Research results of ultra precision technology I Dipl.-Ing. Lars Dick

Different ultra precision manufacturing technologies meet modern optical polymer applications

In the future, machining of very complex high precision optical surfaces will become more important due to the demands of modern optical applications in different branches (medical engineering, automotive, metrology, and lighting). To realize as many different optical designs as possible, different machining methods are needed. As a consequence, the demand for precisely manufactured complex structures (like free-form, non rotational symmetric, micro structured, filigree DOE - surfaces) will rise.

2 – axis diamond turning

This technology achieves a surface roughness of 2 nm < Rq < 10 nm and form deviations (peak to valley) PV < 1 µm. It can be used for on-axis and off-axis diamond turning.
On-axis diamond turning is used for rotational symmetric surfaces like spheres, aspheres, plano surfaces, diffractive optical elements and fresnel structures, whereas off-axis diamond turning is suitable for cylindrical or torical surfaces (at least one meridian has to have a spherical radius) and linear structures on curvatures.
We posses a large assortment of tooling equipment with various radii and angles because it is highly important to chose the right monocrystalline diamond tool for high quality surfaces.

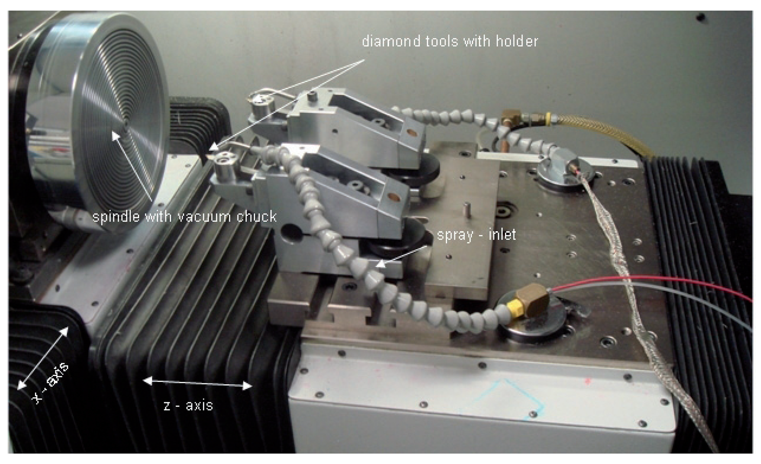


figure 1: machine setup 2 axis diamond turning

figure 2: diamond tools for different applications

The following figures show some of our research results. Figure 3 shows roughness Rq in relation to tool radius and angle of setting. In figure 4 you can see the interconnection between revolution speed and surface roughness Rq.

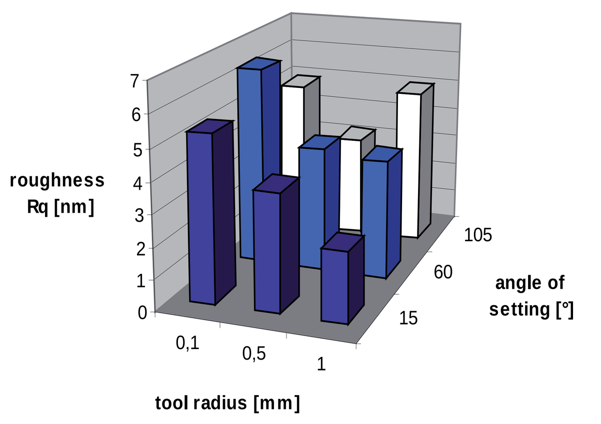


figure 3: surface roughness Rq in relation to tool radius and angle of setting

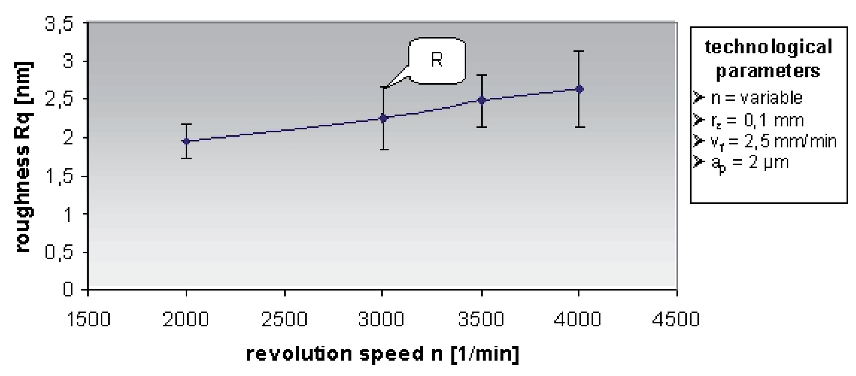
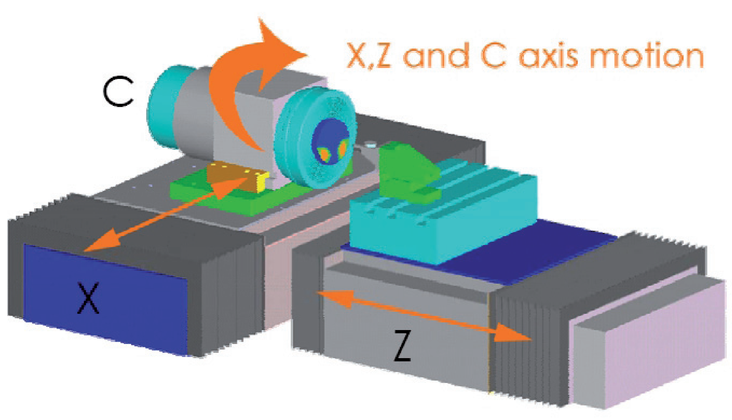


figure 4: surface roughness Rq in relation to revolution speed

Slow tool servo - technology

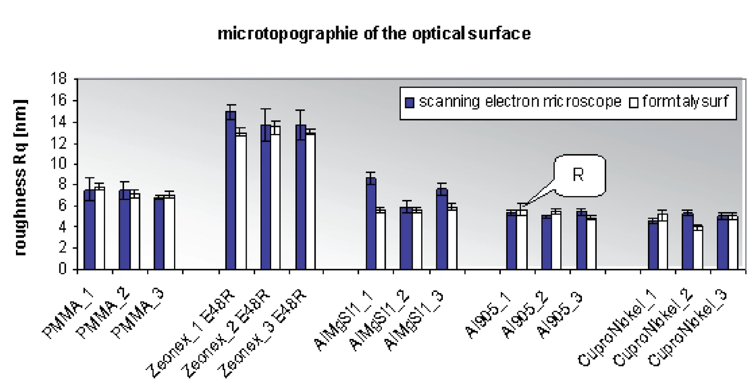
The STS technology generates non-rotationally symmetric surfaces like freeform, Zernike surfaces, toric, biconics and cylinder surfaces on axis as well as off axis. The diamond tool position z is a function of the x – position and therefore the turning angle of the spindle or rather the work piece (z = f(x,c)). This is shown in figure 5. This technology allows for roughnesses of Rq < 10 nm and form deviations of PV < 1 µm.



	STS
Drive & "bearing" technology	Linear motor / Hydrostatic Oil bearing
Characteristic Travel*	10 mm (@ 2 Hz)
Characteristic Bandwidth**	70 Hz
Characteristic Surface finish^	5 nm Ra

figure 5 & table: functionality and general caracteristics of the STS – technology

The graphs below show some experimental results of the JENOPTIK Polymer Systems GmbH. A toroidal surface (on axis) has been generated on materials which are of great interest for the optical industry. Figure 6 illustrates the roughness of the optical surface (Rq) and figure 7 the form deviation (PV).



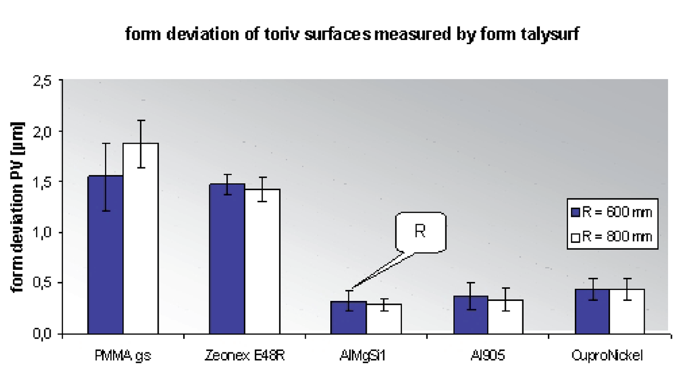


figure 6 & 7: surface roughness and form deviation of diamond turned parts with STS – technology in different materials

Fly cutting technology

With linear fly cutting equipment on a 2-axis diamond turning machine, linear and crossed linear structures like prismatic arrays, diffractive gratings, cylinder lens arrays, pyramid arrays and retro reflector arrays can be realized in high optical quality (Ra < 15 nm and form deviations down to 0,2 µm). Special diamond form tools are needed for this process. Typical structure sizes are 50 up to 1000 µm.

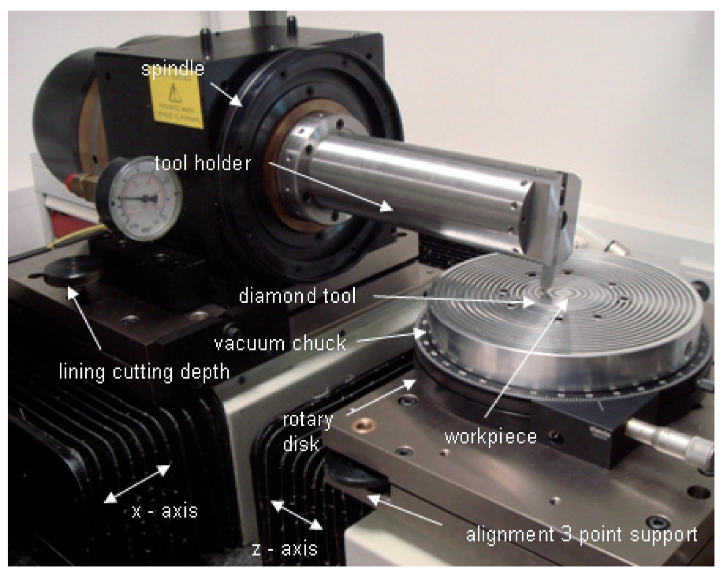


figure 8: machine setup fly cutting technology

Figure 8 shows a modified 2-axis diamond turning machine (Precitech Optimum 2400) prepared for linear fly cutting process. The required equipment are: a tool holder, a vacuum fixture, a 3 point fixture and a B axis / rotary disk (to realize crossed structures).
Some results from JENOPTIK Polymer Systems GmbH are shown below in figure 9. All structures have a background with useful optical applications.

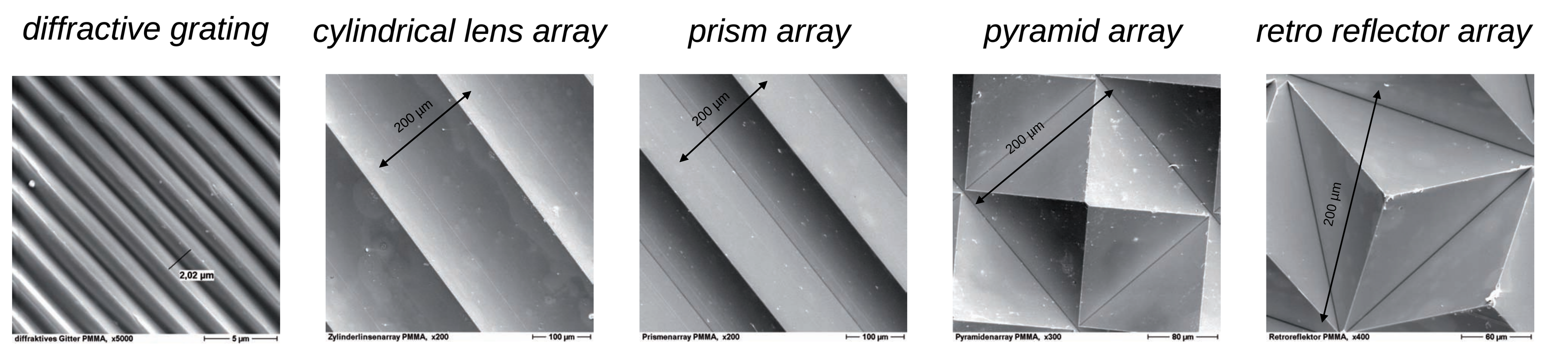
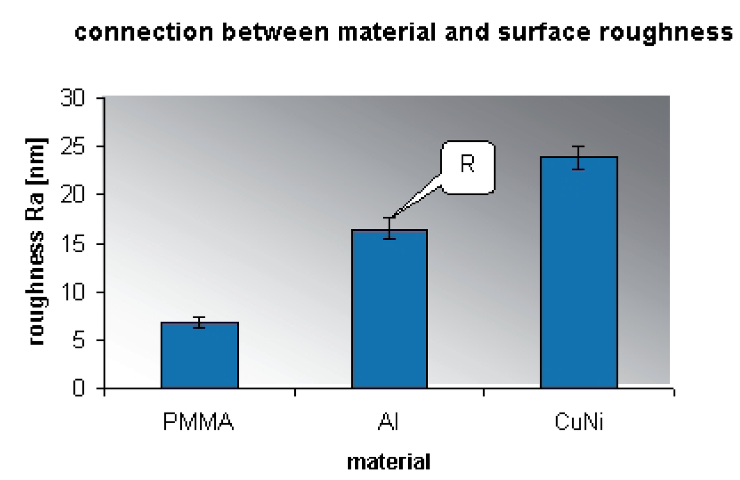


figure 9: REM – figures of structures manufactured at JENOPTIK Polymer Systems GmbH

At JENOPTIK Polymer Systems GmbH many experiments have been carried out to find optimal process parameters. Some results are shown below.



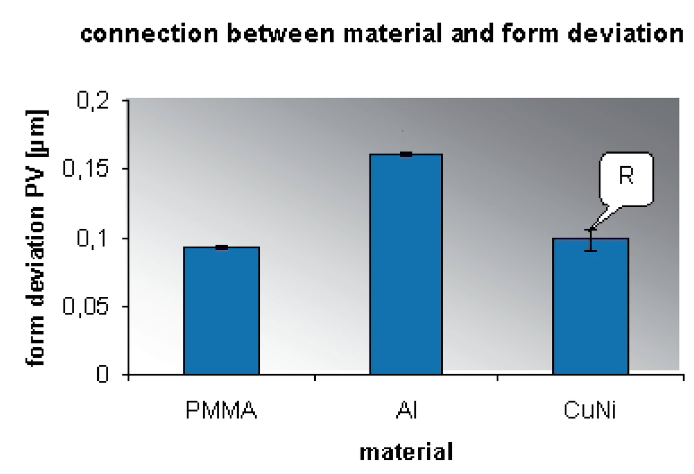


figure 10 & 11: surface topography of microstructures manufactured by fly cutting technology

Contour boring technology

A new technology at the Jenoptik Polymer Systems is the contour boring technology for which we have fixed a special machine setup on a 2-axis diamond turning machine (shown in figure 12). To manufacture these lens arrays, we use special half arc diamond form tools. It enables us to bore lens arrays with typical structure sizes of 50 up to 1000 µm. With contour boring module optical surface qualities like in fly cutting processes are achievable and sharp changeover of the lenses is a result which can't be accomplished using other technologies like fast tool servo.
Contour boring technology can realize form deviations in PMMA and NiP (Nickel-Phosphorus) of about PV < 2 µm and a surface roughness of about Ra < 15 nm. Main applications of the stuctures (shown in figure 13) can be found in lighting technology.

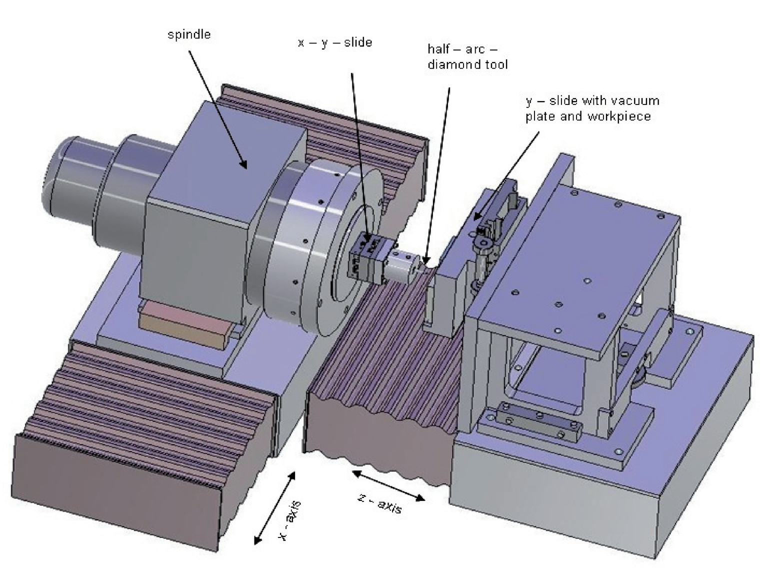


figure 12: contour coring module designed in 3D CAD

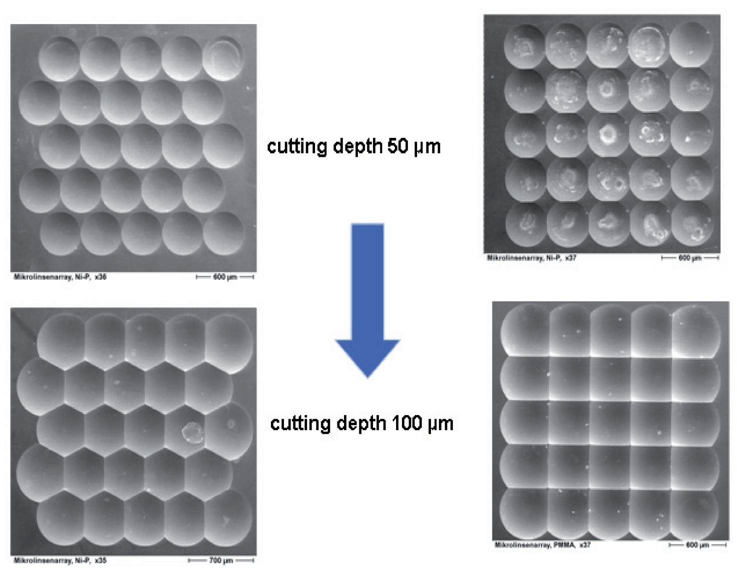


figure 13: micro structures manufactured by contour boring