Ultra-precise Optical Mirrors with Thick Amorphous Silicon Layer

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Abstract

Metal mirrors with excellent optical, mechanical and thermal properties are used for a wide range of modern optical applications like telescopes, spectrometers or scanners.
The surface quality of machined optical surfaces is one of the limiting factors in the manufacturing of ultra-precise optical components. Substrate materials like silicon can be polished very well and very smooth surfaces can be obtained. However, crystalline silicon is very hard and causes a large tool wear which makes the ultra-precise machining of silicon substrates difficult and expensive. Ductile substrate materials like Al, Cu or AlSi-alloys are much easier to machine, however, they can not be polished to very low surface roughnesses. For reflective optics the state of the art is to overcome these limitations by deposition of electrochemical nickel-phosphorus (NiP) onto a machined substrate. The NiP layer can be polished much better than the diamond machined surface. A roughness below 1nm rms can be achieved [1, 2].
This paper discusses a new technology which is based on an amorphous silicon layer with a thickness of several microns deposited onto the surface. First results of diamond turned samples with polished surfaces are shown. This thick amorphous silicon layer can subsequently be polished and very smooth surfaces can be achieved.

1 Magnetron sputtered amorphous silicon

A key component for the presented technology is the thick and machinable silicon layer. It is well known that silicon deposition by magnetron sputtering results in an amorphous structure of the silicon film [3]. During our experiments, various thicknesses of the silicon layers of 1 µm, 3 µm, 6 µm and 10 µm were realized by a modified sputtering technology. During optimization of the sputtering parameters the thickness, homogeneity and porosity were determined by coating of aluminium test samples. The stress of the deposited silicon film was tested by coating of silicon wafers. The structure of the silicon films was determined by X-ray diffraction using a Bruker D5005 diffractometer. For silicon layers with a thickness of 6 µm the most important deposition parameter was a pressure below $7x10^{-3}$ mbar for mid-frequency (MF) dual magnetron sputtering. For thicker layers of about 10 µm the sputtering power was increased from 4 kW to 8 kW and the substrate temperature followed from 70°C up to 100°C. By using these parameters the film stress increases from 210 MPa to 360 MPa for 3 µm films. The silicon layers show for higher film thicknesses an increasing porosity (Fig. 1). A modified way is to prepare the silicon layer as a multilayer stack of several 0.5 - 1 µm layers with interruptions. This reduces the film stress considerably (from 210 MPa to 100 MPa for 3 µm films) and at the same time limits the substrate temperature during deposition to values lower than 65°C.

The main point and an important task was to ensure the amorphous structure of the deposited silicon layer. This is essential for the final polishing step. Figure 2 shows X-ray diffraction (XRD) curves of an uncoated glass substrate and a glass substrate coated with 1 micron of silicon by magnetron sputtering. The graph shows that the sputtered silicon film has an X-ray amorphous structure.

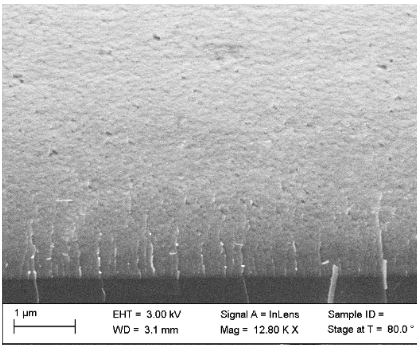

Fig. 1: Cross section of silicon film

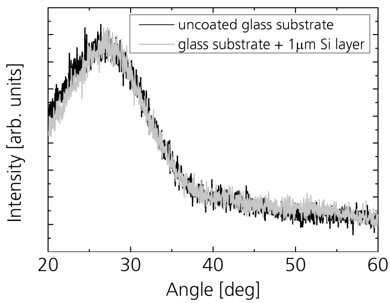

Fig. 2: XRD-spectrum of a silicon layer

2 Process Chain for Metal Mirrors fabrication

Referring to the optical and mechanical design of the mirror the manufacturing technology has to be specified. For applications in the visible and short wavelength range two process chains were reviewed. The combination of aluminium or aluminium-silicon with nickel-phosphorous was published in [2]. A new approach is the combination of aluminium-silicon with amorphous silicon. For this chain a second diamond turning step can be omitted. A schematic view of the process chain is depicted in figure 3.

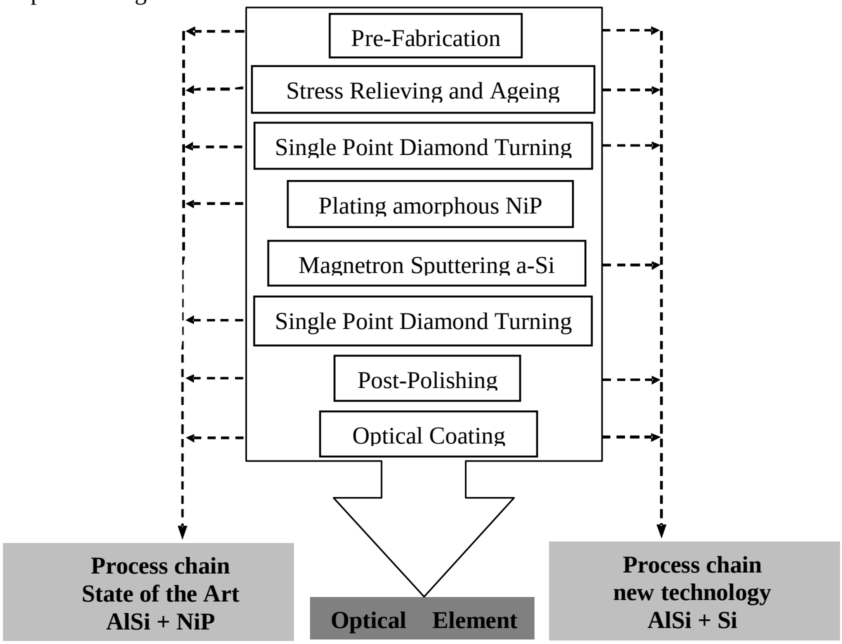

Figure 3: Process chain for ultra-precise optical components with amorphous layer

After pre-fabrication, stress relieving and aging of bulk material, typical materials are Al6061 and AlSi40 alloy of RSP Technology, the shaping of the mirror was realized by single point diamond turning (SPDT). The following coating step covered the entire surface with a film of approximately 3 to 6 µm silicon. The post-polishing step reduces the roughness and smoothes the typical microstructure of the diamond turning process. The microstructure of the optical surface after SPDT is characterized by a periodic turning pattern with a typical pitch of 5…10 µm (figure 4). The smoothing of the turning structure is a challenge for all applications in VIS and UV range. Different polishing techniques were applied. The first results of magneto-rheological-fluid polishing (MRF), jet polishing (JP) and computer calculated polishing with a robot (CCP) are shown in figure 5, 6 and 7 respectively. The roughness was measured with white light interferometry (WLI) by ZYGO New View 600 in a field of 180 µm x 130 µm (Fig. 4) or 140 µm x 110 µm (Fig. 5, 6, 7).

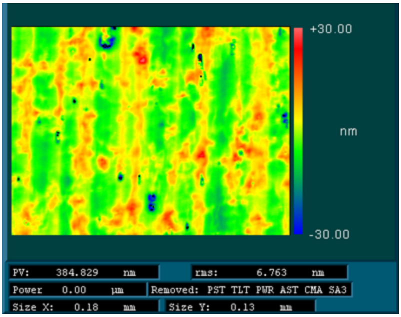

Figure 4: WLI of Al6061 after SPDT (6.76 nm rms)

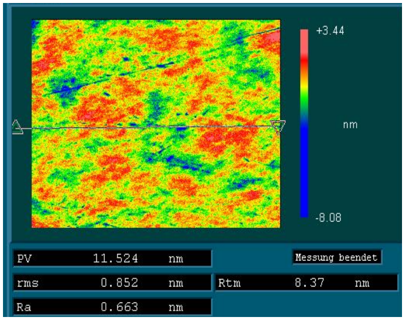

Figure 5: WLI of Al6061 coated with silicon film after MRF (0.85 nm rms)

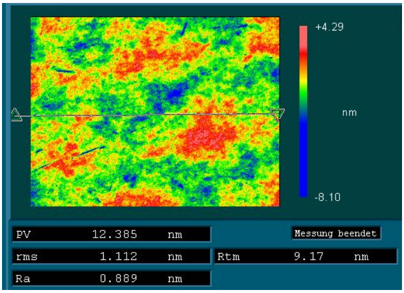

Figure 6: WLI of Al6061 coated with silicon after JP (1.11 nm rms)

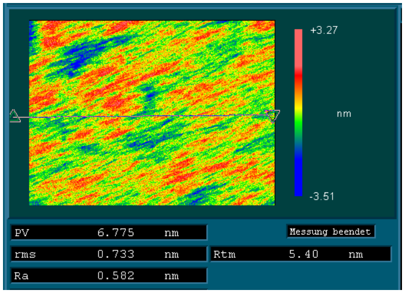

Figure 7: WLI of Al6061 coated with silicon after CCP (0.73 nm rms)

3 Conclusion

The results of silicon coating and silicon polishing indicate that the presented technology can be applied to the manufacturing of ultra-precise optical components.

Acknowledgment

The authors are grateful to the BMBF, Germany, for sponsoring their research in terms of the "Wachstumskern Potential – Verbundprojekt: Ultrapräzise Silizium Optik"-grant under contract no. 03WKP11A.
We would like to thank Prof. Christine Wünsche and her team from FH Deggendorf for successful cooperation in the polishing activities of metal samples.

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