DETECTION OF SUBSURFACE DAMAGE IN OPTICAL TRANSPARENT MATERIALSS USING SHORT COHERENCE TOMOGRAPHY

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ABSTRACT

This paper describes the use of short coherence interferometry for the detection of subsurface damage (SSD) in optical transparent materials. The method is based on an interferometer using a light source with a short coherence length. A time domain (TD) and a frequency domain (FD) approach are explained. The OCT method allows a nondestructive measurement of the SSD compared to the state of the art SSD metrology, where the sample is destroyed. Compared to previous results [Ser10] a frequency domain (FD) setup is build up which allows SSD measurements under production environment conditions. The results of the FD set are presented and discussed.

1. INTRODUCTION

The generation of optical surfaces is often done by a grinding process. In brittle materials like glass, the grinding process can introduce cracks, spreading in the brittle material below the surface. These are called subsurface damage (SSD).

In Fig. 1 the process is sketched. Image 1 shows the unprocessed blank and image 2 the surface after grinding that contains small cracks spreading in the material. The depth of these cracks is related to the processing tools and parameters and determines the amount of material, which have to be removed during the subsequent polishing process.

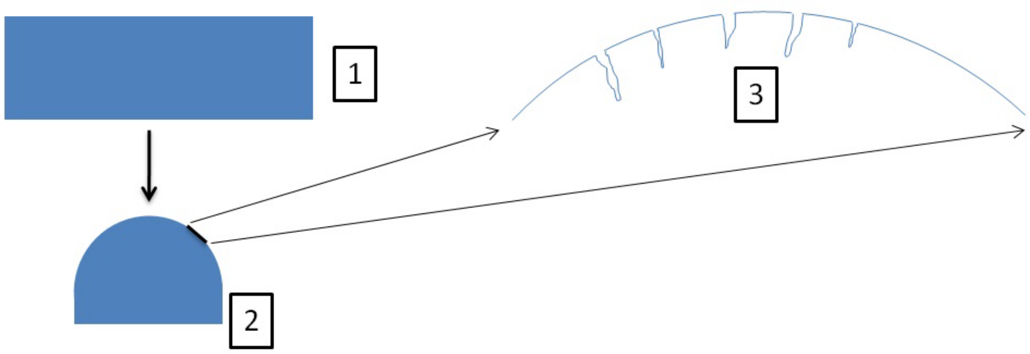

Fig. 1 Generation of an optical surface 1. Unprocessed blank, 2. Ground blank, 3. Cracks in surface (schematic) [Wi11]

To remove the material layer on the optical surface containing SSD the depth of these cracks needs to be detected. There are several destructive methods available that do a partial polishing of sample parts followed by an inspection of the partly polished surfaces. Another method uses corrosive liquids like the haloalkanes to etch down the surface stepwise, inspecting it afterwards. Due to the use of these chemical liquids, the operator itself has to be very careful in handling them.

A non-destructive approach is the use of short coherence interferometry. This technique is known as Optical Coherence Tomography (OCT) in clinical imaging [Bre05, chapter 12] [Dre08]. In this paper two different technologies for OCT are described: the time domain [Ser10] and the frequency domain approach.

2. TIME DOMAIN (TD) TECHNOLOGY

The TD technology is using a Michelson interferometer as sketched in Fig. 2.

For the TD measurement the light source (1), shown in Fig. 2, consists of a source with short spatial coherence, e.g. a superluminescence diode (SLD). The beam splitter (2) divides the light between the reference mirror (3) and the device under test (4). The reflected light from (3) and (4) interferes on the detector (5) when the optical path length of both arms L_R and L_T in Fig. 2 are equal. As long as the material is optical transparent the point of reflection (4) can lay inside the material.

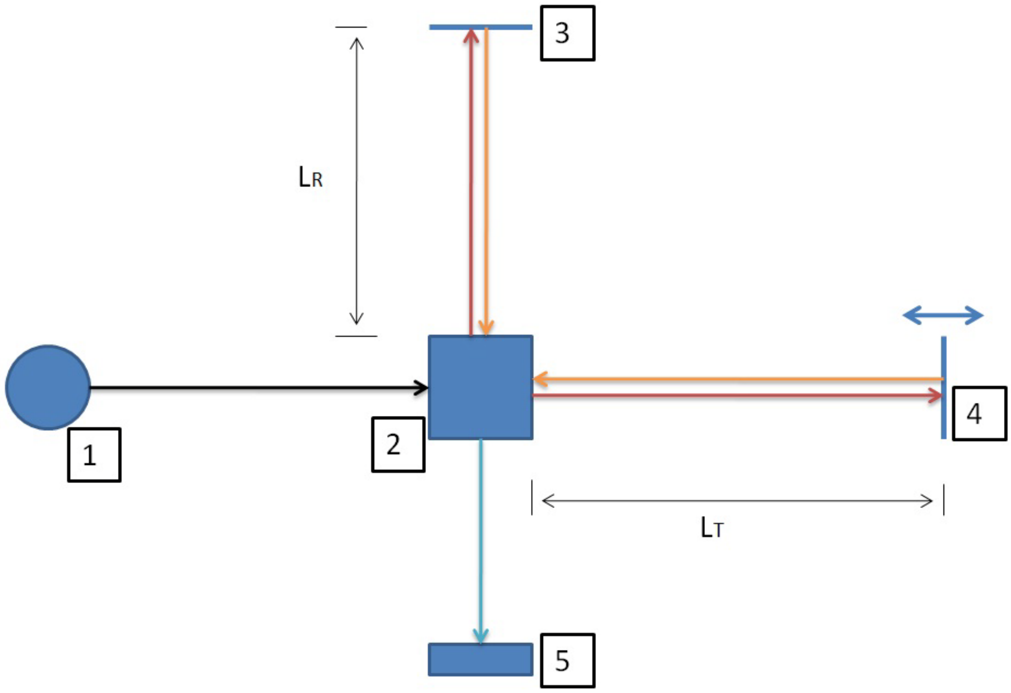

Fig. 2 Michelson interferometer, 1. Light source, 2. Beam splitter, 3. Reference mirror, 4. Device under test, 5. Detector [Wi11]

Changing L_R by moving (3) in a controlled way the detector signal from (5) can be assigned to a known position of (3) and therefore providing a “depth scan”. This provides information of different layers of reflective structures on a single point of the surface.

3. FREQUENCY DOMAIN (FD) TECHNOLOGY

As for the TD technology the FD technology is based on an interferometer. For the measurement the optical path lengths L_R and L_T are a little differing. The setup is sketched in Fig. 3. The point of equal optical path length is equal the focus of the lens (1). The reflected light from (5) and (6) interferes on the detector. The detector consists of a spectrometer that is able to detect the amount of interference in relation to the wavelength.

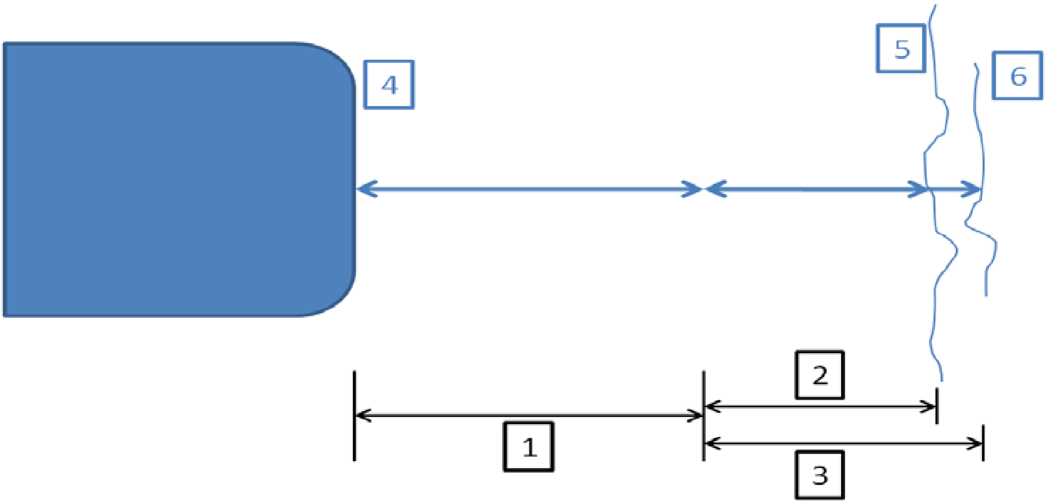

Fig. 3 FD setup; 1. Focus of lens, 2. Distance to surface, 3. Distance to SSD, 4. Interferometer, 5. Surface of lens, 6. Crack inside material. [Wi11]

Depending on the position of the reflective structures (2) and (3) the spectrum of the light source is modulated with a distance-dependent frequency onto the light source spectrum. The depth's information can be immediately calculated by a Fourier-transformation from the acquired spectrum, without movement of the reference arm [Sch99].

4. MEASUREMENT

To practically evaluate the accuracy of both technologies a reference measurement of a known structure was done. The type of structure is shown by Fig. 4 and consists of a rectangular shape with a spacing of 40µm and a depth of 5 µm. The measurement was obtained using a Zygo NewView microinterferometer.

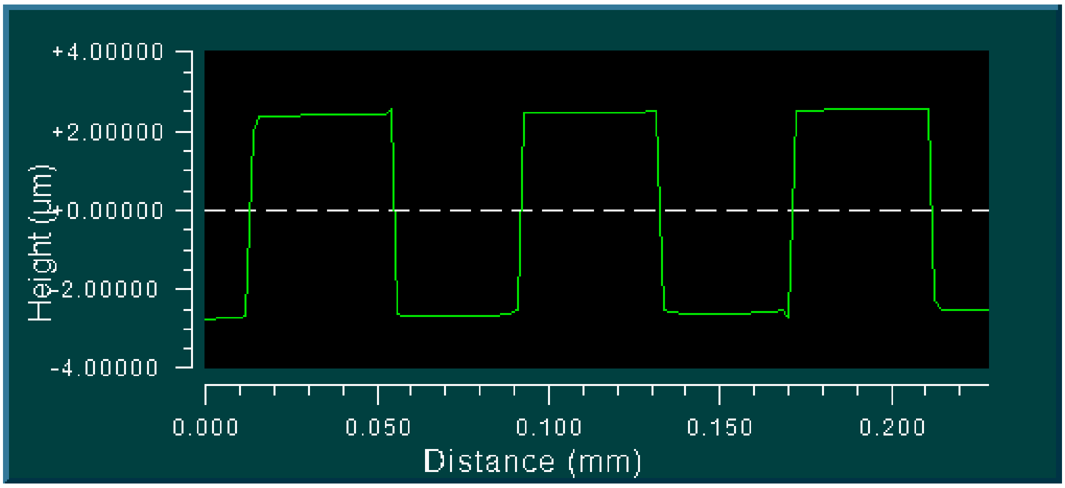

Fig. 4 structures on reference waver with 40µm width [Wi11]

The measurement results of the TD technology is shown in Fig. 5, top, and of the FD technology in Fig. 5, bottom.

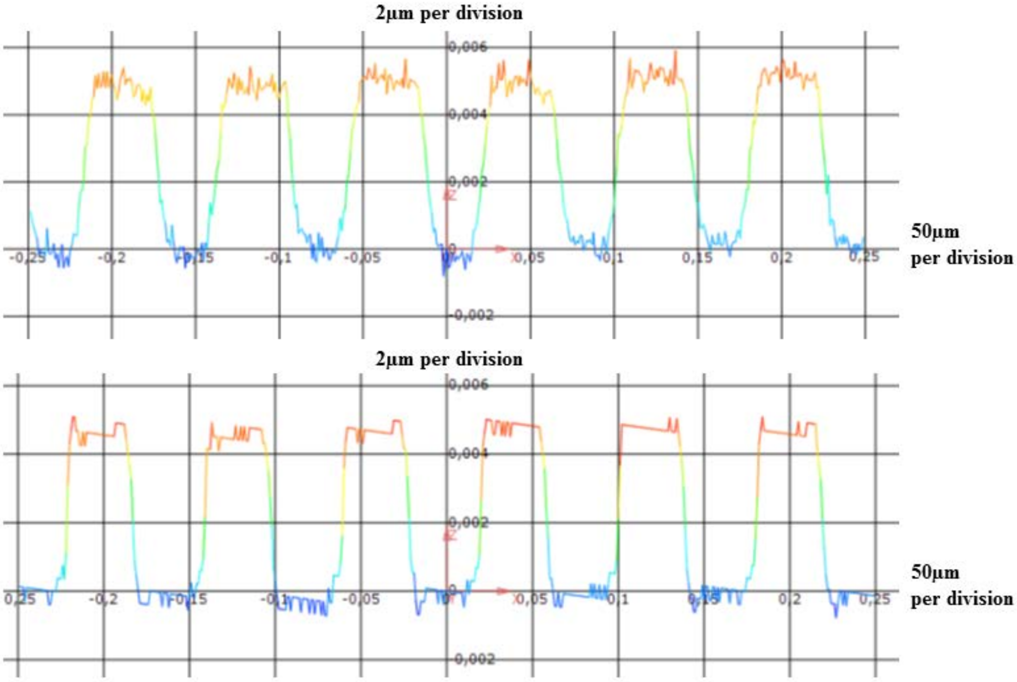

Fig. 5 measurement of reference structure with 40µm width and 5µm height, top: TD measurement, bottom: FD measurement [Wi11]

As shown in Fig. 5, the Reference Structure can be reproduced. Due to the evaluation process of both methods, the results of the Time Domain technology contain analog noise, which can be clearly seen in the results. The Frequency Domain technology on the other hand only has digital noise, which originates from the resolution of the spectrometer itself.

4.1 Axial resolution

To determine the axial resolution a flat reference made of silicon with a surface irregularity of 50,6nm measured from lowest to highest point (peak to valley, pv). A measurement of that surface is shown in Fig. 6, left side, using the Zygo NewView microinterferometer. The slice in Fig. 6 right side, demonstrates the high quality of that surface with about 2nm pv of irregularities.

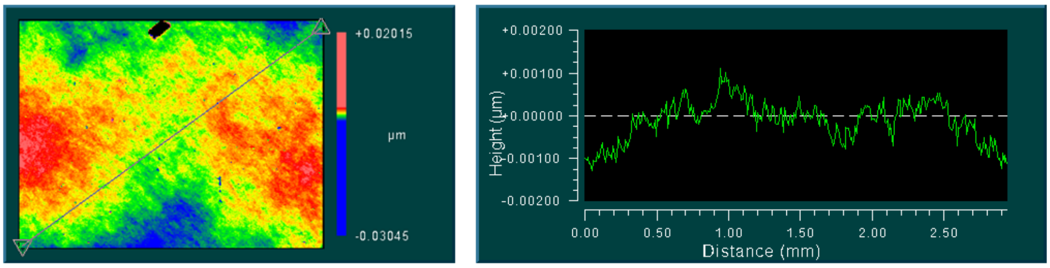

Fig. 6 flat reference surface to measure the axial resolution

Using this reference flat a measurement was done with the TD as well as the FD technology. A slice with a length of about 100µm was measured.

The result of the TD technology can be seen in the upper part of Fig. 7. The graph shows a deviation of about 1.51µm pv. Because the quality of the reference surface is much higher it can be assumed that this shows the analog noise present in the TD technology. The same amount of noise can be seen in the measurement of the reference structure in the upper part of Fig. 5.

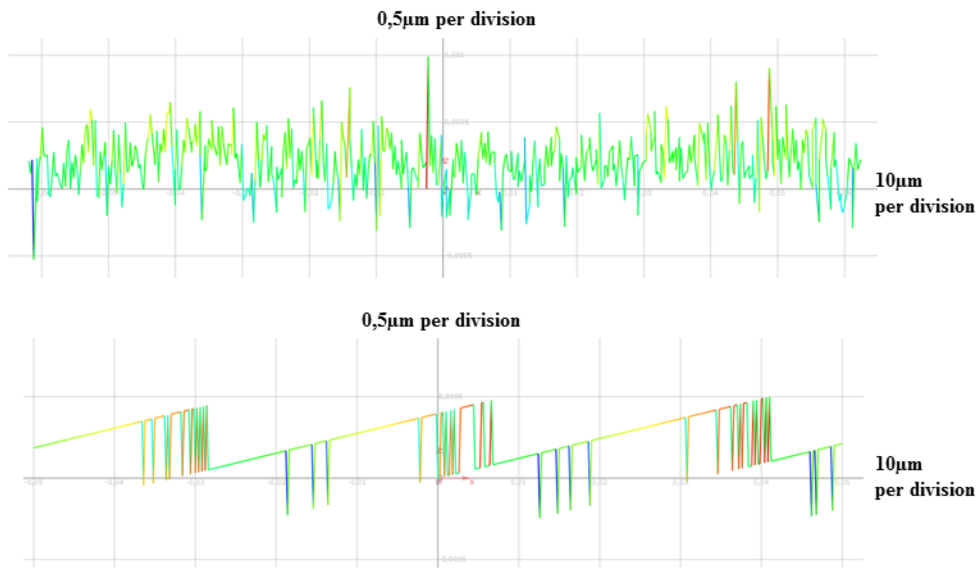

Fig. 7 Fig. 5 measurement of flat surface of 50,6nm pv, top: TD measurement, bottom: FD measurement [Wi11]

The measurement with the FD technology is shown in the lower part of Fig. 7. It shows a different structure with a deviation of about 0.74µm pv originating from the resolution of spectrometer. The same structure is present in the lower part of Fig. 5.

Both measurements show the limitation of the axial resolution of the technology which lies in the range of 1µm for the FD and about 2µm for the TD technology.

4.2 Measurement of SSD

To verify the measurement of SSD using the OCT a reproducible reference is needed. Therefore a ground surface was used that was partly polished with a wedge.

Fig. 8, right side, shows a tactile measurement with the UPMC 550 CARAT from Zeiss. The right part of the surface shows a polished wedge with a maximum depth of about 60µm on the right side. The left side of the surface up to the center is not polished. The tactile measurement shows an almost flat surface in that region.

The left side of Fig. 8 shows an OCT measurement using the TD technology. The wedge starting from the center of the surface to the right is clearly visible and similar to the tactile measurement. In contrast to that the right side of the OCT measurement shows a lot more variation with an amplitude of about 30µm pv. In addition to the roughness of the ground surface spikes can be seen ranging from 0µm down to -18µm on the y-axis marked by the yellow area. This spikes are SSD that is detected by the OCT.

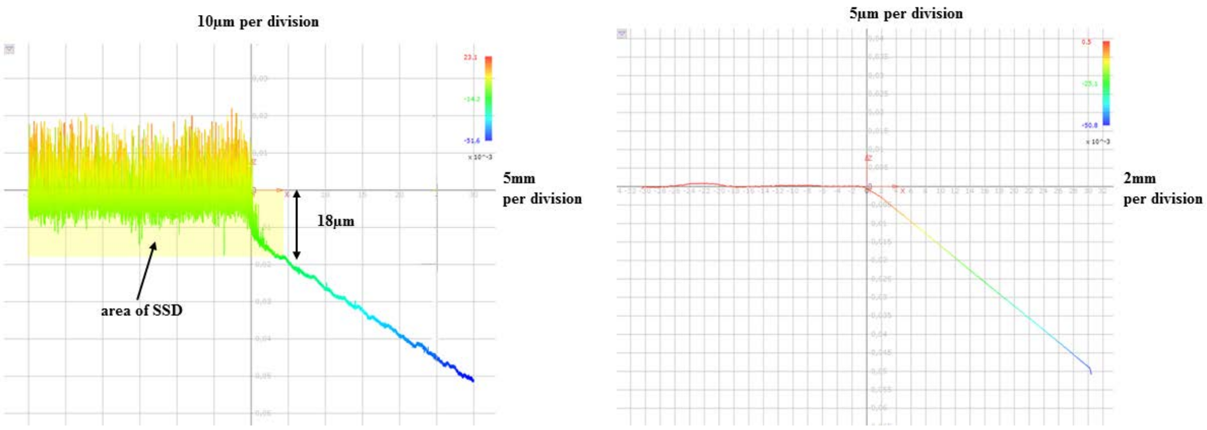

Fig. 8 ground surface, partly polished for detection of SSD, left: measurement with TD technology, right: tactile measurement

In addition to the OCT measurement the SSD were analyzed optically on the wedge of the polished part. The measurement results of both technologies correlate with each other.

Fig. 9 shows the FD OCT measurement of a flat ground optic consisting of zerodur. The measurement shows, that SSD can be seen within the results, having a depth of approximately 16µm.

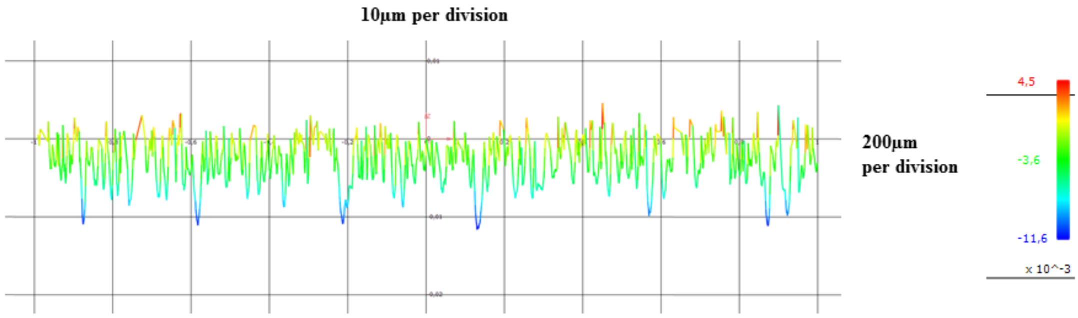

Fig. 9 measurement of ground surface

To show the capabilities of the FD OCT on rough surfaces a measurement of sawed raw flat glass optic prior to the grinding process was done. Fig. 10 shows a measurement of such a BK7 lens, which has deviation of 38.3µm pv.

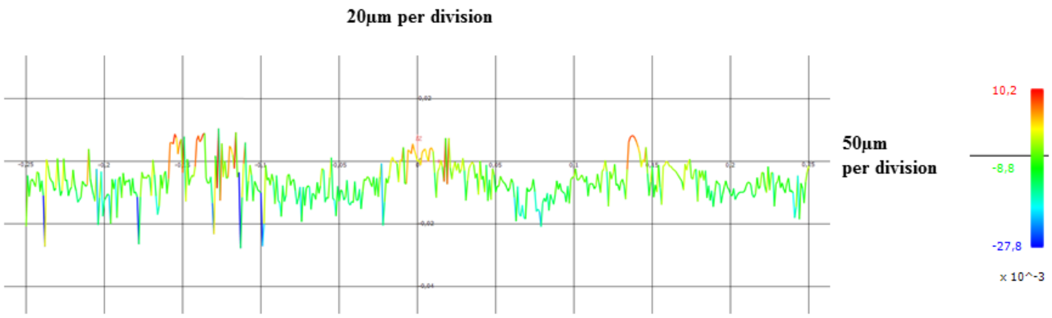

Fig. 10 measurement of a sawn surface

The sharp spikes down to below -20µm on the y-axis again are SSD e.g. at x=-0.1mm. This measurement shows that SSD can be detected even on raw surfaces.

5. DISCUSSION

The results of the OCT measurement of a flat reference surface show a limited axial resolution of about 2µm for the TD technology and 1µm for the FD technology. Both technologies have shown the ability to detect SSD in optical transparent materials. The results of both technologies correlate with each other, the correlation of the TD technology with results obtained by different methods is shown in [Ser10]. Therefore both technologies, TD and FD, can be used to detect SSD.

6. CONCLUSION

For the measurement of subsurface damage in brittle materials the nondestructive technique of Optical coherence Tomography was investigated. Two different techniques where examined and found to deliver comparable results that correlate with existing measurements. The measurement of polished as well as raw surfaces is possible enabling the control of SSD even on rough surfaces.

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