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# Ultra-precise surface structuring in nanometer scale

## New approaches in diamond turning for manufacturing of asymmetric structures

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### Structuring of ultra-precision surfaces

Among other fields, modern lighting and sensing applications rely on high quality mastering processes. High volume roll-to-roll manufacturing technologies like UV- or thermal-nanoimprint require precisely structured drums for replication of basis products like diffusor films in lighting or sensing applications.

There are different system approaches and individual process chains for the realization of large area structures. One differentiation can be made in hard- and soft molds. Nickel sleeves, which are produced in a planar manufacturing step, and diamond turned drums represent the category of hard molds. Whereas silicone sleeves are defined as soft molds. These sleeves can be either directly casted on the drum or wrapped around after a planar manufacturing step. The planar manufacturing step can be realized by direct machining, step-and-repeat hot embossing or lithographic processes. [1]

Substrates with refractive or diffractive surfaces are often demanded in the described applications and set high requirements for potential structuring technologies. In this field, the diamond turning process (**Fig.1**) offers various benefits regarding the surface quality, structure resolution and overall structure size.

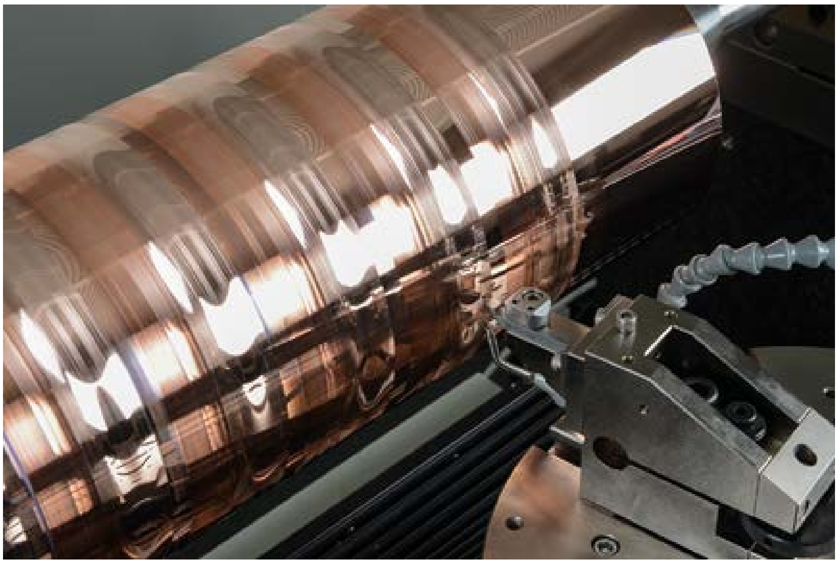

**FIGURE 1: Setup for a diamond turning process on a copper drum.**

### Setup for diamond turning processes

For the realization of an ultra-precision turning process a special and highly precise machine is required. In (**Fig.2**) a Precitech DRL1270 lathe with granite body and air-bearing spindles can be seen. This machine enables the manufacturing of drums up to 500 mm diameter and a length of 1.4 m. In order to create non-rotationally symmetric structures, the turning machine uses next to the main axes Z, X and Y two auxiliary axes. An additional X-axis is used for fast-tool machining. The fast-tool system is using a piezo element, which can move the diamond tool colinear in x-direction with a frequency of up to 2000 Hz and an amplitude of 45 µm. Finally, a B-axis, which enables the turning of the diamond tool around the contact point.

This machine can manufacture structures in sub-µm range. Diamond turned surfaces in this process have optical quality with a surface roughness of ≤ 10 nm Ra (mean roughness index). In addition, diamond tools ensure a


## SUMMARY

Manufacturing of large scale functionalized and structured surfaces require special production processes and machines. Important criteria for those surfaces are the realized surface roughness and contour accuracy. Typical structures for optical applications with a high quality demand are V-grooves, pyramidal and fresnel geometries. The initial mastering process is decisive for the quality in the consecutive replication processes like thermal- or UV-Nanoimprint. Ultra-precision diamond turning can be seen as one efficient methodology for the creation of large area structured drums with a high surface quality.


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FIGURE 2: **Machine setup for a diamond turning at Fraunhofer IPT.**

high wear resistance due to their high hardness. A large variety of tip shapes is the basis for the manufacturing of complex geometries in the direct cutting process.

## Special machine functions

An additional method to increase the flexibility of manufacturing geometrical structures with more degrees of freedom is the implementation of a B-axis. As shown as in (**Fig. 3**), the tool holder can be turned along the vertical tool center point axis (TCP axis). This enables steep perpendicular shapes and more flexibility in the manufacturing of radii.

## Characteristics of diamond turned surfaces

By structuring a surface, various functionalities can be implemented. Inspired by nature, riblet structures, which mimic shark skin properties of lowering frictional resistance, can be manufactured. A thin film substrate enhanced with this structure can be applied to surfaces on a plane as an example to reduce carbon emission. Other examples for structures are used to create anti-fouling properties on underwater surfaces to lower friction during ship movements, anti-reflex properties on solar cells to enhance the efficiency in energy conversion and optical properties to manipulate light with refractive or diffractive effects. In (**Fig. 4**) on the left side a symmetrical pyramid structure with diffractive properties is shown. Whereas on the right side, a non-rotationally symmetric structure, manufactured in a fast-tool assisted process is displayed.

Diamond tools offer a very high geometric definition along with outstanding sharpness. A diamond tool, which is declared as "sharp" offers a residual roundness between 10 nm and 20 nm, which is only visible under the scanning electron microscope. However, the potential of diamond tools cannot be fully explored yet, as the ultraprecision machining of large-area parts is still challenging and vulnerable to thermal and mechanical errors. At Fraunhofer IPT, a study has been conducted

FIGURE 3: **B-axis tool positioning in 315° orientation (left), 0° orientation (middle) and 45° (right).**

## ZUSAMMENFASSUNG

**Ultrapräzise Oberflächenstrukturierung im Nanometerbereich**

Wie neue Ansätze in der Diamantzerspanung die Herstellung von unsymmetrischen Strukturen im Nanometerbereich ermöglichen, wird in diesem Beitrag vorgestellt.

Die Herstellung von großflächigen funktionalisierten und strukturierten Oberflächen erfordert spezielle Produktionsprozesse und -maschinen. Wichtige Eigenschaften für diese Oberflächen sind insbesondere die Oberflächenrauheit und Konturgenauigkeit. Typische Strukturen für optische Anwendungen mit einem hohen Qualitätsanspruch sind V-Nuten, pyramidische sowie Fresnel-Strukturen. Dabei ist der initiale Master-Herstellprozess entscheidend für die Qualität der nachfolgenden Produktionsschritte, wie das thermische oder UV-Nanoimprintverfahren. Die ultrapräzise Diamantzerspanung kann an dieser Stelle als eine effiziente Methodik zur Erzeugung von großflächig strukturierten Oberflächen mit hoher Oberflächenqualität angesehen werden.



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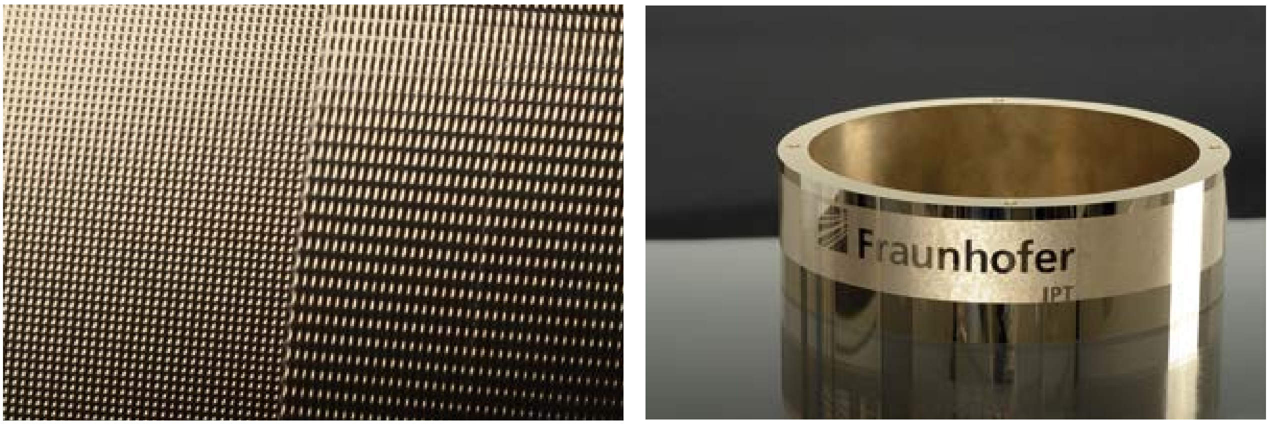


**FIGURE 4:** Geometric (left) and asymmetric (right) diamond turned structures realized in a fast-tool process

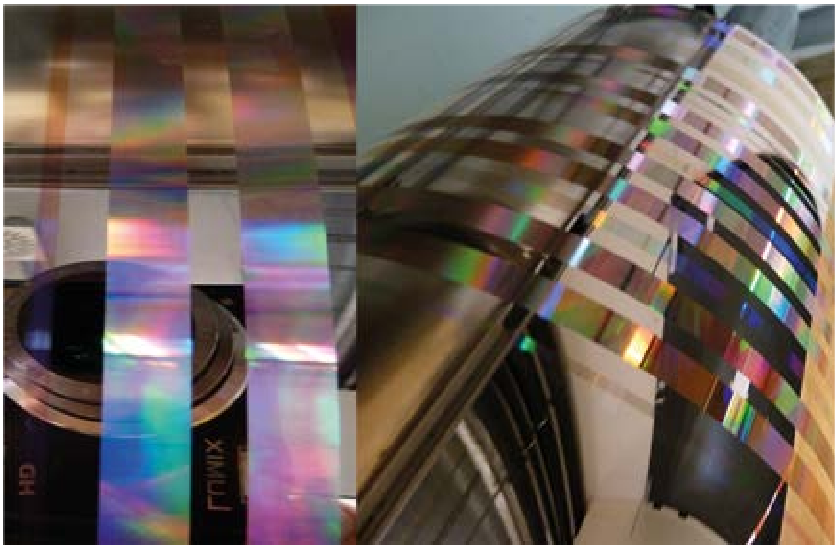

**FIGURE 5:** Sub-micrometer V-groove structures with different pitches (800 nm, 500 nm, 200 nm)

in which the surface of the drum was scanned with a high-precision measurement system. In a subsequent step, the measured deviation from perfect roundness of the drum was compensated with the help of the Fast-Tool axis by signal inversion.

As it can be seen in (**Fig.5**), nanogroove structures with pitches < 1 µm and depth of 800 nm, 500 nm and 200 nm can be manufactured in the diamond turning process.

At this scale, the threshold of the wavelength of visible light is overcome and such structures can potentially be utilized in antireflective applications e.g. in solar or space industry. The further development towards the production of nano-scale features by diamond turning on large area embossing drums is part of the research focus at Fraunhofer IPT.

**Acknowledgement**

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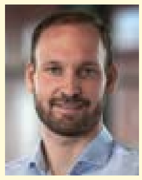

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