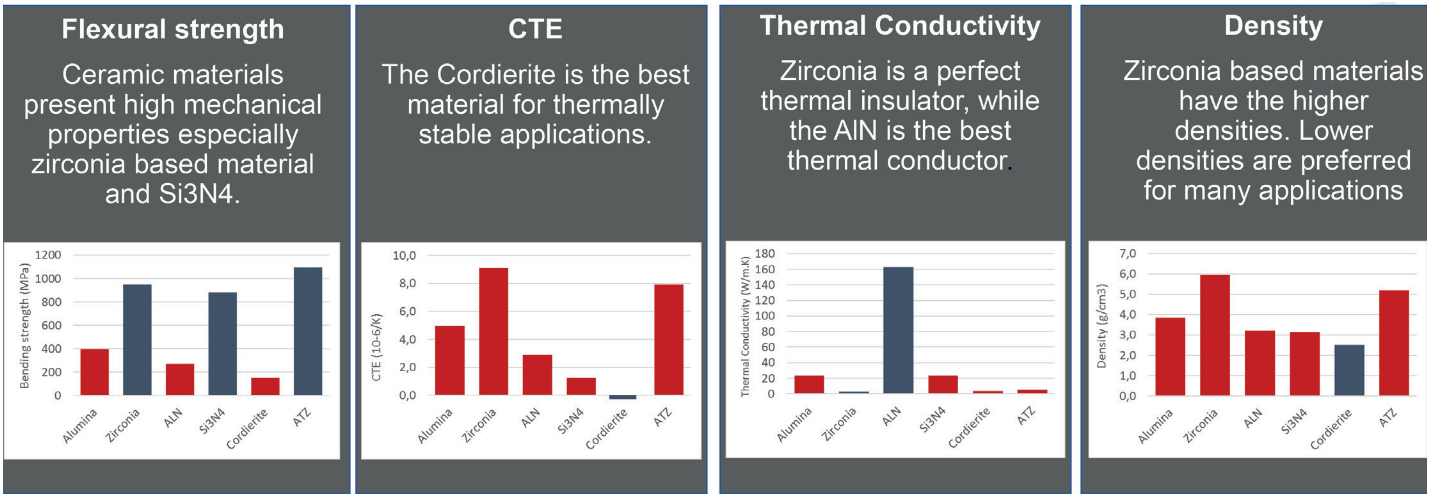

Fig. 5
Properties of the 3DMIX materials able to address aerospace and semiconductor fields

properties when deciding on which ceramic to use:

- The mechanical and thermal properties
- The stiffness and the density
- The Coefficient of Thermal Expansion (CTE)
- The chemical/corrosion resistance.

The properties of the main 3DMIX materials able to address optical and semiconductor fields are given in Fig. 5.

Conclusion

AM brings a new dimension to the usual industrial processes for the production of optical and semiconductor instruments. Indeed, in addition to saving time and reducing production scraps, this technology presents following advantages:

- Creation of breakthrough designs
- Improvement of stiffness to the mass ratio
- Integration of new functions like cooling channels or thermal insulators
- Simplification and optimization of the interface.

Among all AM processes, the stereolithography has emerged as the most suitable for those applications as it allows to achieve the most optimized results in terms of printing quality, spatial resolution and material properties. But in order to increase their performance and lifetime, future manufacturing processes of semiconductor/optical devices will become faster, and even more aggressive. Then, the combination of specific ceramic materials and commercialization of industrial 3D printers are incomparable assets to meet the future challenges of these fields. Moreover, to meet the need for larger and larger parts, the development of a new printer was necessary. So the largest stereolithographic printing platform accessible so far on the whole market has the sizeof of 320 m x 320 m x 200 m (CERAMAKER C1000 FLEXMATIC).

To respond this market demand, 3DCERAM Sinto has developed the C3600 ULTIMATE process: an industrial turnkey solution allowing manufacturers to benefit from a large capacity (600 mm x 600 mm x 300 mm), and an efficient and reliable mean of production. This process represents an unique way to improve both technical and business aspects of the semiconductor and optical industries.