Consecutive sputtering and laser processing of metal layers as a possible means to enhance the resolution of laser micro sintering

Ingo Wirth, Astrid Rota, Haiko Pohl and Frank Petzoldt
Fraunhofer IFAM, Wiener Strasse 12, D-28359 Bremen, Germany
phone: +49-421-2246-232, fax: +49-421-2246-77-232, e-mail: wirth@ifam.fraunhofer.de

Peter Regenfuss, Robby Ebert, Lars Hartwig and Horst Exner
Laserinstitut Mittelsachsen e.V. at the University of Applied Sciences Mittweida, Technikumplatz 17, D-09648 Mittweida, Germany
phone: +49-3727-5814-13, fax: +49-3727-5814-96, e-mail: info@laserinstitut.org

Abstract

Compared to micro moulding, laser micro sintering combines the features of a freeform method with high resolution. To even further enhance this resolving power, a different method to supply accurate, smooth and thin layers is proposed. A sputter process is used to deposit thin layers of different target materials such as gold, copper, tungsten-copper (WCu20) on metal surfaces. The user defined layer thickness of the sputtered materials can range in scale from nanometer dimensions up to a few micrometers. The deposition rate strongly depends on the target material and the argon pressure in the chamber. Subsequent to sputtering the layers can be structured by a Nd:YAG laser. In a consecutive layer-by-layer process micro sintering can be performed with very thin and smooth layers. Different types of sputtered metal layers with the potential to suit this purpose are described.

Introduction

Micro metal injection moulding (µMIM) is a technique for the production of micro parts with high surface qualities. As far as flexibility of the geometries is concerned, however, it has been outrun by the rapid prototyping and rapid manufacturing technique of laser micro sintering. The latter reaches a horizontal resolution of less than 30µm with a presently minimum layer thickness of 1µm.

Substitution of raked powder horizons by sputtered layers would mean a considerable increase in density and evenness of the “powder layer” with the additional advantage of minimal particle size and minimal layer thickness. Particle size and layer thickness are still a limiting factor for the resolution of the process.

Following the comprehensive descriptions of the specifications of micro moulding and micro laser sintering, features of several possibly suitable sputtered layers, generated from different materials are presented. All these materials were deposited on the surface of a silicon wafer.

Micro metal injection moulding

By micro metal injection moulding (μ-MIM) small structures with good surface qualities [1] are obtained. Figure 1 illustrates micro parts produced with μ-MIM [2]. The left picture shows a μ-MIM moulded gear wheel with a diameter d = 175μm. Cubic test structures of 30 by 30μm^2 are visible in the right picture. The material of the parts is WCu20. The Feedstock was injected into micro moulds, which were generated by etching silicon wafers. The μ-MIM sinter temperature of 1350°C was held for 2 hours. The density of the parts lies between 88% and 95%. The theoretical density at this sinter temperature is in the range of 91%. A surface roughness of Ra = 0.55μm and Rz = 3.8μm was measured. The roughness is comparable to other microstructures produced with other powder metallurgic techniques. Densification depends in this case on the tungsten particle size and the copper content. The influence of the copper particle size is small as we are dealing here with liquid phase sintering, the copper providing the fluid phase during the process. The mean particle diameter of the employed tungsten powder is about 1.8μm. A finer powder could lead to higher sinter activities and higher final density. Due to the heat conductivity of these materials it appears useful to heat up the mould to the temperature of the feedstock during injection. Therefore it is possible to produce micro parts without visible cracks and warps as shown in Figure 1 [2].

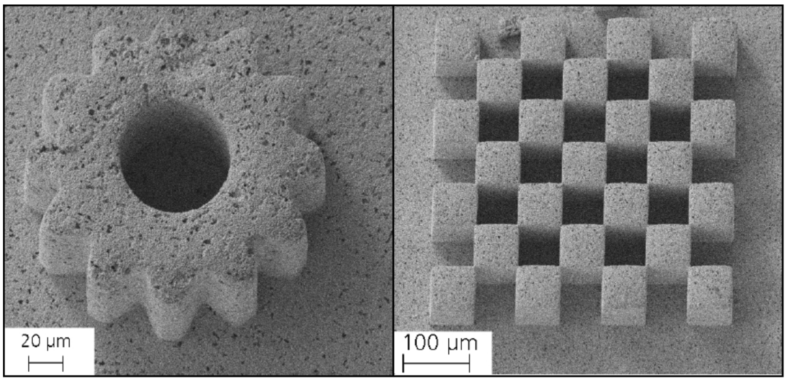

Fig. 1: μ-MIM parts made of WCu20:

a) gear wheel d=175μm

b) matrix structure

Laser micro sintering

"Laser micro sintering" is the name of a technique developed at the Laserinstitut Mittelsachsen e.V. (Mittweida/Germany) [3, 4, 5, 6] to generate micro parts from successively sintered layers. It is based on the established technology of selective laser sintering [7], improving its resolution from heretofore >150μm to <30μm. The minimal thickness of a single sinter layer is presently 1μm. A specific raking procedure facilitates the application of sub-μm-sized metal powders as sufficiently smooth layers. The material is processed under vacuum or reduced shield gas pressures. The technique allows the sintering of powders of refractory as well as lower melting metals. Precision tools featuring aspect ratios >12 and surface roughness R_a down to 1.5μm have already been produced this way.

The components can be generated either firmly attached to a substrate or fixed to the construction platform in an easily separable mode. If supporting structures are employed during the process, undercuts up to 90° are feasible. Without supporting structures a process parameter dependent maximum angle of undercut < 90 is obtained. Present efforts aim at laser micro sintering of ceramics. Figure 2 shows two laser micro sintered tungsten micro parts. Their densities are in the range of 65%, Ra ≈ 3.5µm.

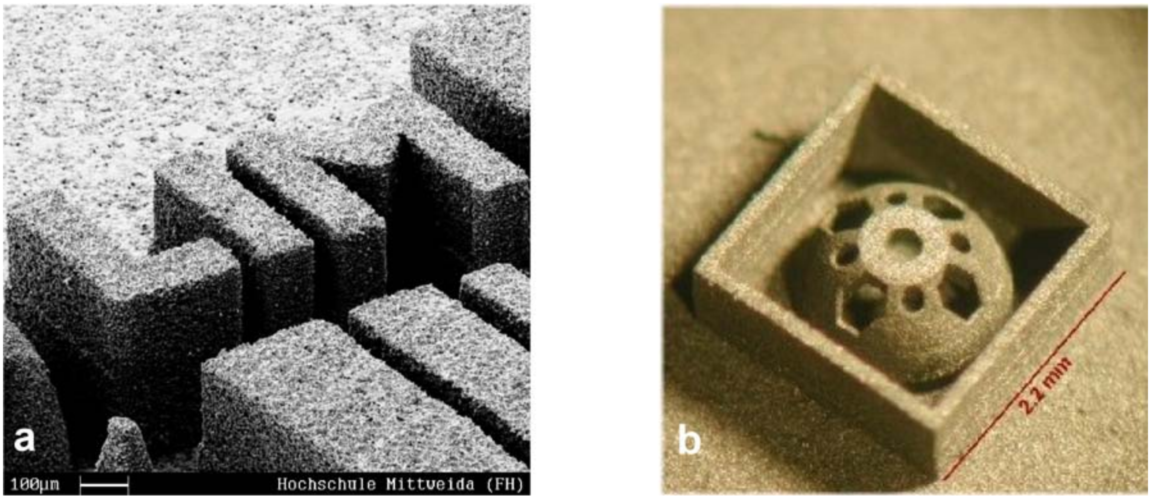

Fig. 2: Laser micro sintering products from a single component powder

a) SEM view of a test structure; overall height: 400µm, aspect ratio: 1:12

b) open work semi sphere

Search for sputtered metal layers suitable for sintering

General

The sputter experiments are implemented in a vacuum chamber, which can be filled with argon [8]. It is possible to create a plasma by using a magnetron. The target material evaporates during the sputter process and condenses on a substrate e.g. a silicon wafer. Depending on the argon pressure in the chamber the layer adopts a specific thickness and structure.

Gold

Gold, an inert element, was chosen as a target material for deposition onto the surface of a silicon wafer. Figure 3(a) shows a SEM micrograph of the breaking edge of the gold layer on the silicon wafer. This layer has a thickness of 3600nm and was produced in a 0.5mbar argon atmosphere in a total sputtering time of 600s. The structure has a fibrous character. Completely different to this structure is the sample shown in Figure 3(b). This structure has a porous character. Here the layer thickness is 6250nm with a total sputtering time of 300s in an argon atmosphere with 1.5mbar pressure.

Around 1.0mbar argon pressure, transition from a fibrous to a porous structure occurs. The density of the fibrous structure is higher than that of the porous probe, the consistency of which is powder like and the layer is easy to remove. This is important for the laser sintering procedure, because the powder, which is not sintered, has to be removed after the process.

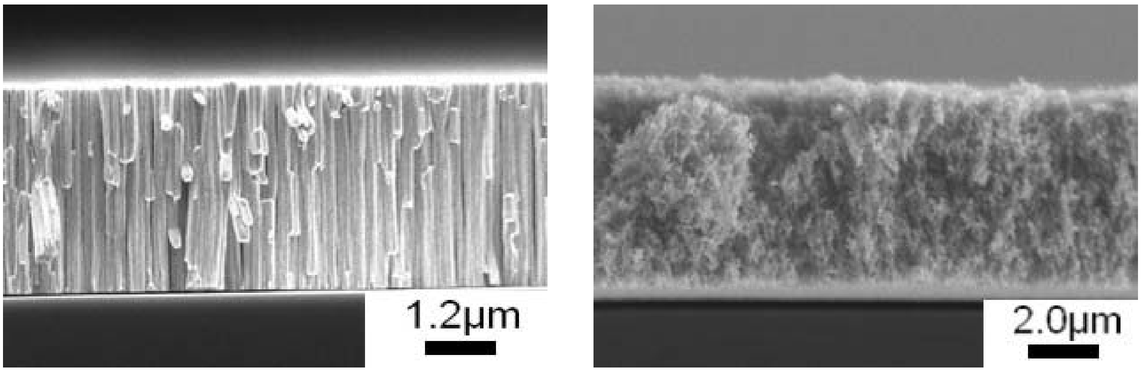

Fig. 3: Sputtered powder layers made of gold under different argon pressure atmospheres:

a) fibrous structure (p = 0.5mbar, d = 3600nm, t = 600s)

b) porous structure (p = 1.5mbar, d = 6250nm, t = 300s)

Copper

Figure 4 illustrates the investigations of copper as target material. Copper has a good electrical conductivity and is therefore a customary material of tools assigned for industrial application.

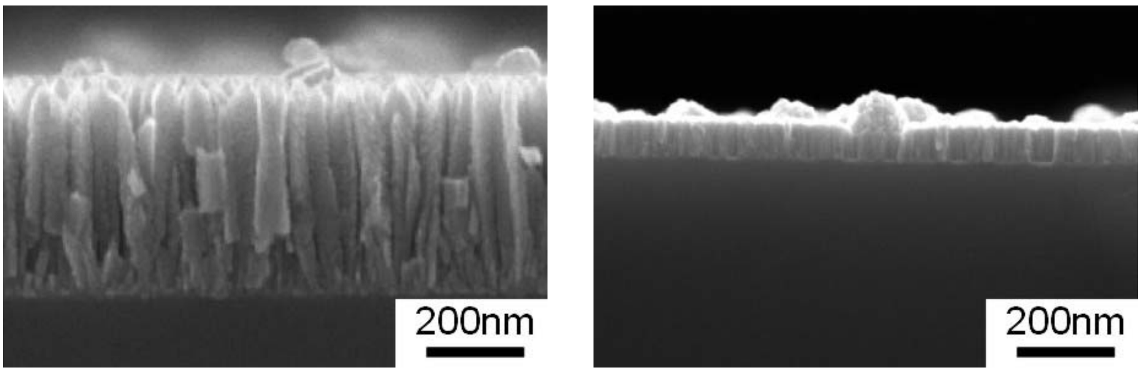

Fig. 4: Sputtered powder layers made of copper under different argon pressure atmospheres:

a) fibrous structure (p = 0.5mbar, d = 450nm, t = 450s)

b) fibrous structure (p = 1.0 mbar, d = 75nm, t = 600s)

The sputter process itself is stable in the argon pressure range between 0.5mbar and 1.0mbar. The thickness of the deposited layer decreases extremely with increasing argon pressure. A comparison of the two pictures in Figure 4 shows a layer thickness of 450nm for an argon pressure of 0.5mbar and only a thickness of 75nm for a pressure of 1.0mbar although the total sputtering time increases from 450s to 600s. This shows that an acceptable pressure for this target material will be in the range of 0.5mbar.

The structure itself has a fibrous character throughout the entire surveyed pressure range. In contrast to the gold samples it was impossible to produce copper samples with a smooth surface. With all copper samples accretions of oxides are observed. Furthermore the layer thickness of all copper samples is very low compared to the gold samples.

Tungsten-Copper

The results of the sputter experiments for WCu20 are shown in Figure 5. Figure 5(a) shows a 2850nm W/Cu20 layer on a silicon wafer surface. This layer was produced with 0.3mbar argon pressure. By choosing a pressure of 0.7mbar a layer thickness of 7500nm can be obtained. The total sputtering time was 300s for both samples. This means, that the layer thickness increases considerably with increasing argon pressure.

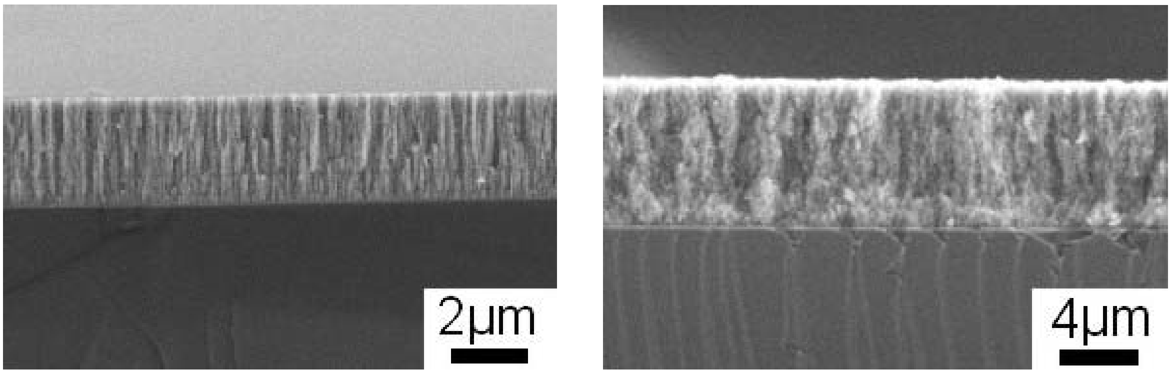

Fig. 5: Sputtered powder layers made of WCu20 under different argon pressure atmospheres:

a) fibrous structure (p = 0.3mbar, d = 2850nm, t = 300s)

b) porous structure (p = 0.7mbar, d = 7500nm, t = 300s)

A closer look upon the layer structure in Figure 5 shows transition from fibrous to porous consistency at increasing argon pressure. On the one hand this is good to produce powder like layers, which are very loose and easy to remove; but on the other hand a fibrous structure with a higher density bears the advantage of minimal shrinkage during the laser sintering process. In any case, due to the high deposition rate it is possible to produce thin powder layers in a short time.

Sinter assay on a sputtered gold layer

A low density sputtered gold layer, generated with the respective process parameters p and t of 1.5mbar and 300s an d a layer thickness of 6250nm (see also Fig. 3b) was sintered with an Nd:YAG laser. Fig. 6b shows an SEM view of a segment of the sintered tracks displayed in Fig. 6a. The width of the track can be defined as in the order of 7µm, which is clearly beyond the minimum resolution presently achieved by micro laser sintering [4-7]. The porous consistency of the chose gold layer admittedly results in a still low degree of interlinkage of the sintered body.

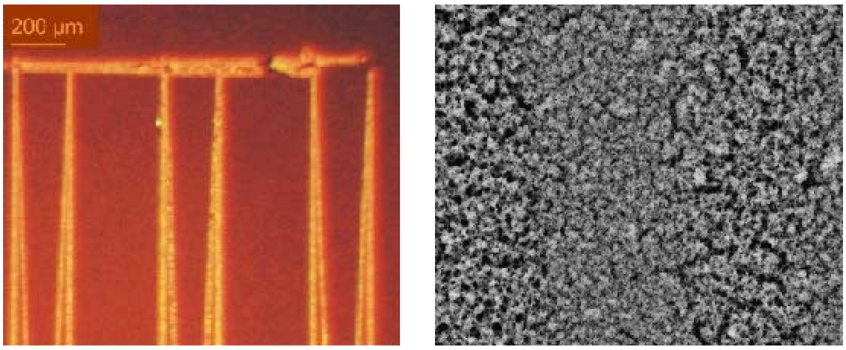

Fig. 6: Sputtered powder layers of gold; porous structure (p = 1.5mbar, d = 6250nm, t = 300s) as in Fig 3b, with sintered tracks:
a) sintered sample (overview)   b) SEM view of a sinter track segment (20x20µm²)

Conclusions and Outlook

In the range of layer thickness form a few hundred nm to a few µm, sputtered metal layers usually have a higher density and with a lower effective grain size than raked powder layers.
Substitution of raked powder layers by sputtered layers thus bears the potential of resolution enhancement of laser micro sintering.
Employment of sputtered material for laser micro sintering could also solve the problem of the lacking availability of many metals in the form of sub-µm-grains.
The resolution that can be obtained with an about 6µm thick sputtered gold layer was observed to be around 7µm, clearly better than the minimum resolution presently obtained by laser micro sintering of raked powder layers.
The yet remaining problem is the still poor density of the sintered body due to the porous consistency of the employed sputtered layer which was chosen because the post sintering process detachability of the unsintered material.

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