Impact analysis of temperature and humidity effects on polishing

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Abstract. The polishing process for optical glass is one with intertwined chemical and mechanical processes. The aim of the present study is to verify whether control of these factors can be used to improve the efficiency of the polishing process.

1 Introduction

The polishing of optical components is a complex process that usually takes place at the end of the value chain. At this point, a large part of the value creation has already taken place, so errors and possible defects have a large effect in the yield.

During polishing, the following target requirements are claimed for the final component [1]: Generation of optical functional surfaces with low roughness and without defects and homogenization of the surface (protection against chemical attacks and deposits of dust, dirt, ...).

The polishing process is understood as the coupled sequence of mechanical and chemical processes and is subject of more than 20 influencing factors which also can interact together. Chemical processes in particular are temperature-dependent and can be exotherm or endotherm. They depend mainly on temperature and on reaction specific constants (diffusion rate, adsorption rate and speed of reaction) [1]. For this reason, temperature experiments are topic of this publication. Mechanical tests (scratch tests) were carried out with varying lens temperature and relative humidity (RH) of the air. Temperature sensors were integrated into the polishing slurry and the polishing slurry was adjusted to a certain temperature range. The parameters for pH-value and density were tested manually. These experiments are to be seen as an experimental case study on applying in-process measurement equipment. The long-term goal is a sensor monitoring of the polishing process. This paper shows an application of integrated sensor technology and first preliminary results.

2 Methods

Two test series were performed. First, scratch tests were carried out on the glass material N-SF56, followed by polishing tests with two glass materials (N-SF56 and N-BK7).

For the scratch test, glass samples were heated up to approximately 250 °C. After heating up, the sample temperature was controlled via IR-camera. At certain temperatures a scratch was introduced via diamond scribe. To control the surface quality of the scribe, it was evaluated by microscope before and after the test. RH during the scratch tests was measured with a digital humidity sensor at the site of scratch application.

In order to keep the scratch tests constant in terms of feed rate and contact pressure, they were carried out on a milling machine. A constant feed rate was set on the milling machine as well as a constant distance to the glass surface. The contact pressure was achieved by pressing the diamond tip against the glass surface with a defined travelling distance. Constant contact pressure was achieved by using a dial gauge stand, as this can compensate for small, machine- and glass-related inaccuracies in the height which can lead to small variations in the distance between glass surface and diamond tip in the steady state before the beginning of the experiment. The prestress of the spring in the dial gauge allows the compensation of small variations (see Fig. 1).

Fig. 1. Photograph of the diamond scribe before an experiment. The use of a dial gauge stand allows to compensate small heigh variations of the glass surface and achieves a constant pressure by a prestressing of the feather.

The polishing tests were carried out with different temperatures of the polishing slurry on a Struers Tegram 21 polishing machine. The following parameters were used for the experiments: velocity (tool and glass): 150 RPM, contact pressure: 30 N, polishing pad: LP-66, polishing slurry: Opaline PZ500, polishing time: 10 min.

The slurry itself was taken from the running process. The temperature was adjusted and measured during the running process. Since the temperature of the polishing slurry can only be adjusted within a limited range, two temperature intervals were selected: 10…20 °C and 65…75 °C. pH and density of the polishing slurry as relevant chemical and mechanical parameters were checked before starting the polishing process. The density is measured with an electronic measuring device with temperature compensation, a measurement with a

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conventional hydrometer is not possible for this application. Decrease of pH with increasing temperature is in good accordance with the literature [2]. The values are 8.61 and 1.017 g/cm³ for 10…25 °C and 8.35 and 1.027 g/cm³ for 65…75 °C.

To avoid falsification due to deposits, the lenses were cleaned before and after polishing using ultrasonic cleaning and acetone. During the low temperature experiments, care was taken to ensure that no layers of condensed water remained on the glass surface. The same temperature of all process components was achieved by heating up/ cooling down all components in the polishing process. The specific design of the polishing machine allows simultaneous processing of four lenses. Therefore, two glass materials were processed simultaneously for this experiment, each with two samples. This circumstance was considered in the calculation of statistical characteristic values.

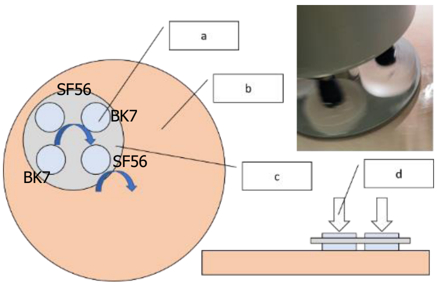

Fig. 2. Sketch and photograph of the polishing experiment. The components are (a) glass lens, (b) polishing pad, (c) lens holder and (d) force. The lens diameter is 40 mm. Polishing slurry is constantly fed to the polishing pad.

3 Results and Discussion

3.1 Results of scratch tests

The scratches were measured using a white light interferometer (WLI Zygo NewView 7200) after the experiment was completed. The evaluation is then carried out over the entire image window with regard to average scratch width, maximum scratch depth and average depth of the scratches. The automated evaluation of the scratches allows a user-independent and objective appraisal of the scratches. The following figures show the evaluation of the scratch experiments.

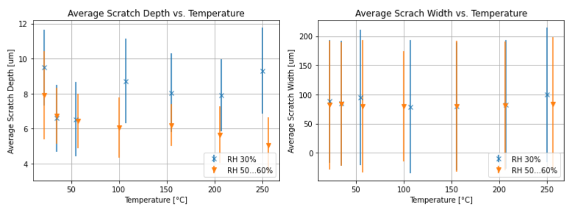

Fig. 3. Average scratch depth for both glass samples at different relative humidity (left side) and maximum scratch width for both glass samples at different relative humidity (right side)

3.2 Results of polishing tests

The polishing tests are evaluated by means of the material removal rate (MRR) in µm/min and the roughness R_a in nm. For the calculation of the MRR the weight of a lens is measured before and after the polishing experiments. By the calculation of the weight difference and by knowledge of the glass specific density and the diameter, the volume change and therefore the height change can be calculated. The density of N-BK7 is 2.51 g/cm³, the density of N-SF56 is 3.28 g/cm³. In the evaluation, the mean value is used for the calculation of the values. Also the standard deviation is calculated as basis for the calculation of the error of the measurements. The following pictures show the results of the polishing tests. The measurement of the roughness is again done by WLI.

Due to the large scatter of the measured values, the median is used in the following figures (see Fig. 4).

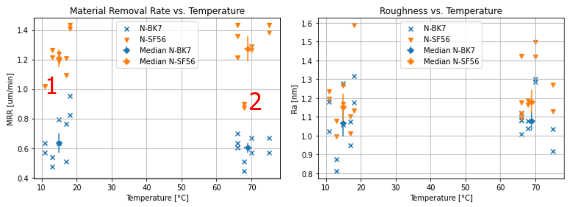

Fig. 4. MRR as function of the temperature for five tests with N-BK7 and N-SF56. The number of datapoints is 10 for each temperature range and glass type, sometimes datapoints overlap (e. g. point 1 or point 2) (left side) and roughness R_a as function of the temperature of the polishing slurry. (right side)

3.3 Discussion of scratch tests

An evaluation of the results shows no strong and unequivocal dependencies, just trends. In Fig. 3, the average scratch depth seems to increase slightly at higher temperatures in the case of a low RH. For a higher RH there seems to be a trend for the mean values that the average scratch depth seems to decrease. This trend seems to be supported by the maximum scratch depth. Nevertheless, it is difficult to interpret the values due to the large standard deviation. In fact, the temperature seems to have no effect on the scratch width with the present test setup. In general, it can also be said that the tests at higher humidity lead to a lower scratch depth, while the scratch width seems not to change.

This effect cannot be explained by wear of the diamond tip. The tests at 25 and 35°C were carried out before and after the application of several scratches on both glasses. The glasses were processed in the following order: Scratch at room temperature (~25 °C), scratch at ~250 °C, scratch at ~200 °C, scratch ~150 °C, scratch at ~100 °C, scratch at ~50 °C and scratch at ~35 °C

This listing shows that the varying scratch depth is not due to the glass cutter. If the cutter is worn, a lower scratch depth and a higher scratch width with increasing wear must be assumed. This is not the case.

Nevertheless, the temperature treatment seems to have caused effects of the material. The second scratch test at approximately room temperature (~35 °C) tends to show a lower scratch depth.

3.4 Results of polishing tests

The evaluation of the polishing tests also shows high scatter in MRR and Ra. Even with the same materials and the same test parameters in the identical test sequence, considerable scatter can be seen in some cases (see Fig. 4). This can be seen exemplary with glass grade N-SF56 at 66°C. Two tests were carried out at 66 °C. In one test, both material removal rates overlap (1.2 µm/min), in another test the removal rates are approx. 1.35 and 1.45 µm/min. Due to the large scatter the following statements are not based exclusively on the consideration of mean values, but in addition on the consideration of the cloud of points and the variance.

Nevertheless, some general striking features of the graphs should be noted. A certain increase of the mean values and the single points of the material removal rate seems to be present for the glass material N-SF56 at higher temperatures as compared to lower temperatures. This behaviour has also been observed by [2]. Also, the harder glass material N-BK7 does not seem to show this trend of an increasing MRR. Deleting the largest outlier, one can assume a reduction in the size of the point cloud at higher temperatures. The roughness scatters within 0,8 nm < Ra < 1,6 nm. It is striking that the lowest roughness values for both materials are gained at the lower temperatures. Nevertheless, this effect basically fits with literary data observing lower roughness at lower temperatures [4]. In general, roughness changes little at either temperature.

These effects may be explained by mechanical or chemical changes in the polishing suspension. In addition, it is known that the mechanical properties of the polishing pad also change as a function of temperature [3]. In particular, the different behaviour of the two glasses is striking. Both glasses have nearly the same resistance against alkaline attack (2.3 for N-BK7 and 2.2 for N-SF56), but N-SF56 is much softer than N-BK7. The Knoop hardness is 610 for N-BK7 and 380 for N-SF56 (values from SCHOTT Datasheet collection, 09.2021) This could be a solution for this behaviour as well as a possible changing of the pad properties due to the different temperature.

The above explanations can help to understand the effects shown. However, further investigations are required to verify these effects unambiguously.

4 Conclusion

As mentioned before, this paper shows first preliminary results for the use of sensors in the polishing process and controlling parameters of the polishing process. The performance of further tests is required and will be part of further research.

The approach is partly based on the concept of Advanced Process Control (APC) from the semiconductor industry, but must be possible at significantly lower cost and with significantly less effort in a flexible manner in order to meet the specific requirements of the optics industry (many medium-sized companies with in part highly specialized processes and machinery).

The results obtained so far show that some dependence of the removal rate on the suspension temperature cannot be ruled out and it works for a conventional polishing process on a plane polishing machine. A disadvantage is the high effort required for the temperature control of the polishing suspension. For this reason, direct control of the temperature of the polishing pad by means of an electronic circuit developed for this purpose is being sought for further trials. This will also change the mechanical properties of the polishing pad, especially with regard to wear. For this purpose, ideal points will have to be determined with regard to pad wear, MRR and surface roughness. This approach also provides the possibility of integrating specific sensors within the polishing pad and to determine e. g. vibrations and temperature distribution within the polishing tool. For further experiments a more elaborate measurement of the roughness will be carried out, especially the use of a greater number of measuring points and a filter [5].

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