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Manufacturing of substrates for curved deterministic areal roughness standards

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Abstract

Deterministic roughness standards for stylus instruments can e.g. be fully manufactured by ultra-precise turning. The roughness profile is deduced from linescans in the radial direction on such a turned disc. Deterministic areal roughness standards on surfaces with curvatures below 1 mm are, however, more difficult to produce due to the spatial arrangement. In the approach followed in this project, the deterministic roughness is therefore created by focused ion beam (FIB) processing. As a prerequisite, the specimen surfaces need to be significantly smoother than the roughness to be written subsequently by the FIB method. In this study, the manufacturing chains for specimens with optical surface quality and different kinds of curvatures are presented. In a first step, a nickel-phosphorus coating was found to be a suitable substrate material for FIB processing, which generates fields of 290 µm x 290 µm with roughness values in the range of 2 nm < Sq < 300 nm. Cylindrical bodies with a radius of approx. 400 µm and spherical bodies with a radius of approx. 600 µm are manufactured as well as correlating convex and concave toric surface elements. Diamond turning is applied for toric surfaces. For the manufacturing of the small spherical and cylindrical surfaces, polishing procedures with suitable pads and kinematics are developed. Atomic force microscopy (AFM) and confocal laser scanning microscopy (CLSM) are used for surface characterization.

Ultra-precision machining, focused ion beam, polishing, AFM, optical measurement

1. Introduction

An artificial topography with a size of 290 µm × 290 µm and a roughness of Sa = 123 nm, as shown in figure 1, had to be reproduced on different curved surfaces [1] in order to allow investigations of the behaviour of surface measurement instruments on curved specimens. The substrates must be suitable for mechanical surface operation and machining in an FIB device. Furthermore, they need to allow subsequent inspection by scanning electron microscopy (SEM), CLSM and AFM. Consequently, the optical, mechanical and electrical properties of the surface and material are restricted.

Figure 1. Targeted topography, as to be produced by the FIB method, size 290 µm × 290 µm × 1.4 µm. Roughness: Sa = 123 nm, Sq = 159 nm, Sz= 1420 nm.

For the creation of the artificial surface texture, FIB technology was chosen, as it allows the modification of the surface on a defined point-by-point basis and can be applied on curved surfaces as well. As the initial roughness of the surface would add to the overall roughness in combination with the FIB-created roughness, the topography of the substrate is of importance and must be validated to minimize its parasitic influence on the resulting surface texture.

2. Methods

In a first step, a suitable material had to be chosen for the coating of the substrates. Nickel phosphorus was found to be machinable for the FIB technology and is a well-known material for ultra-precision machining. Comparing common manufacturing processes for optical surfaces, not all machine-assisted methods can be applied on the miniature objects with radii of curvature of approx. 1 mm. Turned spherical objects may have a point with a cutting speed of zero in their centre (at least this applies for spheres), which means a predictable error in the surface, that needs to be avoided. Conventional polishing machines provide forces which are too large. The results of manual processes strongly depend on the skills of the operator and are typically limited in their repeatability. In addition, polishing tools for microcomponents are custom built and cannot simply be deduced or cut from macroscopic polishing pads. Hence, an additional time for tool and process development must be taken into the account. Table 1 shows the evaluation of the different manufacturing processes for the present tasks. The flat is used for the validation of the FIB process. The structuring of the single and the double curved surfaces are the main focus of the ongoing project.
The manual polishing methods were chosen for the flat specimen, the convex cylinder and the sphere. Diamond turning was chosen for the concave (toric) cylindrical surface.
A very challenging task for polishing processes of curved surfaces is the selection of suitable polishing pads. The small radius of curvature makes it difficult to move the tool on the surface of the workpiece. Local pressures, which significantly

exceed the average value of a stable polishing process, destroy the surface, e.g. by means of scratches.
Thus, several tests were performed with different substrates of different materials and geometries in combination with different polishing media. Finally, polyimide film of 100 µm in thickness was used with a diamond abrasive of 1 µm grainsize. For the manufacturing of the sphere, measurement tips with a high precision spherical shape were used. A simple precision capillary was coated for the convex cylinder.

Table 1 Evaluation chart for manufacturing processes.

Process	Geometry			
	Flat	Sphere	Convex Cylinder	Concave Cylinder
Manual Polishing	+	+	+	-
Machine Polishing	+	-	-	-
Diamond Turning	+	-	+	+

3. Results

Figure 2 shows the CLSM measurement of the convex cylinder. The average areal roughness after coating and polishing is Sa = 7.6 nm. Compared to the targeted artificial roughness, this is better than a factor of 13.

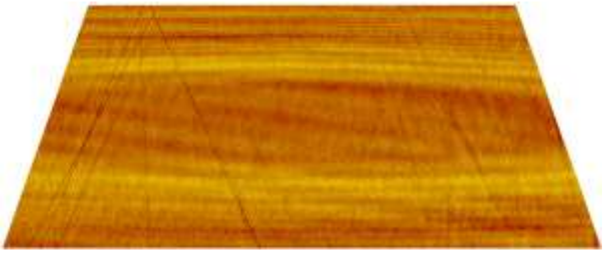

Figure 2. 3D view of a CLSM measurement of the convex cylinder after polishing, before FIB treatment (cylinder subtracted), size 115 µm × 78.5 mm × 117 nm. Roughness: Sa = 7.6 nm, Sq = 9.5 nm, Sz = 117 nm.

The micrograph in figure 3 shows the clear optical contrast of the polished substrate and FIB-processed surface.

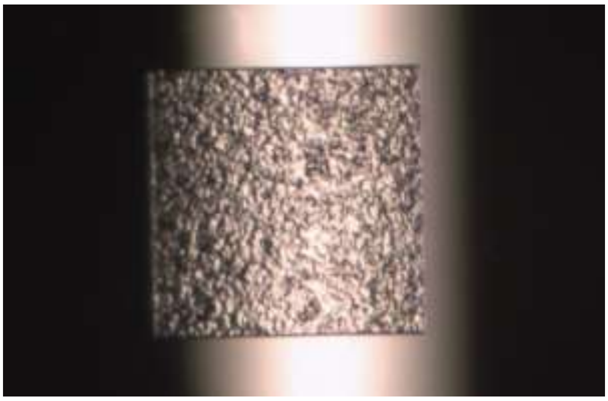

Figure 3. Optical darkfield micrograph of 560 µm × 420 µm with the synthetic roughness area (square of 290 µm × 290 µm) produced by FIB processing on the cylindrical substrate (r ~ 400 µm).

Figure 4 shows a micrograph of spherical specimens before and after the finishing process.

Figure 4. (left) NiP-coated and (right) finished specimen, diameter of spheres approx. 1 mm.

Figure 5. 3D view of a CLSM measurement of finished sphere (sphere subtracted) before FIB, 100 µm × 99 µm × 87 nm. Roughness: Sa = 3.2 nm, Sq = 4.9 nm.

Figure 5 shows the result of the CLSM measurement of the finished sphere. The average roughness is Sa = 3.2 nm

Figure 6. 3D view of a CLSM measurement of the concave cylinder, cylinder subtracted, size 279 µm × 250 µm 264 nm. Roughness: Sa = 3.0 nm, Sq = 3.9 nm, Sz = 264 nm.

Finally, figure 6 shows the roughness plot of the diamond turned concave toric shape with an average roughness of Sa = 3.0 nm

5. Summary

Different procedures and substrates were used for the manufacturing of substrates for the FIB processing of artificial roughness fields on curved surfaces. The average roughness of the FIB-structured surface was at least ten times larger than the roughness of the substrate. In a next step, the influence of the specific roughness values on the measurement result will be investigated.

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References
[1] Hemmleb M, Berger D and Dziomba T 2016 Focused Ion Beam fabrication of defined scalable roughness structures, *The 16th European Microscopy Congress* **DOI:** 10.1002/9783527808465.EMC2016.6098