euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

Surface figure error correction by additive plasma jet machining and ion beam assisted mask transfer

Thomas Arnold, Jean-Baptiste Abadie, Georg Boehm

Leibniz-Institut für Oberflächenmodifizierung (IOM), Permoserstr. 15, 04318 Leipzig

thomas.arnold@iom-leipzig.de

Abstract
Sub-aperture figure error correction techniques are usually required in ultra-high precision optical surface fabrication. Several non-conventional methods based on atomic particle interactions like ion beam figuring (IBF) or plasma jet machining (PJM) have been established in optical workshops. Both methods can be advantageously employed in small sized surface error structures removal. However, IBF suffers from very low removal rates of 1 nm/s or less when using small-sized beam diameters of less than 2mm. Although PJM utilizing local plasma-chemical etching exhibits higher material removal efficiency by a factor of 100 or more even at small tool sizes in the millimetre range, it is restricted to materials that can be converted to volatile products, such as SiO_2, Si or SiC. In order to make use of the highly localized tool function in PJM for the machining of non-etchable materials like optical glasses, ceramics or metals, a new two-step method has been investigated. The first step involves deterministic plasma jet assisted deposition of a polymer film applying locally adapted film thickness according to the inverse of the measured surface error topography. This is accomplished in a second machining step by a broad ion beam etching process in which the deposited film acts as sacrificial mask. In order to establish a surface error correction technique we investigated film deposition rates, film micro-roughness, homogeneity of film properties, and etch selectivity in the ion beam transfer process in dependence on the process parameters. Exemplarily, we present the correction of a surface error topography on Zerodur by means of the new method.

Chemical vapor deposition, Ion beam machining, Optical, Ultra-precision

1. Introduction

Non-conventional deterministic surface machining methods such as plasma jet machining (PJM), or ion beam figuring (IBF) have nowadays been established in laboratories and optical workshops for the manufacturing of high precision optical elements such as aspheres and freeforms. Since more and more versatile optical designs are required from the optics systems developers, the surface specifications with respect to form and roughness parameters are steadily tightened. At the same time, optical manufacturers must be able to fabricate individual elements or very small lot sizes of such optical elements (e.g. lenses, corrector plates, mirrors, prisms) in a very efficient way.

It has already shown that atmospheric pressure reactive plasma jet machining (PJM) is capable to process optics made of fused silica, silicon carbide or silicon achieving high quality surfaces [1-3]. In the frame of the established process chain the plasma tool is utilized for efficient aspheric or freeform generation, and for figure error correction, as it exhibits comparably high machining rates and high spatial resolution of the tool. The plasma is performing a fluorine chemisty-based dry etching process where material is removed from the surface by conversion to volatile reaction products. However, standard optical materials consisting of elements and compounds other than Si, SiO_2 or SiC (e.g. Zerodur, optical glasses, etc.) cannot be machined, since non-volatile products will remain on the surface leading to masking contaminations or total etch inhibition.

IBF is suited to treat virtually all material classes due to the physical nature of material removal. However, IBF suffers from very low removal rates of 1 nm/s or less when using small-sized beam diameters of less than 2mm [4].

In the paper, an alternative figuring correction method is introduced utilizing a combination of PJM and ion beam processing, where the advantages of both technologies are exploited. In a first step a shape adapted polymer layer is locally deposited on the surface compensating the figure error (see Fig. 1 (a) and (b)). In that way the figure error even in the mid-spatial frequency range can be cancelled out.

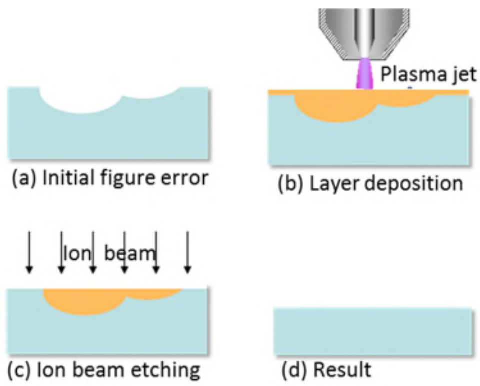

Figure 1. Processing scheme for combined plasma jet and ion beam figure error correction

Since the workpiece is then covered by a foreign material that is not suitable to maintain optical functionality, the surface must be subsequently transferred to the original substrate material. A subsequent step involves broad ion beam etching to transfer the masking layer to the substrate (see Fig. 1(c) and (d)). In order to establish a surface error correction technique plasma deposition rates, film micro-roughness, homogeneity of film properties, and etch selectivity in the ion beam transfer process in dependence on the process parameters have been investigated. Finally, the correction of a surface error topography on Zerodur by means of the new method is presented.

2. Experimental

2.2. Plasma jet layer deposition

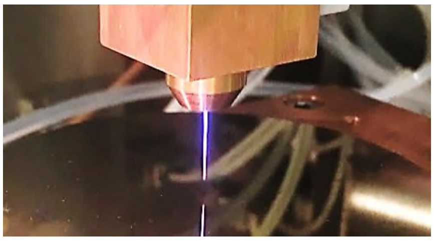

Figure 2. Plasma jet tool for layer deposition

The plasma jet system employed for thin film deposition is similar to the system used for etching purposes (see Fig. 2). The plasma source consists of a coaxial conductor where the inner conductor is the feeding gas tube. The source can be moved by a 3-axes CNC stage system over the surface. The plasma jet is fed by 100 sccm Ar as carrier gas. The layer-forming precursor is acetylene (C_2H_2) with a flow rate of 20 sccm. A peripheral N_2 shielding gas flow of 500 sccm prevents the entrainment of surrounding air into the plasma. Plasma is excited by microwave at 2.45 GHz, applying short pulses of 6.5 µs at a repetition rate of 650 Hz and peak power of 650 W. On average, a power of 3 W is dissipated, which maintains a surface temperature slightly above room temperature.

This basic parameter set has been determined by systematic variation of each parameter in order to find stable plasma conditions. Chemical analysis of deposited layers revealed a $C_xH_yN_z$-polymer. Although the plasma exhibits cylindrical symmetry the working distance between the plasma nozzle and the substrate is an important parameter for the deposition rate and the resulting layer roughness, since the convective and diffusive gas flow pattern and power coupling determines dissociation and polymerization. Figure 3 shows deposition rate and roughness of the layer on a Zerodur substrate depending on the working distance. Roughness should ideally not exceed the substrate roughness (approx. 2 nm). Best conditions have been found between 5.5 mm and 6.0 mm working distance.

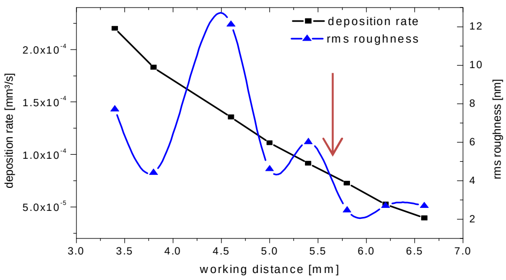

Figure 3. Layer deposition rate and surface roughness depending on the working distance. The arrow indicates an optimal working distance.

2.2. Ion beam etching

For transferring the layer an ion beam figuring system has been utilized. The beam source is fed by Ar gas to produce Ar^+ ions that are accelerated to the workpiece surface. Beam energy was 0.7 keV at a beam diameter of 22 mm and current density of 40 mA/cm². With this parameters an etching rate of 8 nm/s on Zerodur is obtained. The beam was moved by a CNC motion system over the substrate applying a raster path. Since etch rate *ER* of layer and substrate are not necessarily equal, a selectivity (i.e. $ER_{substrate}/ER_{layer}$) must be determined to scale the layer thickness for deterministic correction of a surface topography. Figure 4 shows the selectivity for different working distances. At 5.5 mm the selectivity is approximately 1.4.

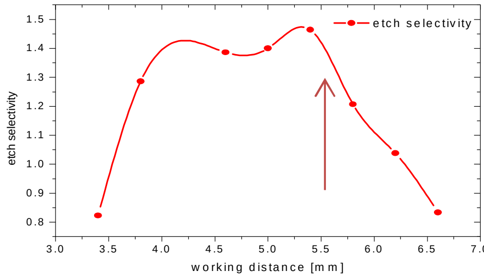

Figure 4. Ion beam etch selectivity of substrate with respect to deposited layer thickness.

3. Machining results

A flat Zerodur surface measured by interferometer is shown in Fig. 5 (a). A layer with variable thickness that compensates the topography was applied by plasma jet deposition, regarding the selectivity as a thickness scaling factor. Subsequently, uniform ion beam etching was performed. The resulting surface is shown in Fig. 5 (b). A significant improvement of the figure error even for small error features such as the vertical line defect in the lower semicircle has been achieved. This experiment proves the principle of additive correction of optical surfaces by the proposed two-step method.

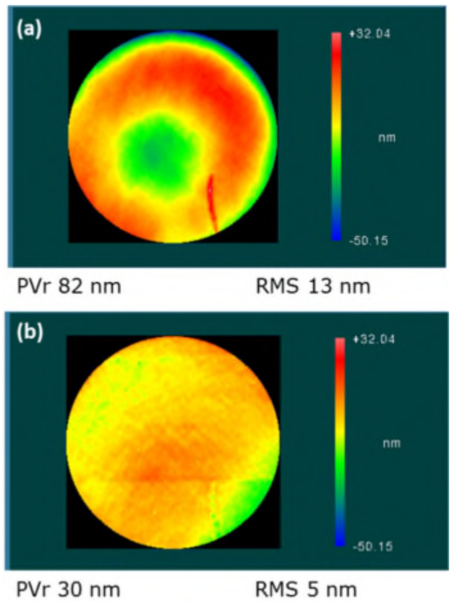

Figure 5. (a) Initial surface figure error, (b) Figure error after layer deposition and ion beam etching of the layer.

References

[1] Th. Arnold, G. Boehm, H. Paetzelt, *J. Eur. Opt. Soc.-Rapid* **11** (2016) p. 16002

[2] H. Paetzelt, G. Böhm, Th. Arnold, *Plasma Sources Sci. Technol.* **24** (2015) p. 025002

[3] Th. Arnold, G. Boehm, *Precision Engineering* **36** (2012) p. 546

[4] Th. Arnold, G. Boehm, R. Fechner, J. Meister, A. Nickel, F. Frost, T. Haensel, A. Schindler, *Nucl. Instrum. Meth. A* **616** (2010) p. 147