Ceramic Additive Manufacturing Process Applied to Aerospace Needs for Optimised Optical Instruments

In the last decade, the optical instrumentation for space and Unmanned Aerial Vehicle (UAV) platform has been optimised in order to reduce the mass and volume of the equipment. In order to meet this specific goal, it was critical to develop new innovative systems taking into account new manufacturing methods.
Additive Manufacturing (AM) as one of the key components in innovative solution to design optimised optical instrument. Products are mainly plane mirrors for front end laser engines (galvo-mirror for high energy laser application), and optical applications.
The innovation therefore lies in the application of AM to the design and manufacturing of optical substrates.
An optical system needs the followings technical characteristics:
- **High stiffness – to improve and guarantee the stability of the line of sight,**
- **High strength – to withstand the harsh mechanical and thermal environment,**
- **High stability – to guarantee the optical performance in orbit or generally during the mission.**

This article explains how the AM process can reach these requirements, and can improve some points.

Manufacturing of optical instruments

The state-of-the-art of optical instrument is such, that traditionally this kind of parts use a common manufacturing process with the following 6 main steps:
1. Blank body – raw material, shaped by moulding or pressing;
2. Light weighting – milling of the blank body to reduce the mass;
3. Grinding – reduces the roughness and gives the near shape;
4. Polishing – decrease the roughness to few nanometer;
5. Coating – apply a metallic deposition to improve the spectral reflectance;
6. Integration of the interface – commonly by gluing.

When it comes to the risk analysis of each operation, step N°2 and 3 are risky. The milling of the ceramic is quite complicated. The operation N°6 is complex because it needs some tooling and the glued part is not very resistant.

Many reasons justify the use of AM for optical parts:
- Reduction of weight of the parts by more complex design (holes, semi close back structure, etc.);
- Reduction of lead time: actual lead time is quite important due to manufacture of a first draft, which has to be lightend by machining;
- Saving of ceramic: often a 90 % weight reduction of optical parts is necessary, but it is more profitable to print the 10 % remaining;
- Disruptive design: new designs, more complex ones can be consider;
- Integration of functions: one can add new functions like internal cannels, electrical track etc.

Keywords
additive manufacturing, optical mirrors, aerospace

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3D-Optic™ process for space and defense applications

The 3DCeram Sinto's process allows to "custom-made" ceramic optical substrates and to decrease risks during manufacturing.

This innovative process originates as mirrors are generally light weighted: 90 % of their original weight is removed using tooling, thus resulting to a high risk of cracks in the ceramic. Consequently, the process developed by 3DCeram Sinto lies on the ability to directly 3D-print the 10 % of material that are really useful.

It can allow customers explore new way to design mirror, with:

- semi-close back structure,
- integrated interface,
- conformal ribs.

It can also open up new perspectives for the next generation of instruments, with:

- compact solution with integrated functions (thermal insulator, cooling channel, etc.);
- limitation of mechanical and thermal interfaces;
- integration of the optical function like a structural device.

The 3D-Optic™ solution enables to simplify and reduce the manufacturing process to following steps:

1. 3D-printing;
2. Polishing – decrease the roughness to few nanometer;
3. Coating – apply a metallic deposition to improve the spectral reflectance;
4. Integration of the interface – commonly by gluing.

Consequently, the user can easily decrease the risk of troubles during manufacturing. This opens a new way of developing cooled optical systems, active optical systems or freeform optical surfaces.

The last innovative point is the capability the produce a custom solution, made on demand, with no specific tooling, from a common optical architecture with the customer requirements.

Because this solution is a "design to print" solution, a change request from customers during their engineering phase will not imply any additional costs compared to traditional methods.

Thanks to this new global conception and manufacturing solution, optical substrates/mirrors can be more and more compact thus allowing for additional functions while still ensuring very small volume and mass. Up to now, this had been impossible thanks to AM a new option is given.

There are 2 types of mirrors: supported mirrors and mirrors who do support a function (Fig. 4 a–b).

3DCeram Sinto has developed turnkey solutions to allow industrial manufacture of optical instruments to benefit from the flexibility and high-performance production through the process of 3-printing.

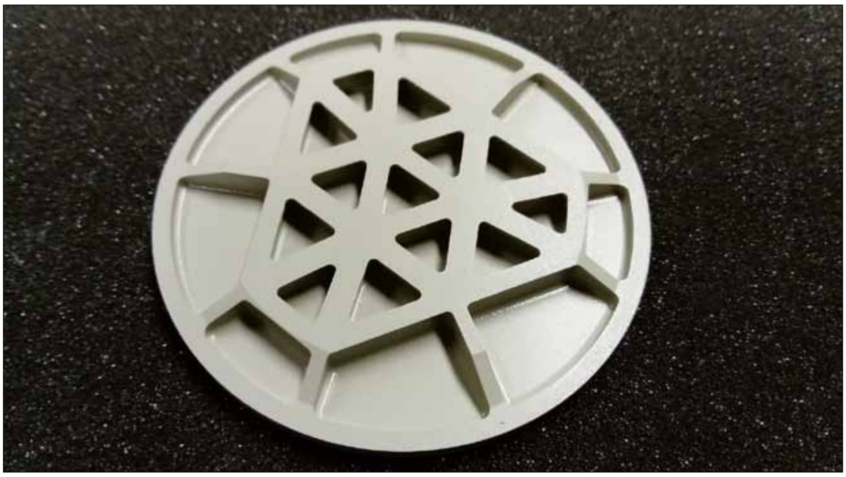

Fig. 1
Mirror printed with silicon nitride ceramic

Fig. 2
Aerospace device

Choice of material

The choice of ceramic used for the production of such parts is a very important decision for the 3D-process. There are some important points that the manufactures of mirrors (or optical devices) must take into account when deciding on which ceramic to use:

- the mechanical and thermal properties;
- the stiffness, and density;
- the CTE.

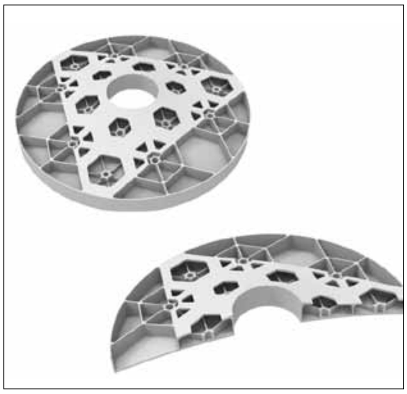

Fig. 3
Mirror with semi-closed back structure

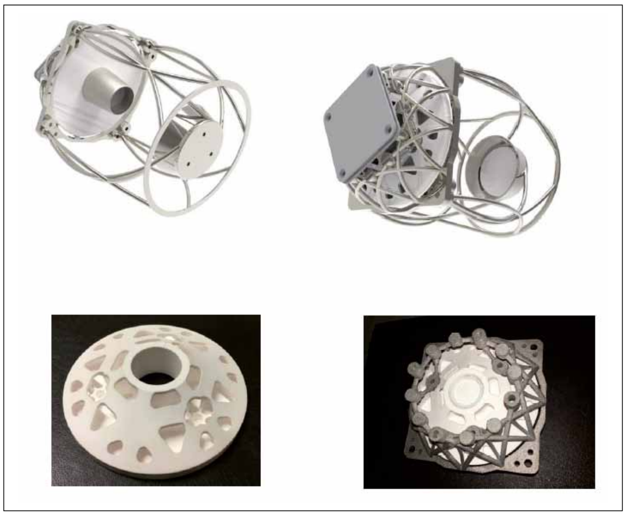

Fig. 4 a
Supported mirror: optical mirror supported by a mechanical structure

Fig. 4 b
Mirror which supports function

3DMIX

3DCeram Sinto has been developing its own pastes since 2001, to use them in conjunction with their 3D-printing machine CERAMAKER® 900. The company has developed a range of pastes and suspensions to achieve an optimal printing results of optical devices. These pastes have been developed to guarantee a quality of product equal to traditional methods. 3DCeram Sinto has optimised its pastes with the customers' criteria in many cases in the form of on demand formulation of ceramic paste to adhere to the machine's parameters. This has permitted clients to use their "own" ceramic powders while using the breaking technology of ceramic 3D-printing.

3DMIX Standard

Following ceramics that are available from 3DCeram Sinto:

- Alumina (Al_2O_3): the 3DCeram Sinto alumina (printed since 2001), has a purity of 99,8 % which confers to the printed parts, high hardness, high using temperature, and electrical insulation properties. Moreover, the CTE is close to the titanium alloys, and alumina has better stiffness and less density with regards to titanium alloys,
- Cordierite: cordierite is a magnesium alumina silicate with the chemical formula $2\ MgO \cdot 2\ Al_2O_3 \cdot 5\ SiO_2$. Cordierite can be used due to low thermal conductivity and low expansion coefficient, resistance to heat and low dielectric loss.
- Silicon nitride: silicon nitride is one of the hardest and most resistant ceramics. The main characteristics of silicon nitride are: low density, excellent resistance to thermal

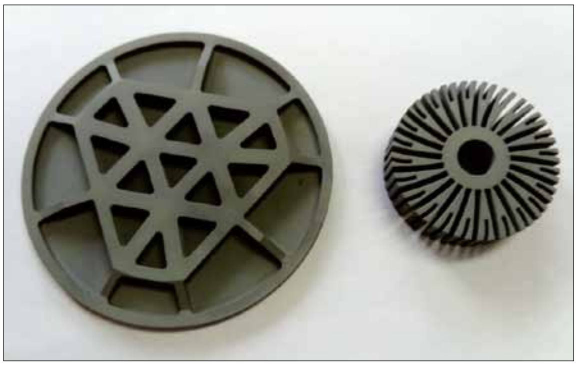

Fig. 5
Parts printed by 3DCeram Sinto with Si_3N_4 *ceramic (after sintering)*

shocks, excellent resistance to wear, and low thermal expansion coefficient.
The printability of silicon nitride was a challenge for 3DCeram SInto's team given the complexity of the curing of such powder (dark and absorption). After 6 months of hard works, the company offered this new paste (named 3DMIX SiN) in order to print silicon nitride parts, with density up to 99,7 % after sintering.

3DMIX on demand

Along with these materials, 3DCeram Sinto proposes on demand services, when a client wishes to use its "own" paste on the CERAMAKER 900. The team of experts will take into consideration the needs and demands of the client. The process to obtain a new paste for the core production is:

- characterisation of the company´s powder;
- reactivity test of the paste once mixed with resin;
- powder optimisation, and determination of machine parameters;
- post-process analysis;
- fabrication of benchmark parts.

This has proven to be very beneficial to manufactures of optical parts. Traditionally, the customers have not altered their powder to adapt to new technologies. It is essential to offer knowledge and expertise to potential customers, to establish a synergy between the machines parameters, and the characteristics of the ceramic powder.

Perspectives

While industrial 3D-printing of foundry cores is expected to represent one of the larger revenue opportunity, Technical Ceramic applications, like space applications, are expected to experience the fastest growth.
Aerospace application, which are currently the existing applications of ceramic AM, remain the most significant revenue opportunity, and represented USD 289 million by the end of year 2027. The CERAMAKER 900 printer has the biggest printing platform available in the market i.e. 300 mm × 300 mm × 100 mm, and soon it will have a much bigger one: 600 mm × 600 mm × 200 mm in Q4 2018.

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Taking into account the shrinkage, one can produce parts with dimensions of Ø 250 mm, extended to Ø 500 in Q4 2018 – it is totally in accordance with the market!

Conclusion

AM brings a new dimension to the usual industrial processes. In addition to saving time and increasing productivity, 3DCeram Sintos breakthrough technology delivers following benefits:

- improvement of the stiffness to mass ratio;
- integration of new functions like cooling channels or thermal insulators near the optical surface;
- simplification and optimisation of the interface management by adding screwing cavities directly on the mirror at the design and 3D-printing step – rather than adding a mechanical interface in a second step.

Ceramics 3D-printing is a way to propose breakthrough design, and improvements on both technical and business aspects.

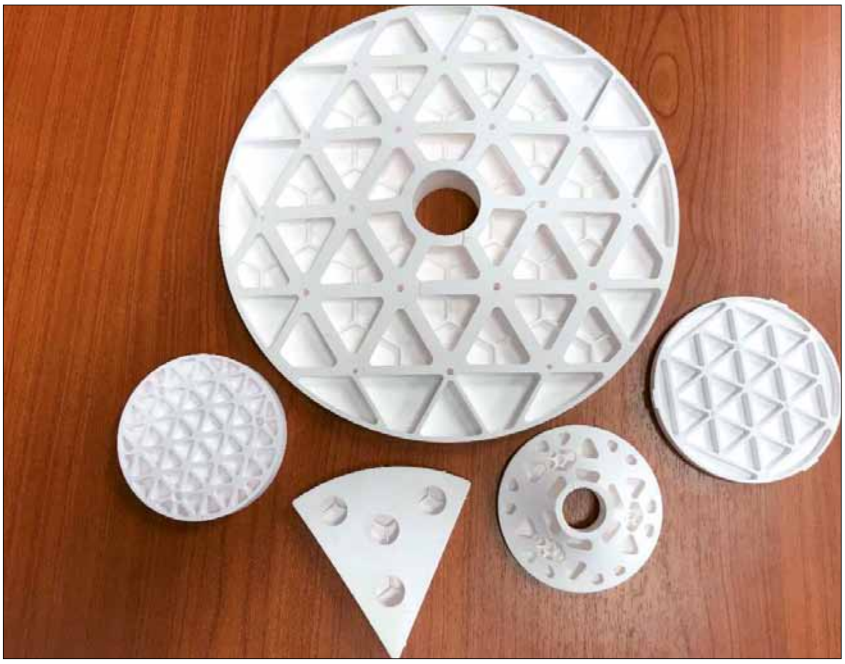

Fig. 6
Various alumina mirrors printed by 3DCeram Sinto: the outside diameter of the bigger one is 250 mm after sintering