Laser Micro Sintering

a Versatile Instrument for the Generation of Microparts

Miniaturization is one of the main imperatives in high-tech development and therefore a persistent challenge for mechanical engineering. Recently a freeform technique – Laser Micro Sintering – has been developed by which micro parts with an overall resolution of 30 µm can be produced from powder materials. The technique is a generative freeform fabrication method based on selective laser sintering; it can produce hollows and undercuts and does not afford shape-specific tools. Functional micro bodies can be generated from metals and ceramics.

Introduction

In early 2003 Laserinstitut Mittelsachsen e.V. (LIM) announced a newly developed modification of selective laser sintering (SLS) – meanwhile referred to as "laser micro sintering"- that shifted the resolution of selective laser sintering below the limits commercial SLS devices had been confined to [1]. The obtained structures show a resolution of less than 30 µm for overall resolution, of 20 µm for ligaments and of 10 µm for notches at aspect ratios of 12 and above, and presently a minimal roughness R_a of 1.5 µm.

Two mayor innovations were necessary to achieve these goals: A novel technique and equipment for the handling and coating sub-µm sized metal powders, and a new laser sintering technique employing q-switched pulses.

The powder handling and processing unit ('sinter chamber') contains two important novelties: Firstly it allows to perform SLS with powder under vacuum or a controlled process atmosphere, the origin dates back to a patent applied in 1999 [2]. Secondly, the powder coating equipment and regime is suited to spread layers of sub-µm-sized powder with sufficient densities. The special laser regime was the choice of an Nd:YAG-laser operated in mono-mode, the

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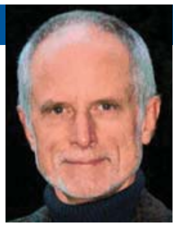

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employment of q-switched pulses and the strategy of setting the pulses during selective sintering. Until then, pulsed laser sintering had been conducted mostly on an experimental level [3].
Meanwhile the technique has been applied for the generation of manifold functional metal micro parts and has gained international advertence and acknowledgement.
The ideas and applications are registered as patents and utility models. The technique and the equipment is marketed under the brand name microSINTERING by 3D-Micromac AG, Chemnitz, Germany.

Laser micro sintering – equipment and process principles

Sinter chamber and powder coating device

In selective laser sintering the powder material is alternately coated and sintered by a laser beam scanning the cross section of the expected sinter part. The early set up - consisting already of a hermetically closed sinter chamber and a special rake has been upgraded to higher efficiency and industrial applicability ("chamber type 2"). It is attached to a turbo molecular vacuum pump and has gate valves for various process gases. The laser radiation enters via a quartz glass window integrated into the lid.
Two or more rakes sweep the powder materials in a circular motion onto the sample piston (sinter platform). This technique allows vertical gradients of material blends or of grain sizes in the sinter part.

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Laserinstitut Mittelsachsen e.V. at Hochschule Mittweida is one of the leading institutions in the area of laser micro structuring. In its laboratories the respective technologies are investigated and developed since more than 30 years. Its up-to-date equipment contains among others five micro sinter set-ups, numerous excimer lasers, two fs-lasers, and a VUV-laser. Further activities are PLD-techniques, laser macro processing, development of laser components, and laser measuring techniques.

Deviant from conventional devices, the blades of the rakes are metal cylinders; they also serve as intermediate powder reservoirs (Fig. 1). The pistons are tight for powders and liquids, allowing processing of slurries. The chamber can be evacuated down to pressures of 10^{-3} Pa. Charging or flushing with process gases is possible and makes the device applicable for the combination of sintering with laser CVD.

The process of laser micro sintering

The early source of the laser pulses was a Q-switched Nd:YAG – laser (λ = 1064 nm) in TEM_{00} mode [1], lately multimode pulses and other lasers with various wavelengths are used. A beam scanner with a scan field of 25 × 25 mm^2 steers the pulses over the corresponding micro body cross section (Fig. 2).
The density and intensity of the pulses are adjusted during the process according to the requirements of the micro body's aspired properties, the geometry of the cross

FIGURE 1: **Ring blade serves as rake and powder storage.**

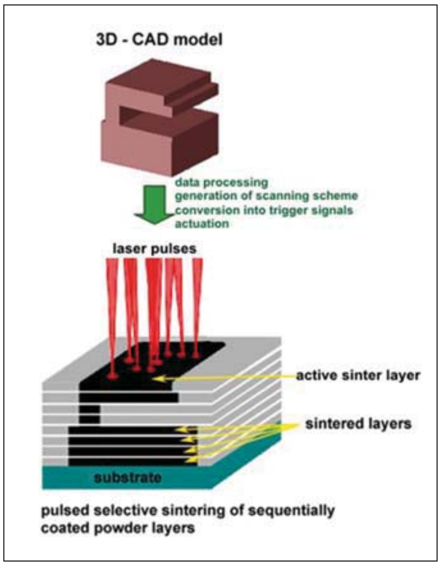

FIGURE 2: **Laser micro sintering with separately set pulses.**

section and the material. This is achieved by application of the proprietary software IVS STL Converter (Version 1.0). It controls the actual 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. Another - home-developed - program allows flexible control of the raking routine. Automatic performance of a complex SLS process including the generation of structural or density gradients is supported.

The mechanistic model of metal laser micro sintering

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 5-10 µm below the mean surface level with crests above between 1 and 3 µm. 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]. The mechanism of pulsed sintering is believed to be a synergism of both melting and boiling [4]: The recoil the molten and solid powder material receives from the occurring plasma and the erupting material creates vertical interconnections between the sintered layers and the material being processed. With each pulse, the new material is attached mainly to or into the already sintered body below. Horizontal cross linking takes place only in the last stage of the sintering of each layer. This is the cause for the high resolution and the noticeable lack of thermally induced stresses.
SEM views in Figs. 3 show the pulsing effects. High intensity pulses result in a higher degree of vertical cross linking and a higher rough-

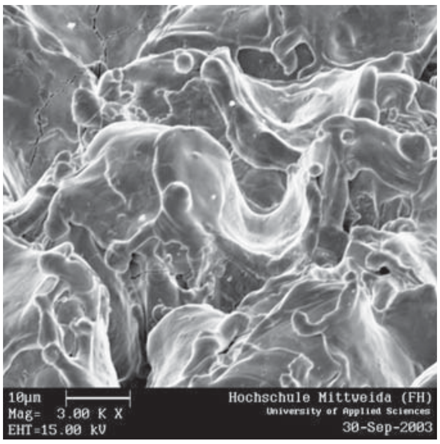

FIGURE 3a: **High intensity pulses.**

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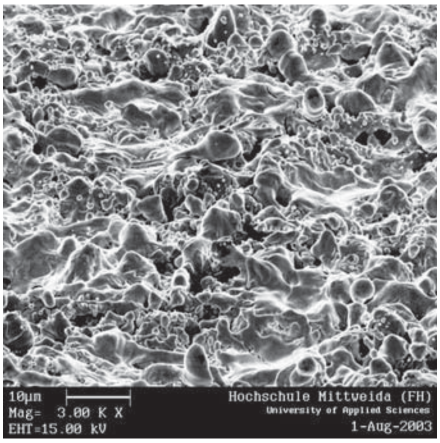

FIGURE 3b: **Low intensity pulses.**

ness. Low intensity pulses as occur e.g. with higher pulse frequencies yield better surface smoothness at reduced vertical cross linking. Via the software bodies with both a sufficient stability and still a good surface quality can be generated.

Results of metal laser microsintering

Resolution of laser micro sintering

Fig. 4 shows a coiled ligament made of tungsten, with a width of 300 µm and a gauge of ≤35 µm. One can detect the typical texture of laser micro sintered bodies, generated from a single component high melting metal powder.

The blow-up view of three nested spheres in Fig. 5 also demonstrates the resolving power of the technique. The structure is somewhat less porous than that of the above presented ligaments as it was generated with slightly different parameters. Still, however, the typical single pulse stitches dominate the appearance of the surface.

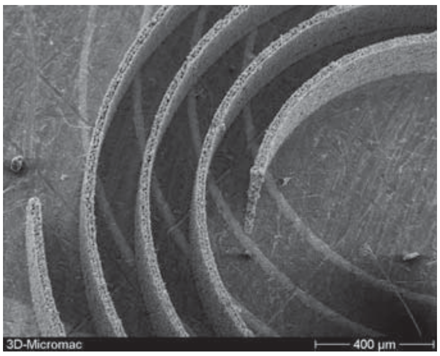

FIGURE 4: **Coiled tungsten ligament; gauge 35 µm.**

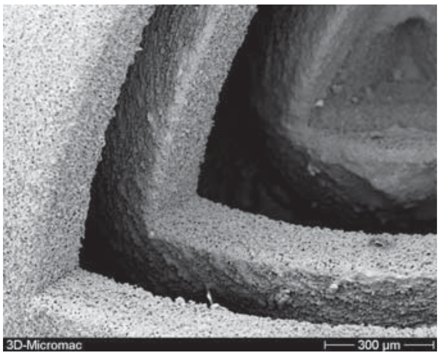

FIGURE 5: **Blow-up of three nested spherical shells (see Fig. 6b).**

Undercuts

The first undercuts in laser micro sintering were achieved with the help of support structures, which were disintegrated after the end of the process [1]. Later on, procedures were developed, that did not require supports (Figs. 6). With those procedures, however, the angle of undercut was limited to a maximum value of 70° which complies with an angle of 30° vs. the horizontal substrate surface.

With a technique to generate bodies from a matrix of partially solidified material the generation of unlimited undercuts became possible (Figs. 7).

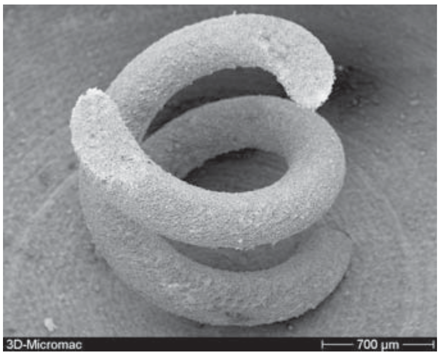

FIGURE 6a: **Bi-helical tungsten coil.**

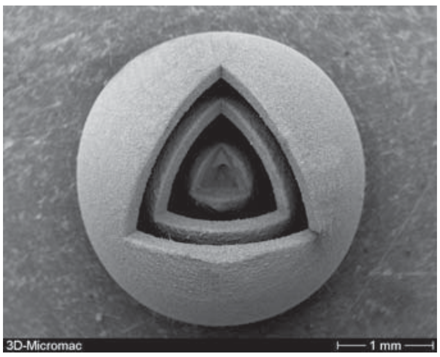

FIGURE 6b: **Three nested spherical shells.**

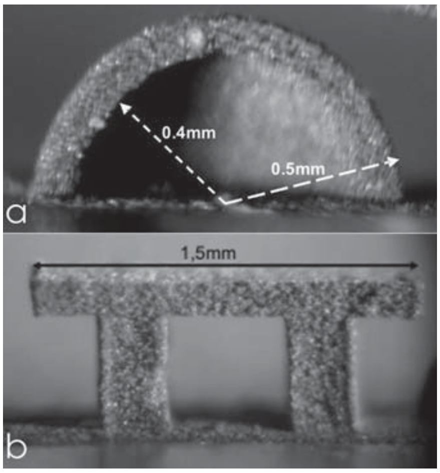

FIGURE 7a,b: **Quarter-sphere shell and traverse structure with 90° undercut.**

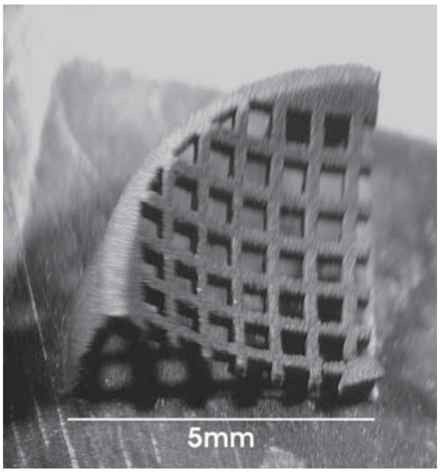

FIGURE 7c: **Grid insert with 90° undercut.**

Laser micro sintering with 1–10 µm grain sizes

The technique was applied for the commercial production of grip bits of micro manipulators, and a test mold generated from a blend of aluminium and tungsten had proved stable enough during injection molding of poly(oxymethylene). Because of the limited availability of sub-micrometer grained metal powders the processing of powders with 1-10 µm grain was investigated. A coarser resolution of the products but also a considerably higher sintering rate and the possibility of conducting the process under normal atmosphere was obtained.

Fig. 8a shows a triple helical structure that was sintered from 1 µm grained 1.4404 steel powder. The required process time was 30 minutes. The molybdenum coil (Fig. 8b) was generated from 1 µm sized powder. Both specimens were produced without a shield gas.

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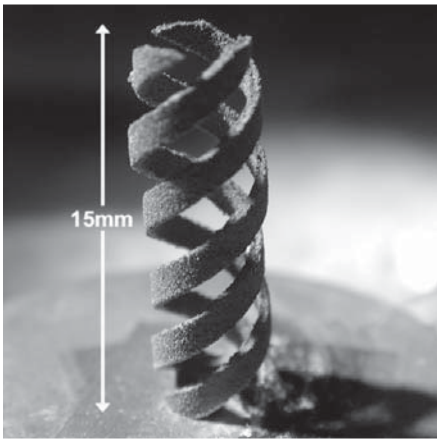

FIGURE 8a: **Triplex helix (steel 1.4404) sintered under normal atmosphere; height: 15 mm).**

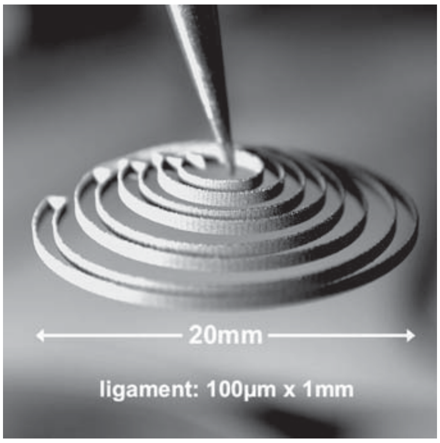

FIGURE 8b: **Molybdenum coil, sintered under normal atmosphere.**

FIGURE 9a: **The processing of two different materials in "chamber type 2".**

Laser micro sintering with alternating materials

"Chamber type 2" allows for the processing of two different materials during the generation of a micro body (Fig. 9a). As a demonstration a cylinder was generated from 1 µm grained powders of silver and copper respectively (Fig. 9b). If the materials are compatible with each other, the interface between the two components will become tight enough for a firm connection (Fig. 9c).

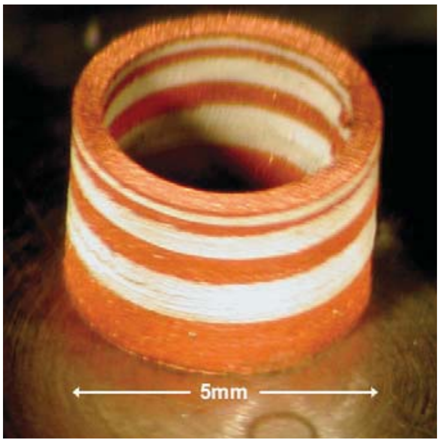

FIGURE 9b: **Laser micro sintered part from copper and silver.**

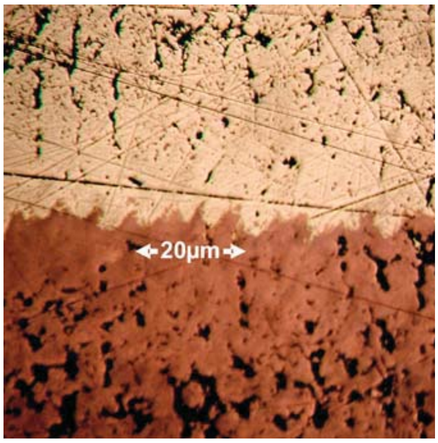

FIGURE 9c: **Cross section view of the interface between a copper and a silver section.**

Performance parameters of metal laser micro sintering

Surface quality and resolution of the products depend on the grain size of the powder material and the respective regime, that has to be applied. Under normal atmosphere higher roughness and lower resolution has to be taken into account (Table 1).

powder type:	grain size [µm]	≤ 1	10
	sinter layer thickness [µm]	1	10
minimum roughness r_a [µm]	normal atmosphere	—	8.5–10
	special oxygen free	1.5-2.5	5.5–8.5
minimum ligament gauge [µm]	normal atmosphere	—	125–150
	special oxygen free	20	55–60
process time for 1000 mm^3 [hrs:mns]	present equipment	65:00	08:00
	upgraded equipment	35:30	02:50

TAB.1: **Performance parameters of laser micro sintering with two powder types: sub-µm (tungsten) and 10 µm (steel; nickel/chromium) grain sizes.**

Direct laser micro sintering of ceramic and glassy materials

Experiments on selective laser sintering of ceramic preforms have started about two decades ago. Those procedures have already reached a very high level and are nowadays performed by commercial machines. Direct selective laser sintering of ceramics without the employment of a binder was reported since 1999 [5, 6]. The resolution of the techniques varies from millimeters down to a few hundred micrometers. A recent paper reports the direct sintering of borosilicate glass.

The development of direct generation of ceramic bodies by laser micro sintering at LIM takes advantage of its tradition in laser processing of ceramics. The powders are oxides from metals and non-metals. Ends of the research activities are the direct generation of ceramic micro bodies.

The first result of the process was too brittle to be considered the appropriate material for a functional part (Fig. 10). After considerable reduction of the glass forming agent the consistency of the product improved (Fig. 11). However, the absorption of NIR laser radiation (λ = 1046 nm) by oxide ceramics is very poor and a function of material temperature. This means, that after initial heating of the material, absorption increases rapidly thus leading to an avalanche effect. The resulting overheating accounts for the poor fidelity of the product in Fig. 11. With a regime of q-switched pulses, finally, a highly resolved product was obtained in a fairly well

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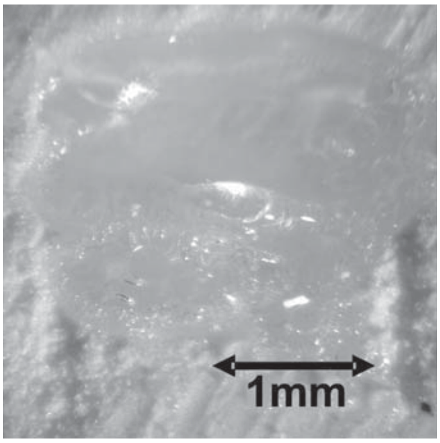

FIGURE 10: **First sintering result with too much glass content in the sintered body.**

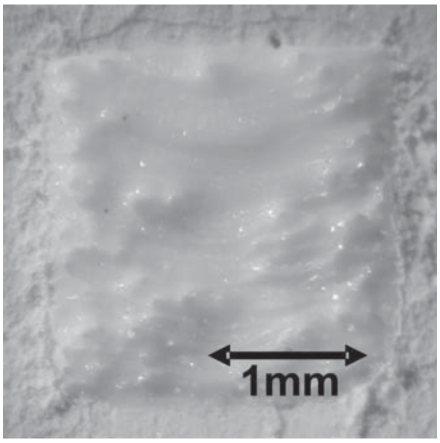

FIGURE 11: **Improved laser sinter result after reduction of the glass-phase.**

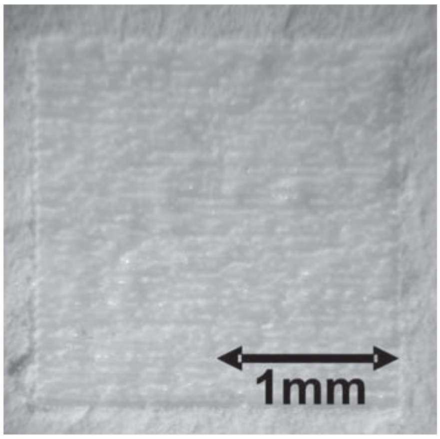

FIGURE 12: **Higher resolution of the process with a q-switched regime.**

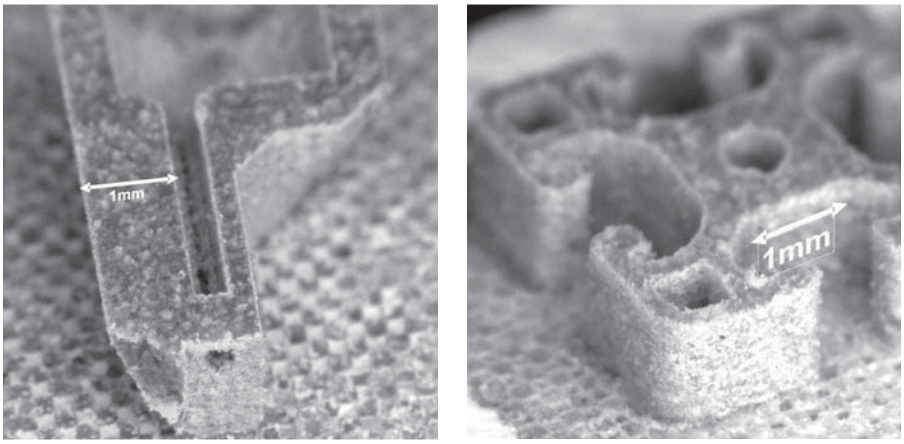

FIGURE 13: **Functional component (left), demonstrator part (right) generated by laser micro sintering from oxideceramic powders.**

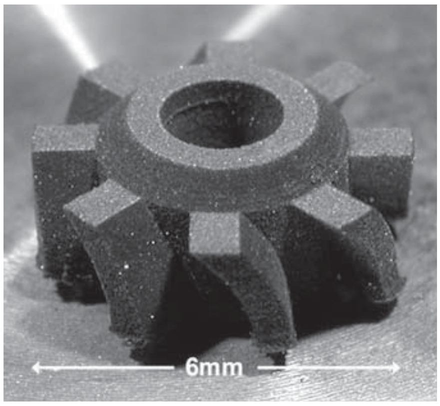

FIGURE 14: **Laser micro sintered cog from SiSiC-powder.**

controllable process (Fig. 12). Each pulse supplies enough power to achieve initial absorption which is followed by partial cooling in the pause preventing an overheating of the material.

max. height	resolution	max. rel. density	flexural strength	crushing strength
10 mm	≤ 80 µm	98%	100 MPa	800 MPa

TABLE 2: **Up-to-date figures of merit for lasermicro sintered parts from oxide ceramics.**

Present state of the art in laser micro sintering of ceramics

After a suitable technique had been developed for the coating of the powder, the technique of laser micro sintering has been applied successfully for the generation of ceramic micro parts.
The samples in Fig. 13 demonstrate that ceramic micro bodies can be generated with high accuracy and resolution; hidden channels are also realizable.The latest developments aim for direct selective laser sintering of non-oxide ceramics. Silicon carbide is a technically interesting material, its laser processing, however, affords special regimes as there exists no liquid phase of un-dissociated SiC under normal pressure conditions. The cog wheel shown in Fig. 14 was sintered from a silicon blended SiC-powder (SiSiC). The hypotheses of the sintering mechanisms that occur during laser processing of the various SiC powder blends, have been described in a separate publication.
Upon refinements of the sinter strategies and the choice of more suitable laser sources the presently generated ceramic micro bodies approach the material qualities for functional ceramics (Table 2).

Summary

Laser micro sintering is a suitable method for direct freeform fabrication of metal and ceramic components. It is based on selective laser sintering of finely grained powders. Its typical performance features rely on a special laser regime and a coating routine, that take into account the difficult handling properties of the respective powder materials.
The sinter equipment, that was developed for the procedure, allows to generate micro-parts under various process gasses. The coating mechanism provides the option to alternate the material along the vertical axis or to realize vertical material gradients in the generated products.
The resolution of the generated structures is presently the best, that can be achieved with any laser sintering method. The properties of the sintered materials are sufficient for practical applications.

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