JOURNAL OF THE EUROPEAN OPTICAL SOCIETY

Sub surface damage measurements based on short coherent interferometry

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During grinding step in manufacturing process of glass lenses it is important to control such parameters as shape and sub-surface damage (SSD) with high accuracy which essentially influences the duration and costs of the subsequent polishing process. Typically used methods suffer from limited resolution and are time consuming. That is why the nondestructive measurement of SSD is a challenge for the metrology of grinded surfaces. In order to detect these damages, the scanning short-coherence interferometer, a method very similar to optical coherence tomography, is setup and tested at Aalen University. The lens under test is mounted on a rotation stage which can be translated in lateral direction. The sensor beam of the interferometer is focused onto the sample and can be moved along the axial direction. Lateral positioning accuracy is 2 μm and lateral resolution is 4 μm. The system is able to measure SSD at several positions on a lens within 10 min inside the optical workshop. [DOI: 10.2971/jeos.2010.10003]

Keywords: optical coherence tomography, sub-surface damage, non-destructive measurements, grinding, glass, optical manufacturing

1 INTRODUCTION

The grinding step of the manufacturing process of lenses is very essential for the overall achievable accuracy of the final optical surface. Surface deviations introduced by a deficient grinding process can be hardly corrected in the subsequent polishing step. That is why, to make the whole process cheaper and faster, grinding should be well optimized to bring the lens as close as possible to final specification. Therefore, there is a need for a measurement device to monitor the surface parameters determined by the grinding process.

First of all the shape of the grinded surface should be monitored. Tactile measuring machines [1] are the most common method for shape measurements. They deliver sufficient precision regarding form accuracy. The disadvantage of this metrology is that especially soft material could not be measured by a contacting stylus and the method suffers from limited lateral resolution in the case of ruby ball.

Another important output parameter of the grinding process is sub-surface damages (SSD) of the substrate which modify the substrate in a third dimension and have to be removed by subsequent polishing.

There are destructive [3, 4] and non-destructive [5]–[8] techniques which are able to perform measurements of surface micro-cracks. The disadvantages of these methods are that they modify the surface under test irreversibly and are time consuming. Therefore, non-destructive measurement of SSD is a challenge for the metrology of grinding surfaces.

We have investigated and tested [2] optical coherence tomography (OCT) as an interesting alternative to existing methods. It is a non-destructive three dimensional optical imaging technique with high dynamic range based on short coherence interferometry.

2 MEASUREMENT METHOD

In principle, OCT is a Michelson interferometer (see Figure 1). Light is emitted from the broadband, low-coherence

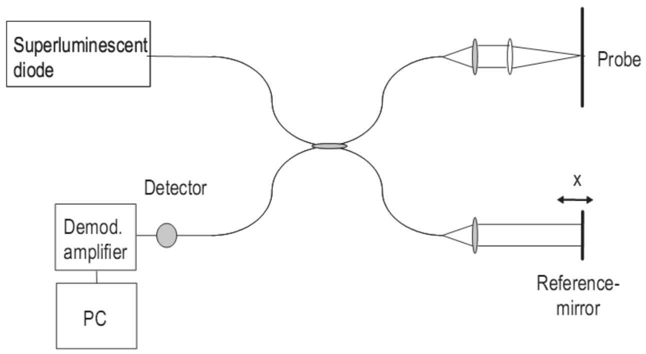

FIG. 1 Optical coherence tomography (OCT) principle layout.

Received May 19, 2009; published January 17, 2010
ISSN 1990-2573

(or "white", we used SLD with $\lambda = 670$ nm, $l_c = 20$ μm) light source. Then it is split into two arms; reference and measurement. The reference wave front is reflected back by a cyclically scanned mirror (travel range of 1.8 mm, scan rate of 68 Hz). The measurement wave front is focused onto the sample hits it, being also reflected (or, better, scattered) back by it. These two wave fronts are joined, and forwarded to the detector. If the path length difference of these two wave fronts is small (within the coherence length of the source), the detector will see the interference, otherwise, they will not interfere and the detector will just see the mean value of intensity. The computer unit controls the scanner mirror movement and records the incoming signal from the detector as a function of the mirror position. The oscillating detector signal is demodulated to receive the envelope of the signal (see Figure 2). The task is to find the maximum of the interference function which corresponds to the position of the scanned mirror where path length between this mirror and the reflecting sample layer are the same. This is how the A-scan (depth scan) is accomplished. Then the computer translates the sample laterally relative to the focused probe beam and makes another A-scan at a different point on the sample. A series of these A-scans form a B-Scan (lateral scan). Combining those B-Scans at various cross-sections a full 3D surface scan can be accomplished.

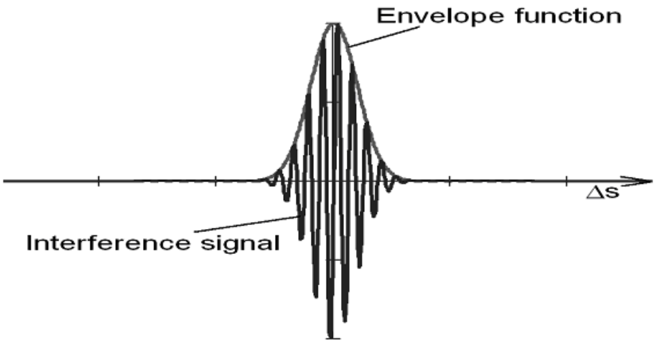

FIG. 2 Interference signal of a short-coherence light source.

3 RESULTS AND DISCUSSION

3.1 Calibration

In order to calibrate the set-up, we designed and manufactured, in collaboration with Furtwangen University, a test sample of rectangular grating structures (see Figure 3) with varying width starting from 600 μm and decreasing down to 1 μm (see Figure 4)

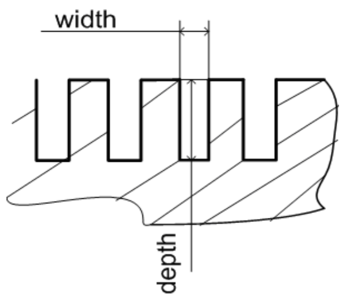

FIG. 3 Test-sample principle sketch.

To define the modulation transfer function (MTF) the structure of 100 μm was chosen (see Figure 5(a)).

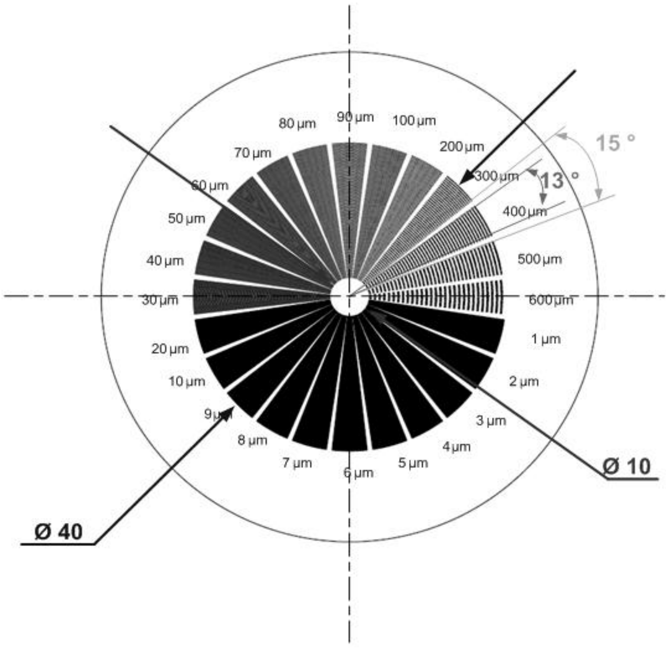

FIG. 4 Silicon test wafer for OCT set up. It consists of 24 angular segments (13 degrees each with 2 degrees spacing) of patterns (rectangular z-profiles) of different spatial frequencies (starting with 1.2 mm pro period and ending with 2 μm).

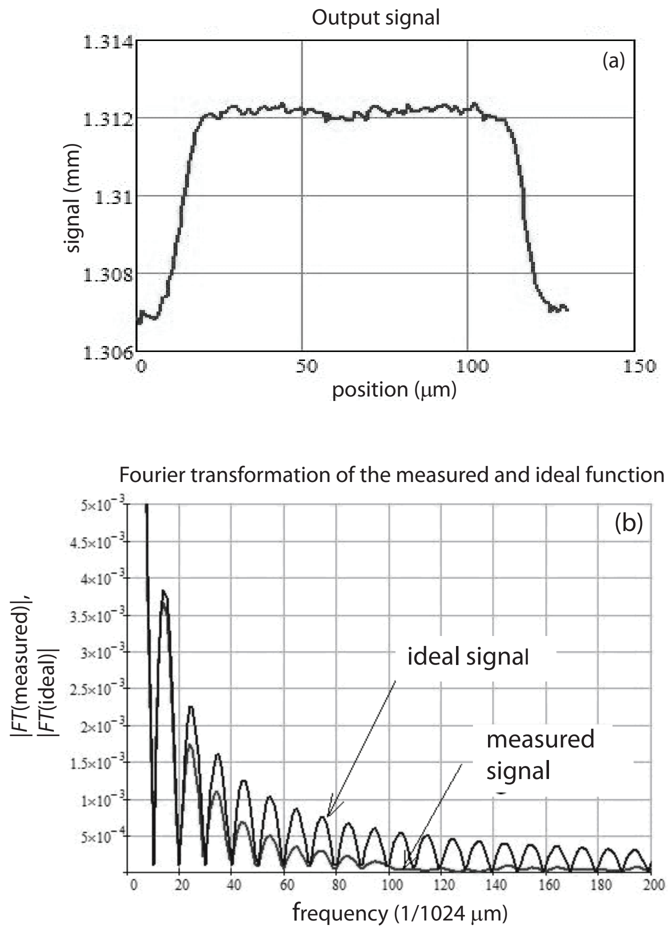

FIG. 5 (a) One step (half period) of the structure of 100 μm width measured using OCT. (b) Fourier transformation of the measured step function of 100 μm width (measured signal) and the ideal step function of 100 μm (ideal signal).

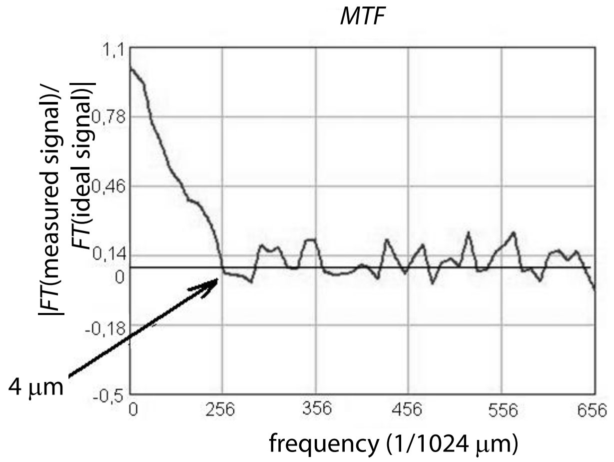

FIG. 6 Modulation transfer function.

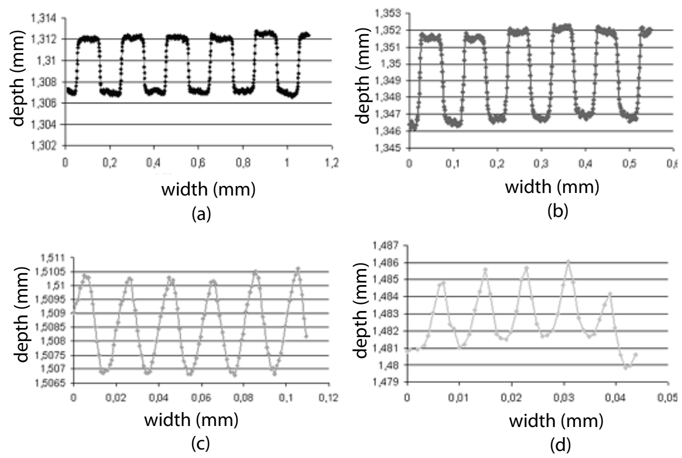

FIG. 7 Typical OCT results of measured structures: (a) 100 μm, (b) 50 μm, (c) 10 mm, and (d) 4 μm. Sampling is about 1 μm.

In frequency domain, the rectangular (one step function) is represented as a sinc(x) function (see Figure 5(b)).

According to the formula for MTF

$$MTF \equiv \left| \frac{FT(\text{measured signal})}{FT(\text{ideal signal})} \right|, \tag{1}$$

the calculated MTF is plotted in Figure 6.

The MTF function (see Figure 6) shows the total lost of contrast after about 0.25 line per mm or 4 μm what means that with our set-up it is possible to resolve the structures equal or bigger then 4 μm.

To prove it experimentally, we measured further all the structures from 600 μm to 1 μm (see Figures 7 and 8). The shape of the rectangular structures stars to smooth after approximately 50 μm what corresponds to 50% lost of the contrast (see Figures 7(b)–7(d)) The last detected structure was of the width of 4 μm (see Figure 7(d)). By the structure of 3 μm width no structures was detected.

The measurement results prove the theoretical calculated values for lateral resolution of the set-up of 4 μm.

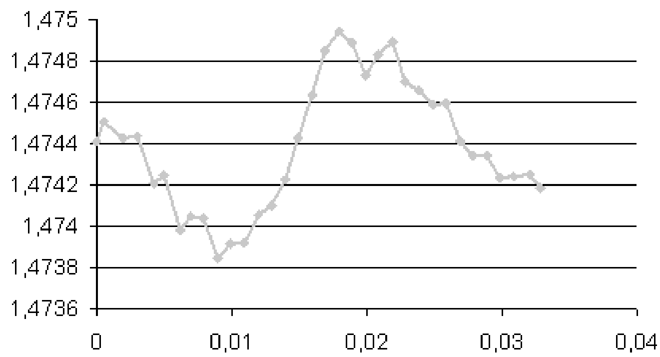

FIG. 8 Measured structure of 3 μm width. The measured distance is about 30 μm which means that about 5 structures of 3 μm width should be detected. No structures were detected because of limited resolution of the set-up.

3.2 Measurements of the sub-surface damages

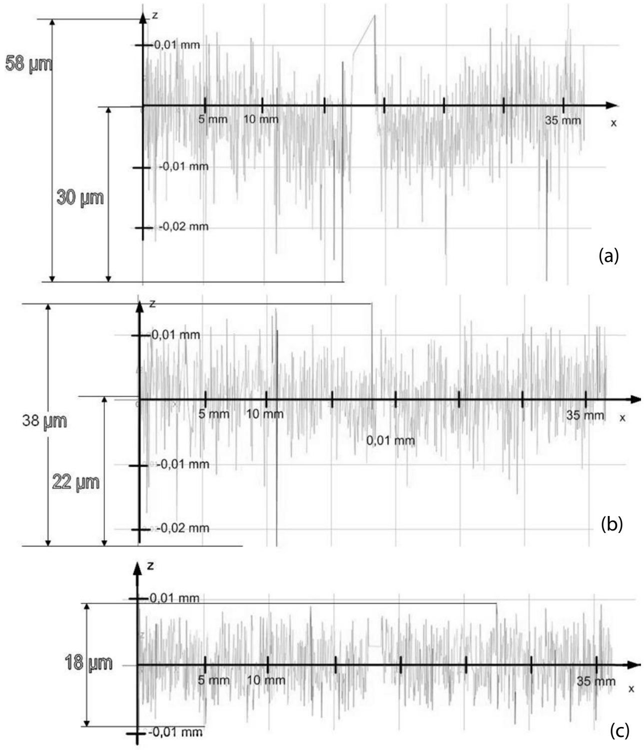

FIG. 9 Topography of surface grinded with (a) D91, (b) D46 and (c) D20. The lens was scanned across the center with the sampling of 1 μm, the peak in the center is due to no perfect geometric shape correction.

3.2.1 Glass S-BSL7

For the deterministic grinding process, there exists the "rule of thumb" [9] that predicts, depending on art of the glass, that the SSD for grinded lenses is approximately of the size of the grinded tool diamond. As a first step we used an "ALG 200 Asphero line grinder from Schneider" with 3 diamond tools (with the subsequent grain size of 20 μm, 45 μm and 91 μm) to produce 3 grinded samples (glass S-BSL7). The surface topography including vertical cracks is measured on all samples (see Figure 9). The results in Figure 9 obtained using OCT show a good agreement with expected values in manufacturing process.

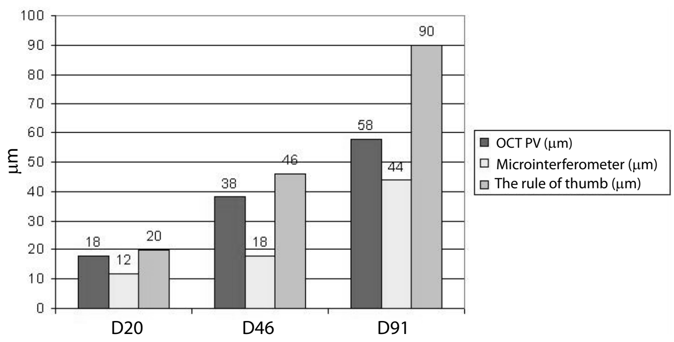

FIG. 10 Comparison of the results obtained using OCT and microinterferometer Zygo with the rule of thumb.

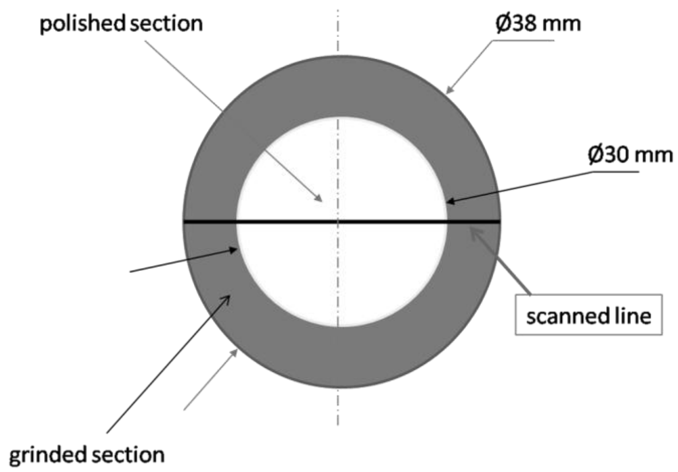

FIG. 11 Sketch of the polished procedure: each grinded sample was about 38 mm in diameter; 30 mm in diameter was removed with ABB 4400 robot; the lens was scanned across the center with the sampling of 1 μm.

Furthermore, we compared the results with existing metrology, like the Zygo NewView 200 [10]. The white light interferometer shows the lower values caused by insufficient reflection from the deeper material layers which results in lost points. While the OCT gets the signal back from all points and therefore deliver the complete information about SSD rough grinded surfaces.

According to the obtained results (see Figures 9 and 10), as the second step we polished the lenses in the middle (see Figure 11) removing about 40 μm of the material from samples that was grinded with D91 and D46 tools and about 20 μm from the D20 sample (see Figure 12).

As it could be seen from the results presented in Figure 12, no sub-surface damages were detected within the polishing surface for all samples.

3.2.2 Sapphire wafers

To prove the applicability of OCT in optimization of grinding process we tested 20 grinded sapphire samples obtained from the production. Each wafer has the same size and was produced on the same machine but with various grinding parameters.

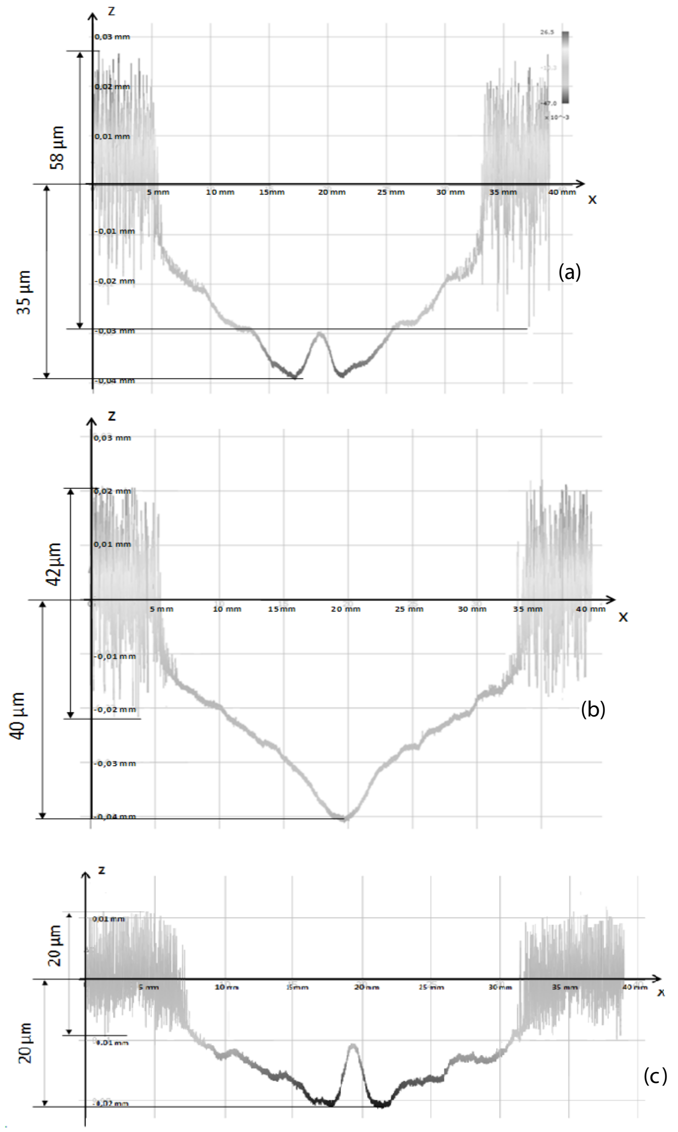

FIG. 12 Topography of surface grinded with (a) D91, (b) D46, (c) D20 with subsequent polishing section of 30 mm.

Using conventional methods it was not possible to detect the difference in topography between wafers, the roughness Ra is about 3.5 μm is similar for all wafers.

The measurement procedure was: to perform five scans of 2 mm length with 1 μm sampling along a radial line with equal spacing using OCT.

In Figure 13 some of the results are presented. As it is visible, OCT detect the vertical deep cracks for sample of the same roughness.

Compare the peak to valley values (see Figure 14), it is obvious that the difference comes from the existence of SSD.

4 CONCLUSION

The measurement results show that the optical coherence tomography (OCT) is a promising technique to perform measurements of grinded surfaces in respect to sub-surface dam-

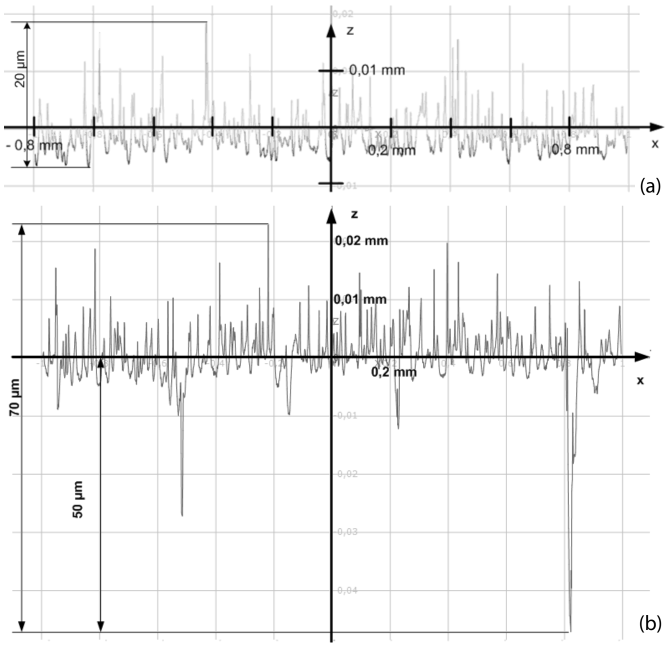

FIG. 13 Two examples of measured wafers (a) and (b).

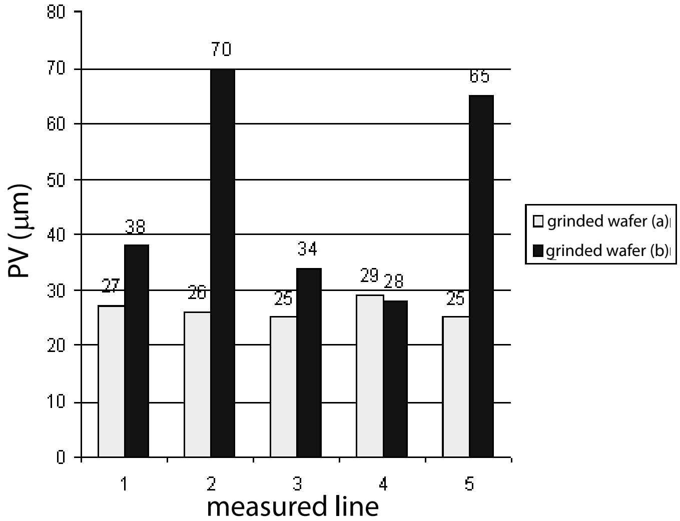

FIG. 14 Comparison of the results of wafer (a) and (b).

ages (SSD) which is a powerful tool to optimize the manufacturing process of the lenses itself.

ACKNOWLEDGEMENT

The work is supported by the Landesstiftung Baden-Württemberg foundation under the contract "Photon^N".

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