Additive Manufacturing Applied to Aerospace Needs: Optimized Optical Instruments

In the last decade, the optical instrumentation for space and unmanned aerial vehicle (UAV) platforms has been optimized in order to reduce the mass and volume of the equipment. To meet this specific goal, it was critical to develop new innovative systems taking into account new manufacturing methods.

Additive manufacturing is one of the key components for an innovative solution to design optimized optical instruments. Products are mainly plane mirrors for front end laser engines (galvo-mirrors for high energy laser applications) and optical applications. The innovation therefore lies in the application of additive manufacturing to design and manufacture an optical substrate.

An optical system needs high stiffness to improve and guarantee the stability of the line of sight and high strength to withstand the harsh mechanical and thermal environment. Furthermore, it needs to have a high stability to guarantee the optical performance in orbit and in general during the mission. This article explains how additive manufacturing can meet these criteria and improve the manufacturing process of optical instruments.

Traditionally, an optical instrument is produced in six main steps. Firstly, the blank body is produced by shaping raw material by molding or pressing. The second step is important to receive a lightweight component: The blank body is milled to reduce the mass. As a third step, grinding of the component reduces its roughness and gives it the near shape. Next, the component is polished to decrease the roughness to a few nanometers. This is followed by the coating of the part with a metallic deposition to improve the spectral reflectance. Lastly, the component is integrated into the interface, this is commonly done by gluing.

When it comes to the risk analysis of each operation, step two and three involve a higher risk: The milling and grinding of the ceramic component is complicated. Also, the operation six is complex as well because several tools are needed and the glued parts are not very durable.

For this reason, additive manufacturing is of great use in the production of optical parts. The weight of the parts can be reduced while more complex and disruptive designs such as holes or semi-closed back structures can be applied. Also, the lead time can be reduced, because the first draft can easily be produced by additive manufacturing. Another important advantage of additive manufacturing is the saving of material in comparison to conventional manufacturing methods. With additive manufacturing, new functions like internal channels and electrical tracks can be integrated into the objects.

This is why 3DCeram Sinto has developed a new range of optical substrates adapted to the most complex environments for space and defense applications: 3DOptic. The 3DCeram Sinto process allows the fabrication of "custom made" ceramic optical substrates and to decrease the risks during manufacturing. In comparison to the general production process, this new process developed by 3DCeram Sinto offers the possibility not to remove 90 % of the original weight of the product by tooling but to print a part out of the remaining 10 % without any material waste. In addition, the high crack probability in the traditional manufacturing process can be avoided by additive manufacturing.

By 3D printing the part, the customers have the possibility to explore new ways to design mirrors, for example with a semi-closed back structure, integrated interfaces or conformal ribs. The process opens up new perspectives for the next generation of instruments, with a compact solution with integrated functions such as thermal insulators or cooling channels and the limitation of mechanical and thermal interfaces. Also, optical functions such as structural devices can be integrated.

The 3DOptic solution enables simplifying and reducing the steps in the manufacturing process to:

1. 3D printing
2. Polishing: The roughness is decreased to a few nanometers

About 3DCeram Sinto

Created in 2001, 3DCeram Sinto (www.3Dceram.com) is a company based in Limoges, France, owned and managed by Christophe Chaput and Richard Gaignon since 2009. 3DCeram Sinto combines expertise in the technology of 3D printing, offering a complete package by accompanying their clients on their chosen projects, choice of ceramic material, production specification, R&D, modification of 3D parts for industrialization, on demand production, the selling of the Ceramaker 900 printers and the associated consumables and services.

3. Coating: A metallic deposition is applied to improve the spectral reflectance
4. Integration of the interface: This is commonly achieved by gluing

Consequently, the user can easily decrease the risk of complications during manufacturing. This opens up new ways of developing cooled optical systems, active optical systems or freeform optical surfaces.

Design to print

The last innovative factor is the ability to develop a customized solution that can be manufactured on request, without special tools, from a common optical architecture with the customer's requirements. Because this solution is a "design to print" solution, a change request from customers during their engineering phase will not cause any additional costs compared to traditional methods.

This new conception and manufacturing solution allows optical substrates and mirrors to be designed more compact thus allowing the implementation of additional functions while keeping volume and weight to a minimum. This was previously not possible but is now, thanks to additive manufacturing.

There are two types of mirrors: Supported mirrors, where the optical mirror is supported by a mechanical structure and mirrors who have a support function.

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

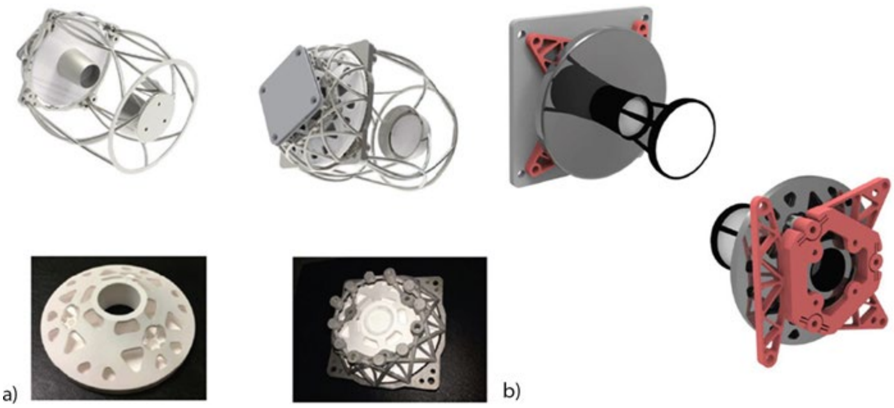

Figure 1 a) Supported mirror: The optical mirror is supported by a mechanical structure b) Mirrors who have a support function (© 3DCeram Sinto)

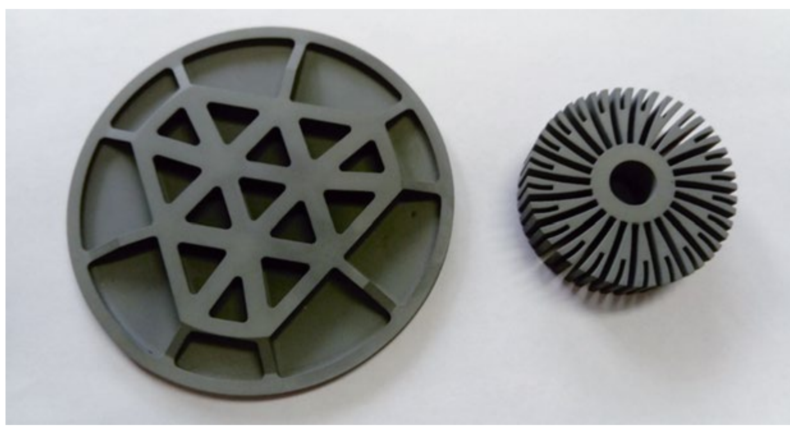

Figure 2 Parts printed by 3DCERAM with Si_3N_4 ceramic (after sintering) (© 3DCeram Sinto)

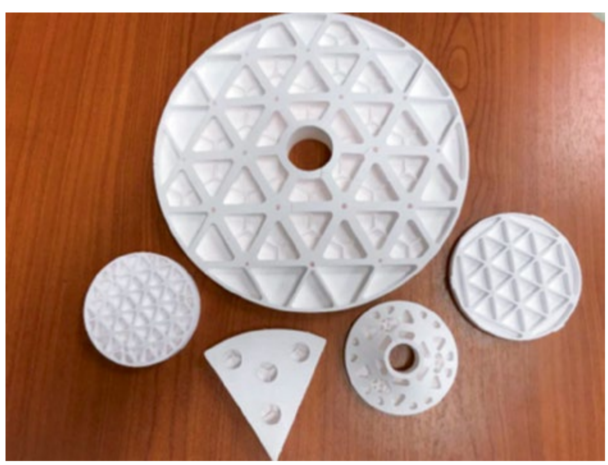

Figure 3: Sample components that have been produced by a Ceramaker 900 (© 3DCeram Sinto)

Choice of material

The choice of ceramic used for the production of such parts is a very important part of the 3D printing 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 of the material
- The CTE (coefficient of thermal expansion)

3DCeram Sinto has been developing its own paste since 2001, which is used in combination with the 3D printing machine the Ceramaker 900. Scientist at 3DCeram Sinto have developed a range of pastes and suspensions to achieve optimal printing results of optical devices. These pastes guarantee a product quality that matches that of traditional methods. 3DCeram Sinto has optimized its paste according to the customer's criteria in many cases in the form of an on-demand formulation of the ceramic paste to comply with the machine parameters. This has permitted clients to use their own ceramic powders while benefiting from the technology of ceramic 3D printing.

Figure 4: The Ceramaker 900 printers offer the largest printing platform on the market as of today (300 x 300 x 100 mm). (© 3DCeram Sinto)

Figure 5: 3DCeram Sinto has been developing its own paste since 2001, which is used in combination with the 3D printing machine the Ceramaker 900. 3DCeram Sinto offers Alumina (Al_2O_3), Cordierite and Silicon nitride as materials. (© 3DCeram Sinto)

3DCeram Sinto offers Alumina (Al_2O_3), Cordierite and Silicon nitride as materials. The 3DCeram Sinto Alumina (used for printing since 2001), has a purity of 99,8% which confers high hardness, high operating temperatures and electrical insulation properties to the printed part. Moreover, the CTE is close to that of titanium alloys, but alumina offers better stiffness and less density than titanium alloys. Cordierite is a magnesium alumina silicate with the chemical formula $2MgO.2Al_2O_3.5SiO_2$. It has excellent properties such as low thermal conductivity and a low expansion coefficient, resistance to heat and low dielectric loss. Silicon nitride is one of the hardest and most resistant ceramics. The main characteristics of silicon nitride are: low density, excellent resistance to thermal shocks, excellent resistance to wear and a 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 absorbing). After six months of hard work, the company offered this new paste (named 3DMix SiN) in order to print Silicon nitride parts with a density of up to 99,7% after sintering.

In addition to these materials, 3DCeram Sinto offers on demand services. If a client wishes to use his 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 core production is:

- Analyzation of the characteristics of the new powder
- Testing of the reactivity of the paste once mixed with the resin
- Optimization of the powder and determination of machine parameters
- Post process analysis
- Fabrication of benchmark parts

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

Perspectives

While industrial 3D printing of foundry cores is expected to represent one of the larger revenue opportunities, technical ceramic applications like space applications are expected to experience the fastest growth. Aerospace applications, who are currently existing applications of additive manufactured ceramics, remain the most significant revenue opportunity and represent 289 million USD by the end of year 2027.

The Ceramaker 900 printers offer the largest printing platform on the market as of today (300 x 300 x 100 mm). The company is launching a new printer this year, the Ceramaker 3600 with a printing platform of 600 x 600 x 300 mm. Taking into account the shrinkage, parts with a diameter of up to 250 mm can be produced. This will be extended up to 500 mm in diameter with the newly developed printer soon to be introduced to the market.

Conclusions

Additive Manufacturing brings a new dimension to the traditional industrial processes. In addition to saving time and increasing productivity, 3DCeram's technology delivers the following benefits: The stiffness to mass ratio can be improved and new functions like cooling channels or thermal insulators near the optical surface can be integrated. Furthermore, the technology offers a possibility to simplify and optimize the interface management by adding screwing cavities directly onto 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 both technically and commercially.

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