Rapid Prototyping of Polymer Waveguides by Contour Shaping

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We present a novel method for manufacturing polymer waveguides. The main part is the structuring of the grooves by ultra-precision shaping. Afterwards the grooves are poured with a UV-sensitive core polymer, covered and cured. We demonstrated that ultra-precision shaping enables mechanical micro structuring for rapid prototyping of optical components and in higher lot sizes the possibility of making a replication step obsolete.

1 Introduction

Optical interconnects and waveguides are one of the most crucial parts in integrated optical sensor systems. In higher lot sizes, the production of those is often realized by mechanical micro structuring of masters and further replication steps. Fly cutting and micro milling are two prominent examples for manufacturing those masters. The major drawback of those are the low feed rates of up to 100 mm/min resulting in high production times [1]. Compared to that ultra-precision shaping delivers feed rates of up to several m/s retaining the high surface quality of the conventional methods [2, 3]. Ultra-precision shaping is a mechanical micro manufacturing process with non-rotational tool. The structuring is realized by direct tool movement with an infeed so several micrometers. However, shaping machines are normally limited to linear surface structuring. In order to expand the process capabilities a minim um of four axes is needed to realize a 3D structuring. For each spatial direction, a high dynamic axis is needed. Since geometrically defined diamond tool are used an additional rotatable tool mount is need to set the rake face in cutting direction (Fig. 1).

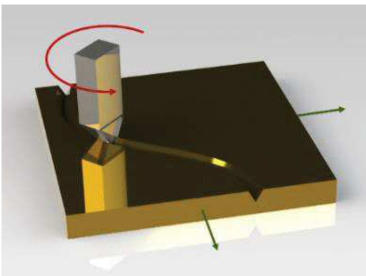

Fig. 1 *Process schematics of contour shaping*

Fanuc demonstrated that contour shaping is possible by using an ultra-precision milling machine. Therefore, the diamond tool is mounted on the A-axis of a Fanuc ROBOnano machining center. The drawback of this approach are the low feed rates of several tenth millimeters per minute. [4]

2 Ultra-precision shaping

In preliminary experiments, we have shown the capability of ultra-precision shaping in terms of achievable surface quality and feed rates [3]. The outcome of these experiments is a custom build ultra-precision shaping machine (USM) which was developed together with Aerotech GmbH Nürnberg (Fig. 2 left). Three linear air-bearing stages can react during shaping with feed rates of up to 1.5 m/s. The tool mount is placed on an indexed spindle and the workpiece is placed on a rotary stage for changing the cutting direction. In Figure 2 the tool center point with a mounted diamond tool and a structured PMMA workpiece is shown.

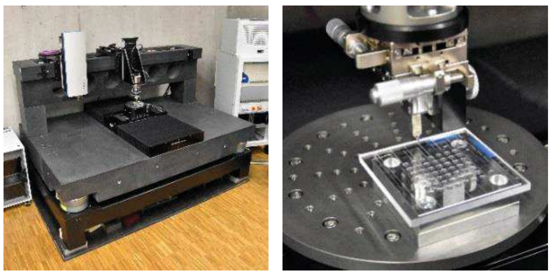

Fig. 2 *USM (left) and tool center point with linear structured grooves in PMMA (right)*

For an in-line process control and characterization on an additional slide of the X-axis a Nanofocus µsurf custom confocal microscope head mounted.

3 Experimental

The process chain for manufacturing polymer waveguides is divided in four steps. In the first step grooves are directly structured into the surface of a PMMA substrate by linear shaping. These grooves are afterwards poured with a UV-sensitive PU resist (step 2). In step three an unstructured PMMA cover plate is pressed with a force of 1 kN onto the substrate in order to avoid an intermediate PU layer between the PMMA plates. In the last step when the final force is reached the PU resist is cured by UV illumination (365 nm, 2.8 mW/cm^2).

3.1 Cutting parameters

For the cutting experiments a Tool with a rake angle of 60° and an edge radius of 100 µm was used. Seven grooves were shaped into the surface with a feed rate of 500 mm/s and an overal depth of cut of 100 µm. The depth was achieved by nine roughing steps of 10 µm and ten finishing steps of 2 µm. The high amount of finishing steps is needed to remove possible local melting defects on the surface. The PMMA workpiece has a dimension of 80 mm x 80 mm x 5 mm and the grooves have a pitch of 10 mm.

3.2 Results

The left picture in figure 3 shows the PMMA substrate with manufactured grooves where as the right picture is a 3D surface plot of a single groove. Each groove was measured with a magnification of 100 on seven different position in 10 mm steps from the tool entrance point. Afterwards the data was analyzed with the Digital Surf MountainsMap® analysis software.

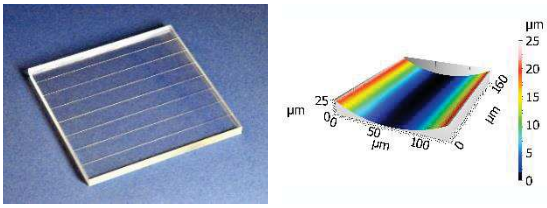

Fig. 3 *Structured PMMA sample (left) and 3D surface plot of a single groove bottom (right)*

49 profiles were generated out of the center of each measured positon and the surface roughnes was calculated.

The plot in figure 4 shows the mean value of each groove and the error bars are the standard deviation. The overall mean is 5.1 nm Ra with a standard deviation of 1.1 nm. The results of one groove were verified with a Zygo® NewView 5000 whitelight interferometer.

After the curing of the PU resist a functional demonstration of the waveguides was performed. Therefore, one waveguide was excited by a 532 nm laser source and the relative intensity measured at the other end. Figure 5 shows the intensity plot over the waveguide outlet.

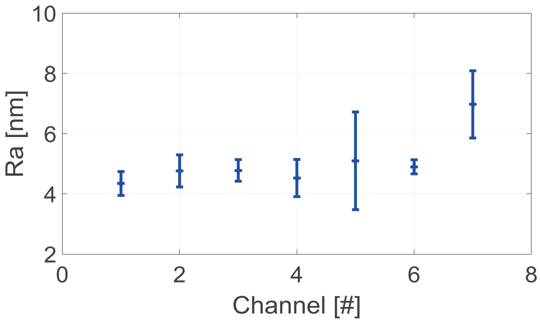

Fig. 4 *Ra with standard deviation of each groove*

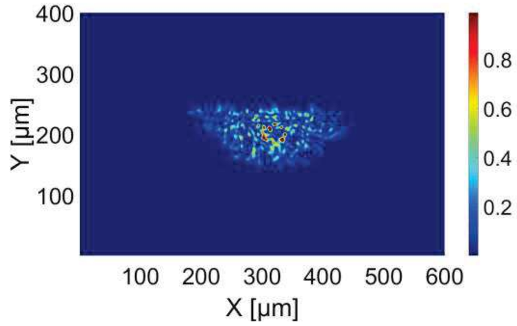

Fig. 5 *Intensity plot of the waveguide outlet*

4 Discussion and outlook

Contour shaping is a versatile and reliable process for structuring polymer sample for waveguide manufacturing. The achievable surface roughness of about 5 nm Ra in PMMA is an excellent value for optical applications. In figure 5 a slightly increase of the Ra value of groove five and seven can be recognized. This behavior is maybe related to sticking of chips on the diamond tool from former cuts since no lubricant was used for machining. In addition it cannot be noticed from groove 1 - 4, which were manufactured manual and chips were removed in between by blowing with Nitrogen. Groove 5 - 7 were generated completely automatic without blowing of Nitrogen. Finally, the optical functionality was demonstrated.

For further investigations, the sticking of the chip and a cutting parameter optimization will be performed and afterward the optical parameters of the waveguides should be further investigated.

5 Acknowledgement

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