Industrial freeform generation of microtools by laser micro sintering

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Abstract

Precision tools with structural resolution reaching the 20 micrometer range can be generated on an industrial scale by "laser micro sintering". Components featuring aspect ratios above 12 and a roughness R_a down to 1.5 micrometers have already been produced from sub micrometer grained metal powders. The components can be generated either firmly attached to a substrate or fixed in an easily separable mode. If supporting structures are employed, undercuts up to 90° are feasible, without, a process parameter dependent maximum angles of undercut below 90° are obtained.

The process has been introduced into the market, labeled microSINTERING by 3D-Micromac AG.

1. Introduction:

As mechanical engineering industry encounters a growing demand of µm-sized or µm-structured components for an increasing range of applications, miniaturization is presently ranking among the most important goals in product and tool development. Compared to still higher resolving techniques, selective laser sintering (SLS) bears the advantages of relatively low production cost and short processing times even for series productions of micro parts. Furthermore, next to prismatic or tapered microstructures, undercuts and hollows can be realized. Manufacturers usually describe the performance of their devices in terms of accuracy or minimal layer thickness which yield but little information on the actual feasible minimal structural feature size. Until recently commercial metal SLS units were unable to generate micro parts smaller than 100 µm /1,2,3/.

In the past five years research groups have worked on laser sintering of various metallic powders with pulsed or q-switched pulsed regimes /4,5,6/. Solid bodies were obtained. Wall thicknesses which were reported in two cases. Considering these as a criteria for the resolution, it remained at values of 100µm and above.

A novel modification of SLS commonly referred to as *"laser micro sintering"* together with a new setup, developed by Laser Institut Mittelsachsen e.V., extends the resolution to less than 30 µm for overall resolution, 20µm for ligaments and of 10µm for notches at aspect ratios of 12 and above, and presently a minimal roughness R_a of 1.5µm can be achieved with a minimum roughness of 1.5µm /7,8,9,10/.

Since its first public announcement in May 2003 laser micro sintering /7,8/ has gained advertence and acknowledgement among toolmakers and users. The once innovative set up - consisting of a hermetically closed sinter chamber and a special rake – which already fitted the needs for the handling and selective sintering of sub-µm grained metal powders - has been upgraded to higher efficiency and industrial applicability. The specific procedure including the laser sintering regime has become a sufficiently reproducible routine by which functional micro-freeforms are obtained from a number of powder materials. Ceramics laser micro sintering is still in development.

2. Characteristics and Performance of the Technique

A schematic of the process assembly is displayed in Fig.1. The set-up consists of a sintering chamber, an attached turbo molecular vacuum pump, a ScanLab beam scanner with a scan field of $25x25mm^2$, a Q-switched Nd:YAG – laser (λ = 1064nm) with an output of 0.1-10W in TEM_{00} mode and 0.5-100kHz pulse frequencies, gate valves for various shielding and reaction gases as well as the power supply and the control unit for the coater and piston drives.

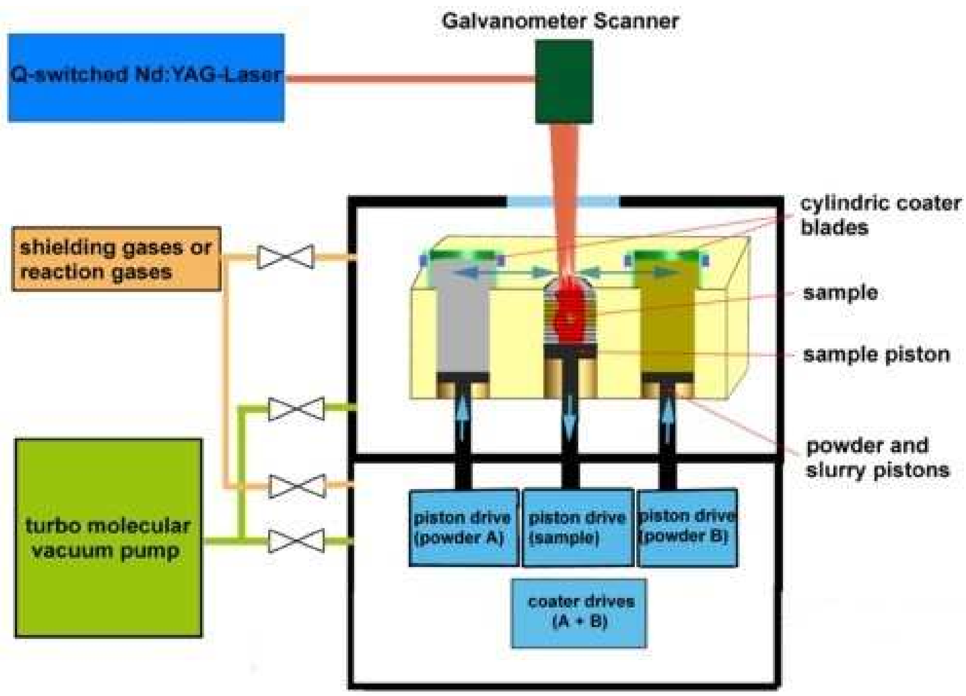

Figure 1: Schematic set-up for laser microsintering ("chamber type 2")

The sinter chamber is a vacuum tight stainless steel casket which is bisected into an upper and a lower compartment. The bisection allows the drives and the controls in the lower compartment to be kept unaffected by the reaction atmosphere. The lid on top of the casket holds an integrated quartz glass window with transmission for the applied laser radiation.

The process platform has one or more cylindrical bores for the powder supply and one for the sample piston. Two or more rakes [Fig. 2] sweep the powder materials in a circular motion onto the sample piston (the sintering platform). This technique allows realizing vertical gradients of material or respectively grain sizes along the vertical axis of a 3D-micro body.

The blades of the rakes are metal cylinders with a sharpened edge. Because of their geometry the rakes also serve as intermediate powder reservoirs [Fig. 3]. The pistons are tight for powders and liquids, which allows to process also emulsions and ceramic slurries. The chamber can be evacuated by the attached turbo molecular pump down to pressures of 10^{-3}Pa and it can be charged with shielding gases or reaction gases at any pressure in the range between 10^{-3}Pa up to $4x10^{5}$Pa. Flushing with reaction gases, which is possible at pressures of ≥1Pa, makes the device applicable for laser chemical vapor deposition (Laser CVD).

The 3D-micro bodies are generated by sintering the body cross section of the respective layer with a special regime of q-switched laser pulses. The proprietary software *IVS STL Converter (Version 1.0)* that was developed especially for this purpose controls the sinter process. STL – data can be processed with a high resolution on a micrometer scale. Especially curves are executed at fast rates with high precision. Outline and filling parameters can be adjusted arbitrarily. This feature enables the operator to realize structural or density gradients in the micro body. Continuously repeated calibration of the scanner is integrated into the software accounting for the fidelity and precision of the technique, even at high aspect ratios.

Figure. 2: *Multiple rakes and powder supplies allow varying compositions*

Figure. 3: *Ringblade serves as rake and powder storage*

With single component powders the texture of the resulting solid area is not a closed coating of metal, but is more a network of craters or wedges that root about 5-10µm below the mean surface level with crests above between 1 and 3µm. Densities between 40% and 75% arise from those materials. Blends, especially those consisting of a refractory and a lower melting metal, yield densities of 90% and above [1].

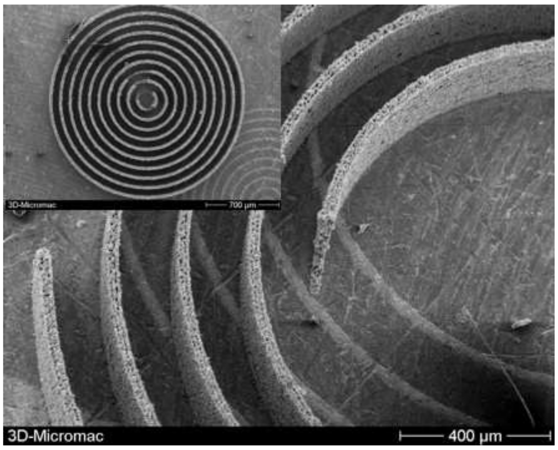

Fig. 4: *Coiled tungsten ligament*

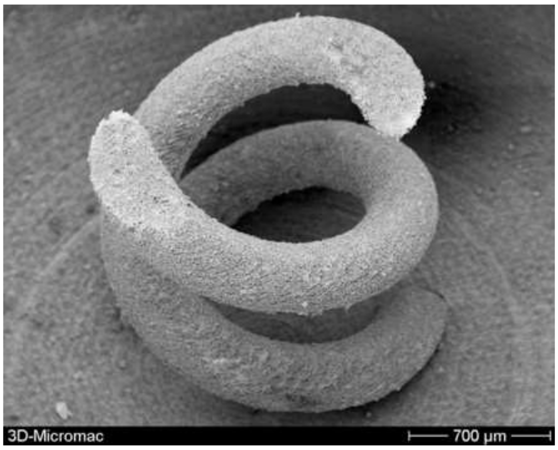

Fig. 5: *Bihelical tungsten structure*

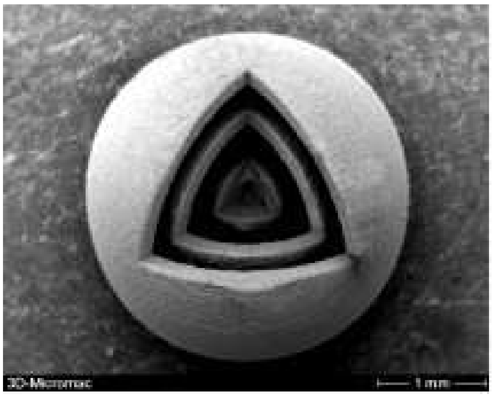

Fig. 6: *Three nested hollow spheres.*

Metallic micro freeforms can be either fused to the metal substrate or attached to the substrate surface by narrow sinter necks, frail enough to be sheared off without destruction of the generated free form but stable enough to fix the part throughout the raking and sintering process.

All the examples of functional tools presented further on in this report [Figs. 7-11] have been fixed to the platform in this separable mode during generation. Description of the morphology of the interface between work piece and platform have been presented at earlier events /7,8,9,11/.

The SEM views in Figs. 4-6 give an impression of the resolution of laser micro sintering and its efficiency in the realization of undercuts, which in the case of the presented samples were realized without the use of support structures. In Fig. 6, the base of the outer shell of the tree nested spheres starts with an angle of 30° to the platform surface which complies with an undercut angle of 70°.

3. Functional Tools produced by Laser Micro sintering

The functional parts displayed below are generated from a blend of metal powders. The tools are employed as grip bits for micro manipulators or micro positioning devices. The drawings, which were released to our disposal by MiLaSys Technologies, show the functional environment of the components. Figs. 7 show a bit for the lifting and positioning of small lenses. The tool has an open and hollow cylindrical base. Via the three visible channels vacuum can be applied.

Fig 7a: *Grip bit for the positioning of an optical lens*

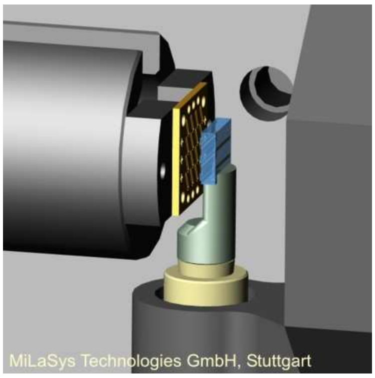

Fig 7b: *Blow-up of the functional environment*

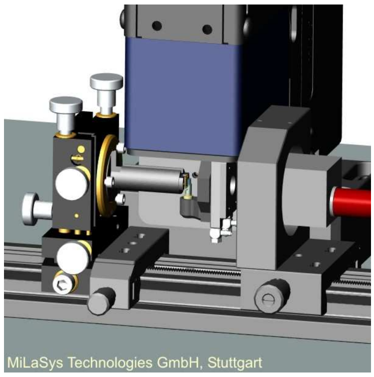

Fig 7c: *Lens positioning device. Functional environment*

The wafer lifter bit in Figs. 8 has the shape of a square flat funnel and is employed to lift circuit boards or wafers by aspiration.

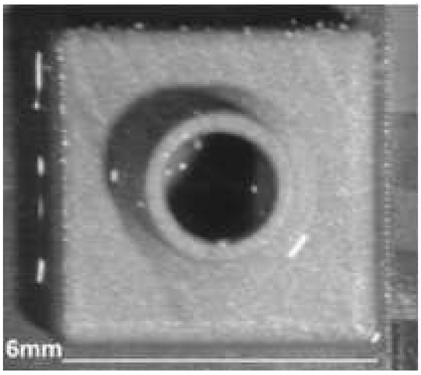

Fig 8a: *Grip bit for a wafer lifter. The glare is from remainders of the cleaning fluid*

Fig 8b: *Blow-up of the Functional environment*

Fig 8c: *Wafer lifter. Functional environment*

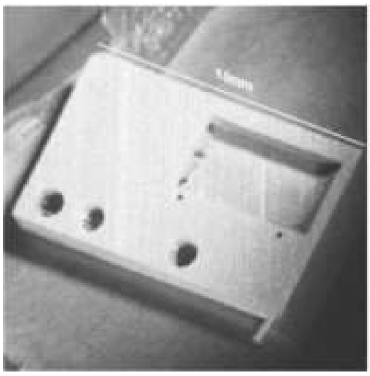

Fig 9a: *Aspiration box of the fiber holder*

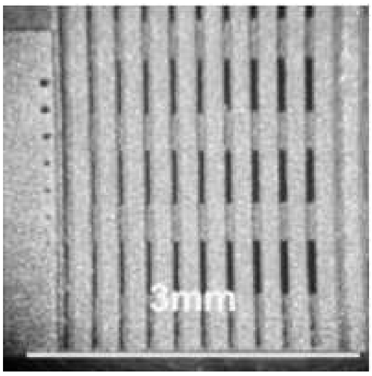

Fig 9b: *Grid plate for fiber aspiration*

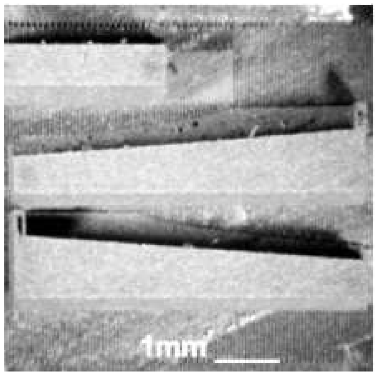

Fig 9c: *Grip bits of tweezers*

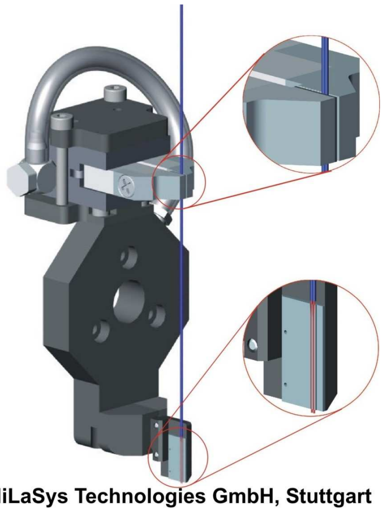

Fig 9d: *Fiber holder device*

Figs. 9a-c show three parts of a fiber holder: A box (a), that holds a grid (detail view in b) onto which the fibers are attracted by aspiration through the channels in the box, and the two grips of tweezers by which the fibers are fixed mechanically (the tweezers in Fig. 9c are of a different type than the ones displayed in the drawing in Fig. 9d).

A photograph view of a mechanical stop lock is presented in Fig. 10a together with a drawing presenting a cut open view of the construction (10c), which describes the openings and hollows of the part. The generation process had to be interrupted in the first assay because of a power breakdown in the beginning (Fig. 10b), yielding the operator the chance of a photograph of the part at an unfinished stage.

Another component of the same machine with a similar purpose is shown in Figs.11.

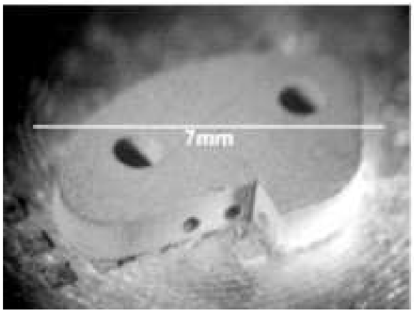

Fig 10a:*Stop lock*

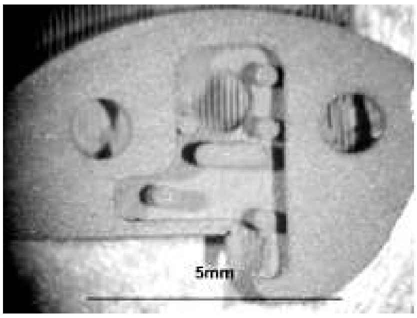

Fig 10a: *Inside view of stop lock (unfinished part)*

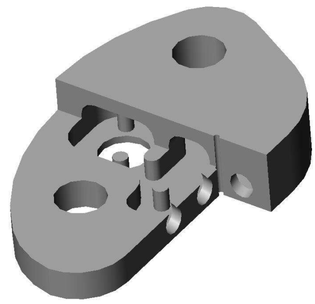

Fig 10a: *Stop lock; drawing of inside view*

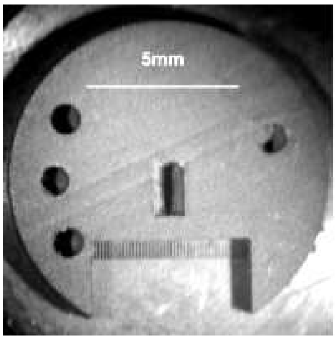

Fig 11a: *Positioning machine component*

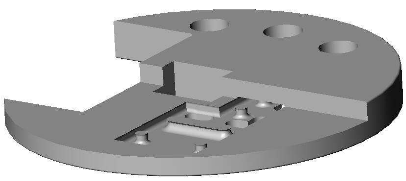

Fig 11b: *Inside view of machine component*

Processing times for a product like the above presented stop lock are listed below in the following chapter.

Besides the above presented applications, laser micro sintered tools have been tested amongst others as electrodes in EDM (electrodischarge machining) /11/. Although the generated electrodes principally functioned in the process, there is still need of development as far as material composition and process parameters are concerned. With regards to material composition, multiple component selective laser sintering as described in chapter 2 could supply completely new possibilities.

4. Machining time effort

The stop lock presented in Fig. 10 was produced as a unicate in the ***chamber type 1*** /7,8/ with a pulse frequency of 30 kHz. As it was the only part in the production cycle (batch size = 1) it required 3.6 hours to be built. The corresponding data set is outlined in the top section of Table 1. Depending on the type of laser, one can raise the pulse frequency considerably for the process.

Table 1: Process times for the stop lock displayed in Figs. 10

Chamber type 1				pulse frequency: **30kHz**
Batch size	Total coating time (in hours)	Total sintering time (in hours)	Total processing time (in hours)	**Process time per part (in hours)**
1	**1.71**	**1.89**	**3.6**	**3.6**
6	1.71	1.34	13.05	**2.18**
15	1.71	28.35	30.06	**2.00**
43	1.71	81.27	82.98	**1.93**
Chamber type 2 (upgraded coater)				pulse frequency: **30kHz**
Batch size	Total coating time (in hours)	Total sintering time (in hours)	Total processing time (in hours)	**Process time per part (in hours)**
1	0.61	1.89	2.50	**2.50**
6	0.61	1.34	11.95	**1.99**
15	0.61	28.35	28.96	**1.93**
43	0.61	81.27	81.88	**1.90**
Chamber type 2 (upgraded coater)				pulse frequency:**75 kHz**
Batch size	Total coating time (in hours)	Total sintering time (in hours)	Total processing time (in hours)	**Process time per part (in hours)**
1	0.61	0.95	1.56	**1.56**
6	0.61	5.70	6.31	**1.05**
15	0.61	14.25	14.86	**0.99**
43	0.61	40.85	41.6	**0.96**
Chamber type 2 (upgraded coater)				pulse frequency: **100 kHz**
Batch size	Total coating time (in hours)	Total sintering time (in hours)	Total processing time (in hours)	**Process time per part (in hours)**
1	0.61	0.63	1.24	**1.24**
6	0.61	3.78	4.39	**0.73**
15	0.61	9.45	10.06	**0.67**
43	0.61	27.09	27.70	**0.64**

We are presently working at a pulse frequency of 100 kHz and substrates (or platforms) which allow batch sizes of as many as 43 items equal or similar to the above mentioned part. The difference between ***chamber type 1*** and ***type 2*** for the interpretation of Table 1 is merely the time required for the coating of the powder.

Neglecting the loading and unloading of the chamber, the resulting machining time (“process time”) per part ranges between 40 and 45 minutes. Of course, as in all other versions of selective laser sintering, combination of different work pieces on a single platform is possible. Vertical stacking of several layers of work pieces, however, has not been performed yet.

5. Suitability of the Sintered Material for Injection Molds

One of the purposes of laser micro sintering is the generation of micro structured molds for pressure injection molding (PIM) or micro structured inserts into the molds. The respective sintered material has to withstand the temperature changes and the occurring drag forces when the mold is opened and the product is ejected.

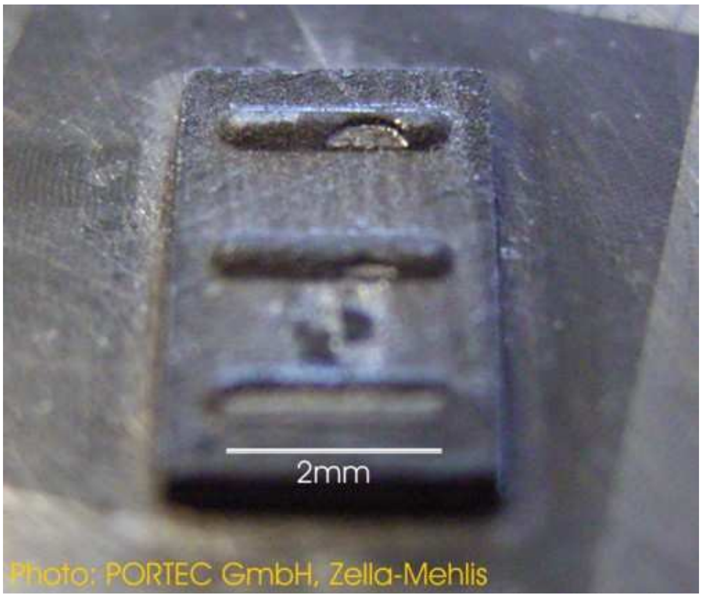

***Fig**: **12a:** Three protruding bars (2.5mm x 0.5mm) as a testing mold for the suitability of the material for PIM. The indentations are due to an inital false positioning of the countertool. Tool after casting experiments*

To prove the suitability of the sintered material a simple structure of three protruding horizontal bars was generated from an appropriate blend as an insert for a mold. The tool is displayed in Fig.12a (the indentations are due to false setting of the counter mold prior to the first cast). As demonstrated in Fig. 12b the tool allows the molding and deforming of more than 500 casts with poly(oxymethylene) type Delrin 911P (“POM”). As reported by our project partner, PORTEC GmbH, more subsequent casts from the same mold were performed with POM and other polymers under conventional and variotherm temperature regimes without any affect on the microstructure. The material proved dense enough to avoid infiltration of the injected hot material as well as sufficiently resistant to the drag forces during deforming.

Fig. 12b: *The laser micro sintered mold remained unaffected after 500 casts with POM*

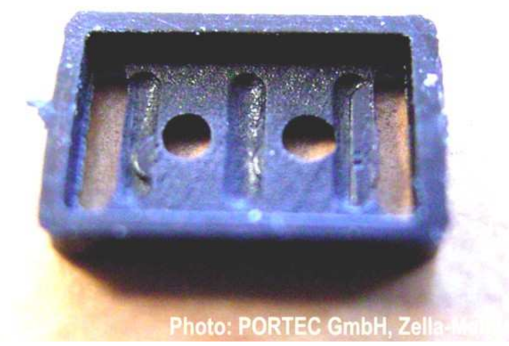

Fig. 12c: *POM-cast from laser micro sintered structure*

6. Conclusion and Perspectives:

Since its introduction in May 2003 laser micro sintering has gained advertence and acknowledgement among toolmakers and users. The once innovative set up - consisting of a hermetically closed sinter chamber and a special rake – which already fitted the needs for the handling and selective sintering of sub-µm grained metal powders - has been upgraded to higher efficiency and industrial applicability. The specific procedure including the laser sintering regime has become a reproducible routine by which functional micro-freeforms are obtained from a number of powder materials.

Figure 13: *Prospective design of the commercial microSINTERING device which is built and will be marketed by 3D-Micromac AG, Chemnitz (Germany)*

The technique has proved suitable for the production of functional tools; material qualities can be achieved that meet the requirements for injection molds. Profitability estimations anticipate a reasonable cost range for the up scaled production. Ceramics laser micro sintering is still in development.

The ideas and applications of the innovation are registered in Germany and worldwide as patents and utility models.

7. Appreciations:

The research and development of laser micro sintering was supported within the scope of the cooperative project *#02P1110 Vakuum-SLS* promoted by Deutsches Bundesministerium für Bildung und Forschung. We also use the opportunity to thank all our industrial partners, not mentioned so far, for the prolific cooperation.

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