Optimisation of polishing processes by using iTIRM for in-situ monitoring of surface quality

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ABSTRACT

The possibilities of iTIRM, an in-process surface measurement tool, are explored in this research. Experiments are done to test the applicability for qualifying and optimising finishing processes for optical surfaces. Several optical glasses, different polishing agents and ductile grinding are included in these experiments. It is concluded that iTIRM can be used for both mentioned applications but that it is, at least for now, an R&D tool only and not applicable in production.

Keywords: surface measurement, in-process measurement, polishing, ductile grinding

1. INTRODUCTION

iTIRM [1] is a measurement tool that makes it possible to analyse the surface quality of a precision optics workpiece during polishing. It makes use of the principle of internal reflection and the scattering of light at all non-ideal surfaces. Since iTIRM can be used in-process it is possible to qualify and compare different polishing processes even if the resulting surfaces are identical [2]. To explore the possibilities of this qualification system experiments will be done with different polishing processes with predictable outcome. Polishing costs and planning in the optical workshop could be greatly increased if one could, for example, accurately qualify the "polishability" of different glasses [3]. The physical properties, like hardness, of these glasses can be used to verify the outcome of the experiments.

Another possible application of iTIRM is the optimisation of surface finishing processes. To this aim, one can monitor a steady state polishing process and at a certain point in time change a parameter like the type of polishing agent, pH-value, etc. As the process monitoring continues one can see if the surface quality has changed for worse or for better. Multiple experiments like this result in an optimal value for the parameter in question.

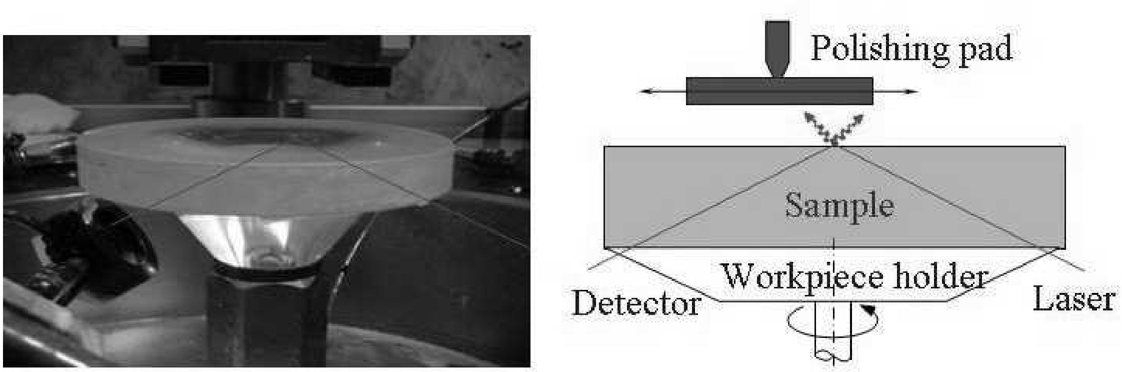
The two applications mentioned above could make iTIRM a powerful tool for optical workshop research. Without replacing existing qualifying techniques like microscopy or white light interferometry, which have their own advantages, it could add the aspect of being able to measure in-process.

2. MEASUREMENT SETUP AND MEASURING PROCEDURE

As stated above, iTIRM uses internal reflection and scattering to analyse an optical surface. A full description of the iTIRM measurement principle is given by Faehnle et al. [1]. The measurement setup used for this research is shown in Figure 1. Basically, a standard polishing machine is used. Functioning as workpiece holder, a quartz conical frustum is mounted on the polishing spindle. The different workpieces (samples) are plan parallel glass discs that are brought into optical contact with the workpiece holder. A HeNe laser is used as a light source. The sufficiently collimated beam enters the workpiece holder and subsequently the glass sample under an angle that allows for internal reflection. The iTIRM detector catches the beam, which is now attenuated because of scattering at the surface being processed, after it leaves the workpiece holder.

For the purpose of analysing the measurement data a Newport 2832-C power meter, a personal computer and a LabVIEW programme are used. The LabVIEW programme is programmed in such a way that it collects data during a user-defined time interval, after which the maximum, the minimum and the average value for the laser beam intensity are calculated. These values are stored in an array. The values shown in this paper are the average values. It was found that these give the best representation of the experiments as there tend to be erratic data points that can be filtered out by averaging.

The measurement setup as described above was calibrated before carrying out the experiments to test the consistency of



(a) (b)

Figure 1: A picture (a) of the iTIRM setup and a drawn cross section in the plane of the laser beam (b).

the measurements. One of the experiment glass samples, SCHOTT PSK53, both sides polished, was monitored on the turning spindle without being polished. This was done once with the clean PSK53 surface and once with a “pool” of polishing agent on the glass surface. The results are shown in Figure 2. The fact that the second curve is clearly lower than the first one is explained by the fact that the construction of the setup causes the laser beam to be practically on the angle of total reflection in the case of a glass-water transition, accounting for more losses than the glass-air transition.

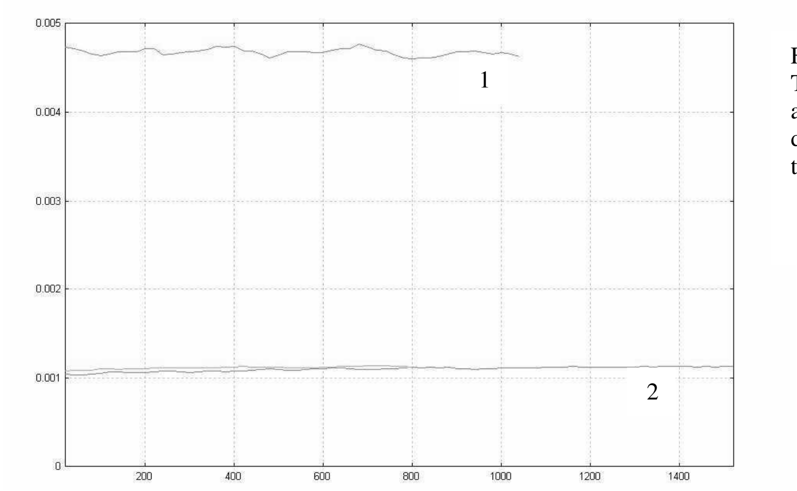


Figure 2: Calibration of the measurement setup. This was carried out without polishing agent (1) and with polishing agent (2). Vertical axis: detected power in W. Horizontal axes: elapsed time in s.

3. EXPERIMENTS

In the course of this research, iTIRM applicability experiments were done as well as process optimisation experiments. Both are covered separately below.

3.1 Applicability experiments

The first experiment carried out in this context compares two polishing processes with different loads. In both cases Gugolz pitch and 10% water based Cerium Oxide polishing slurry are used to polish a ground BK7 surface. The machine is set at the same rotation and oscillation speed, the only difference being that polishing loads of 1 kg and 4 kg, respectively, are used. Figure 3 shows the measurement results.

The typical pattern of a polishing process monitored with iTIRM can be seen in Figure 3. At a certain point in time, the power value reaches a plateau, indicating that the surface is fully polished. It can be seen that the 4 kg curve reaches this plateau faster than the 1 kg curve as is to be expected and that both plateaus are of the same height, i.e. of the same surface quality.

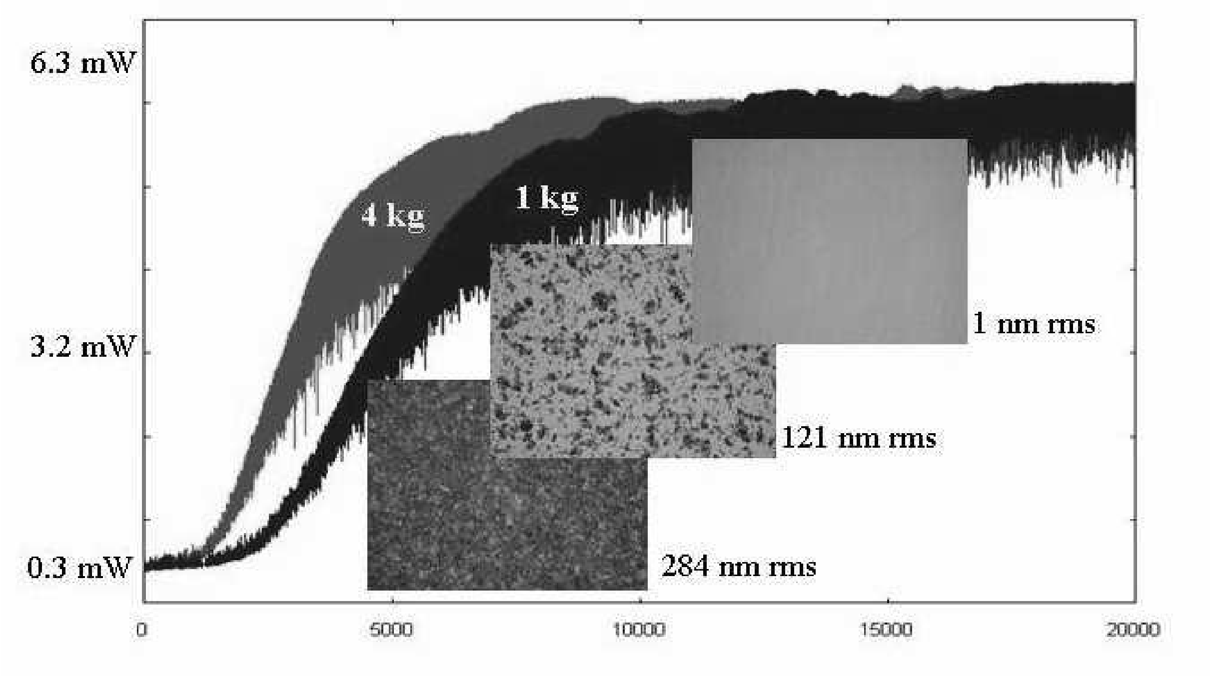


Figure 3: Polishing of a ground BK7 surface with different polishing loads of 1 kg and 4 kg. Vertical axis: iTIRM power of laser beam in mW. Horizontal axis: polishing time in seconds. Inserted in the diagram are Nomarski microscopy images of the surface in different phases of the process with their respective roughness.

The second applicability experiment concentrates on the difference in time needed to polish optical glasses with differing hardness. Three optical glasses with a clear difference in hardness, SCHOTT SF6, PSK53 and N-LASF31, are identically ground with 800# SiC abrasive. The glass surfaces are then polished whilst being monitored, the results of which can be seen in Figure 4. The polishing conditions are the same as those for the experiment described above with identical loads of 2 kg. It can be seen that the polishing times differ considerably for the different glasses. SF6 is polished in 90 minutes time, PSK53 takes 150 minutes and for N-LASF31 more than 450 minutes are needed. The glasses have a respective Knoop hardness of 370, 440 and 770. As expected, harder glasses take longer to polish.

3.2 Optimisation experiments

To optimise a surface finishing process, one can try out different polishing agents and compare the results. When the measuring is done in-process it can be seen how long it takes for a change of polishing agent to result in a change in surface quality. This is done for four different optical glasses: the three used in the last experiment plus SCHOTT LAFN21. The results are shown in Figure 5. Two Cerium Oxide-based polishing agents from different manufacturers were used which will be called ‘A’ and ‘B’ from here on. A stable polishing process using polishing agent A is maintained up until the vertical line in the diagrams. From that point, polishing agent B is used. It can be seen that for three of the four different glasses an improvement in surface quality is observed. Only LAFN21 shows neither improvement, nor degradation, of the surface quality. In that case it can be seen, however, that the measurement data are more scattered after changing slurries. This could be explained by a slight difference of refractive index between the polishing agents, effecting the (total) reflection of the laser beam.

In the final experiment it is tried to achieve a considerable improvement in polishing time by using a combination of ductile grinding [4] and polishing as surface finish instead of just polishing. Diagram 4c is taken as reference. 10% water based Cerium Oxide slurry was used to get the results observed there. The data of Figure 4c are copied in Figure 6. The second data set is produced by starting the surface finish (on an identically ground N-LASF31 surface) with a water based 1% 3µm diamond slurry under otherwise identical conditions until a plateau is reached. The last step towards a polished surface is done with the same polishing slurry as in the first case. Figure 6 indicates that the latter surface finish takes about 85 minutes. This is a significant improvement over the “old” one which takes over 450 minutes as shown in subsection 3.1.

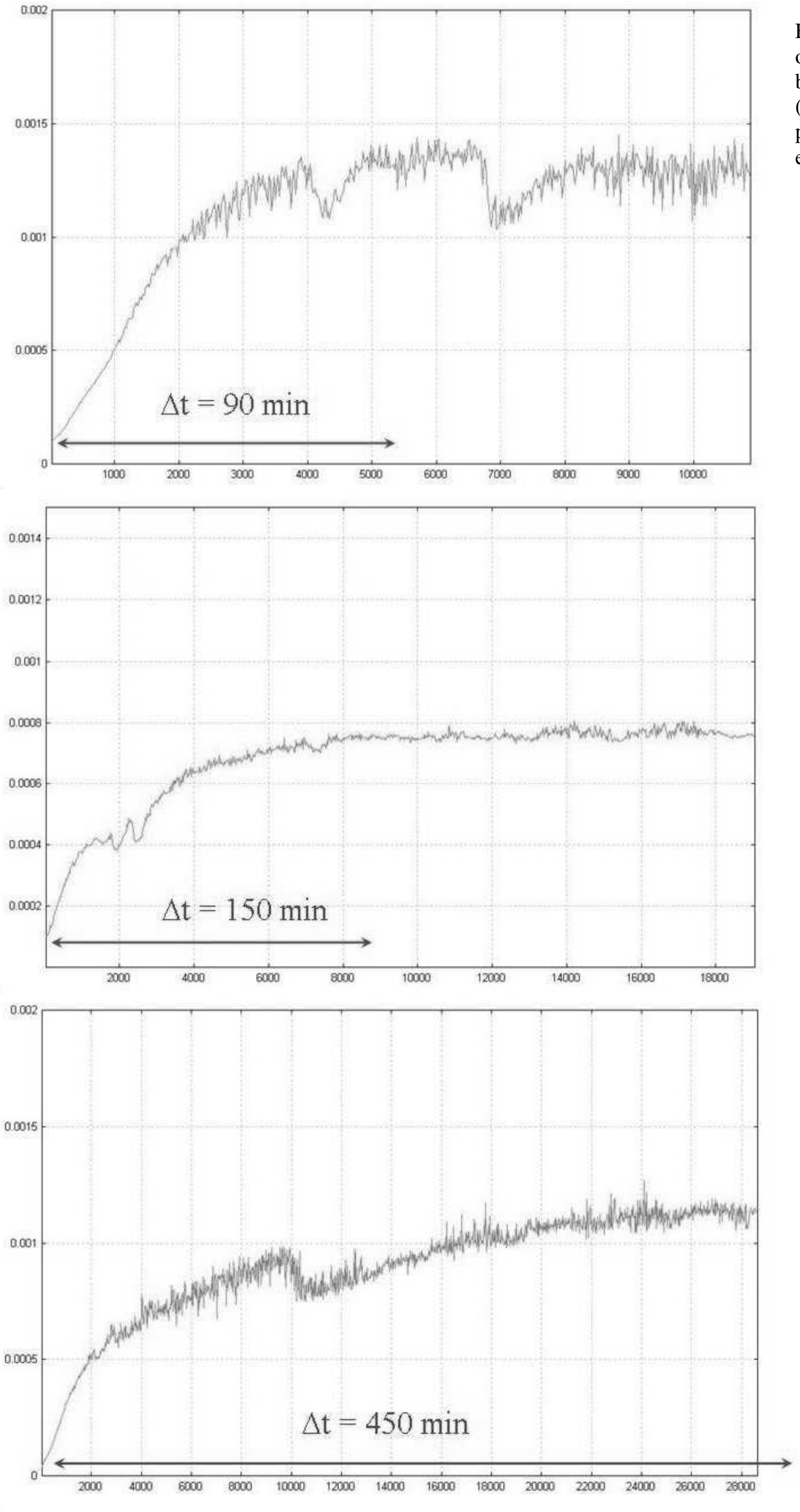


Figure 4: polishing different optical glasses. From top to bottom: (a) SF6, (b) PSK53 and (c) N-LASF31. Vertical axis: power in W. Horizontal axis: elapsed time in seconds.

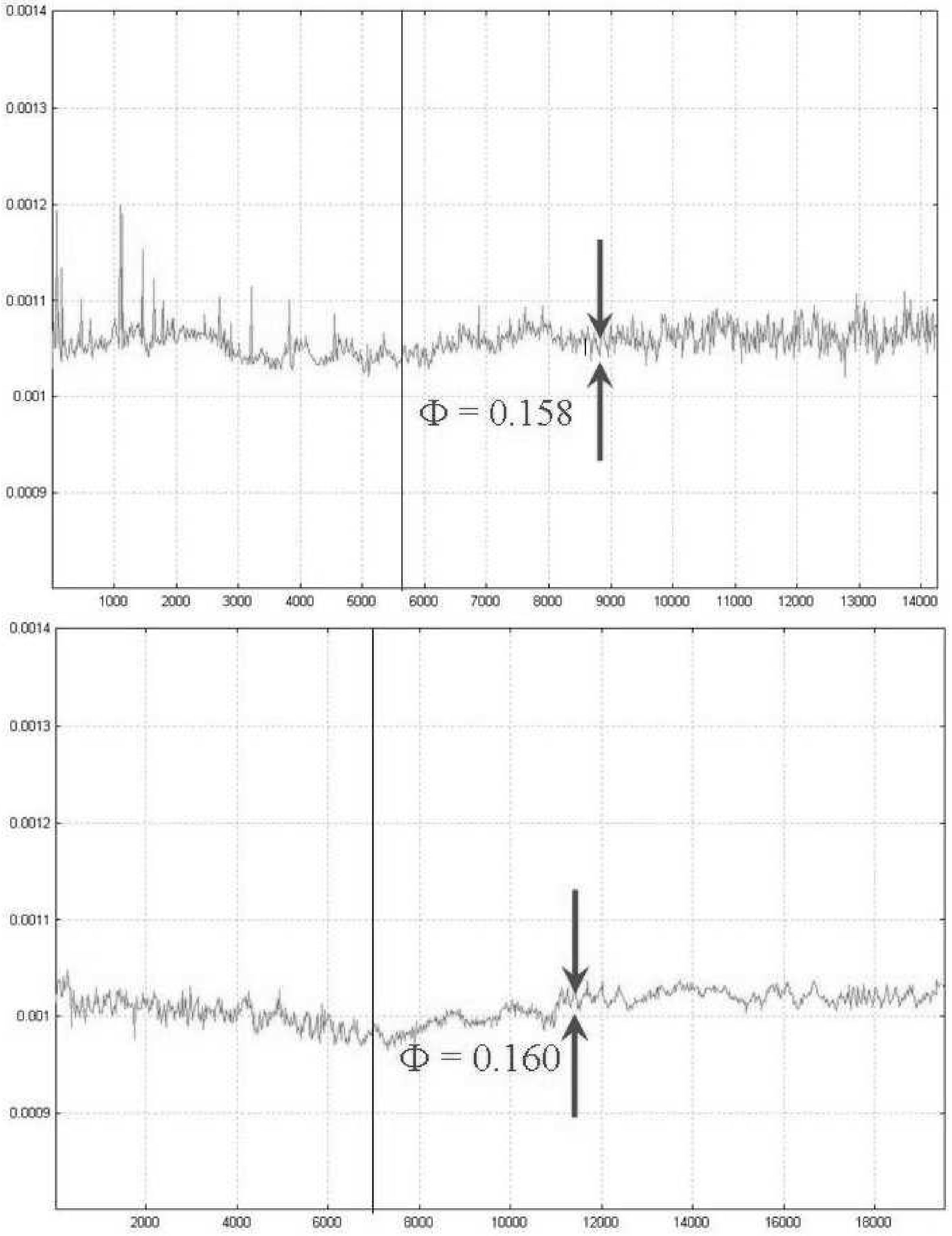


Figure 5a (top) and 5b (bottom): experiments with different polishing agents as described in Section 3.2. Results for SF6 (a) and PSK53 (b). Vertical axis: power in W. Horizontal axis: elapsed time in seconds. Φ is the relative difference in average surface quality between polishing agents A and B.

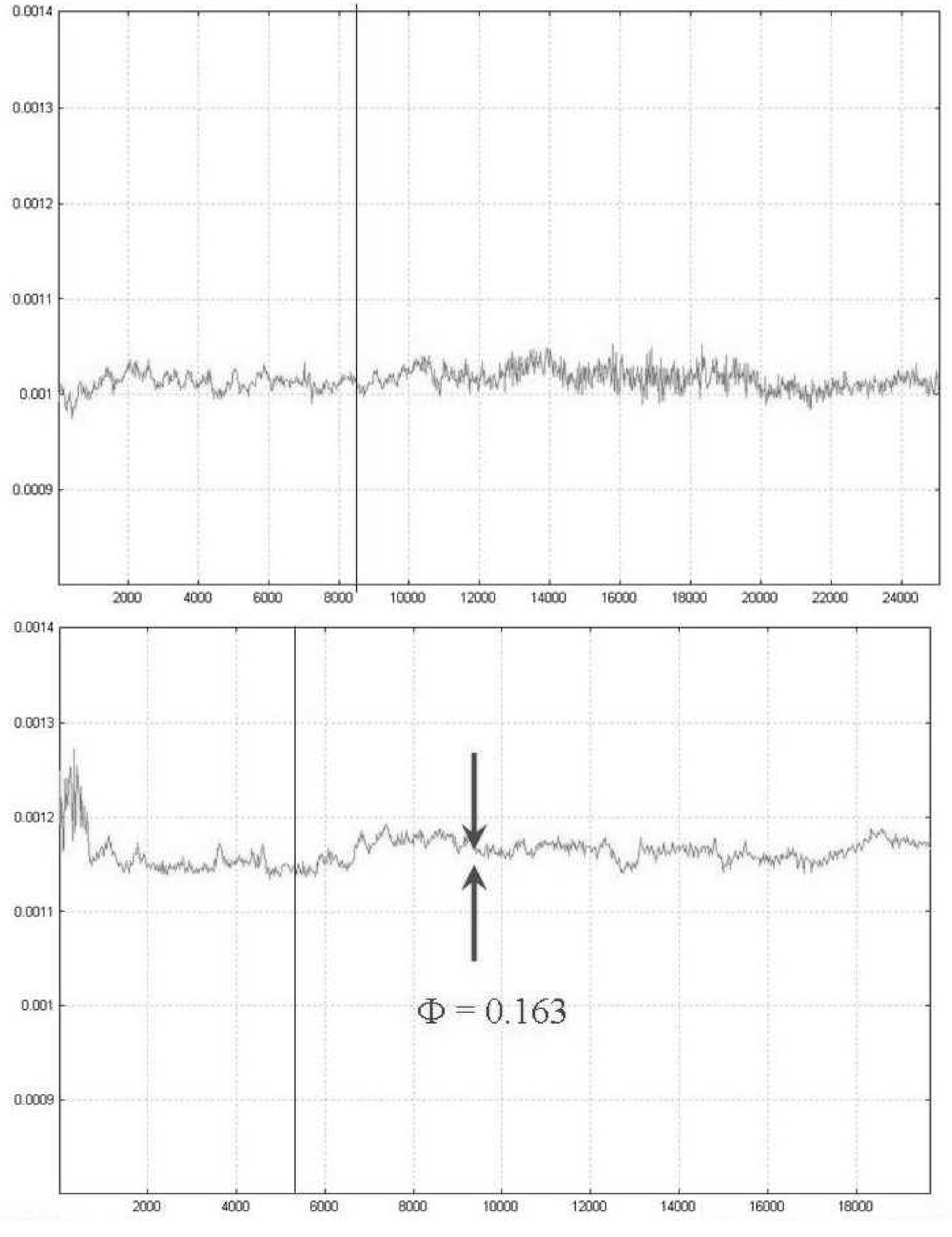


Figure 5c (top) and 5d (bottom): experiments with different polishing agents as described in Section 3.2. Results for LAFN21 (c) and N-LASF31 (d). Vertical axis: power in W. Horizontal axis: elapsed time in seconds. Φ is the relative difference in average surface quality between polishing agents A and B.

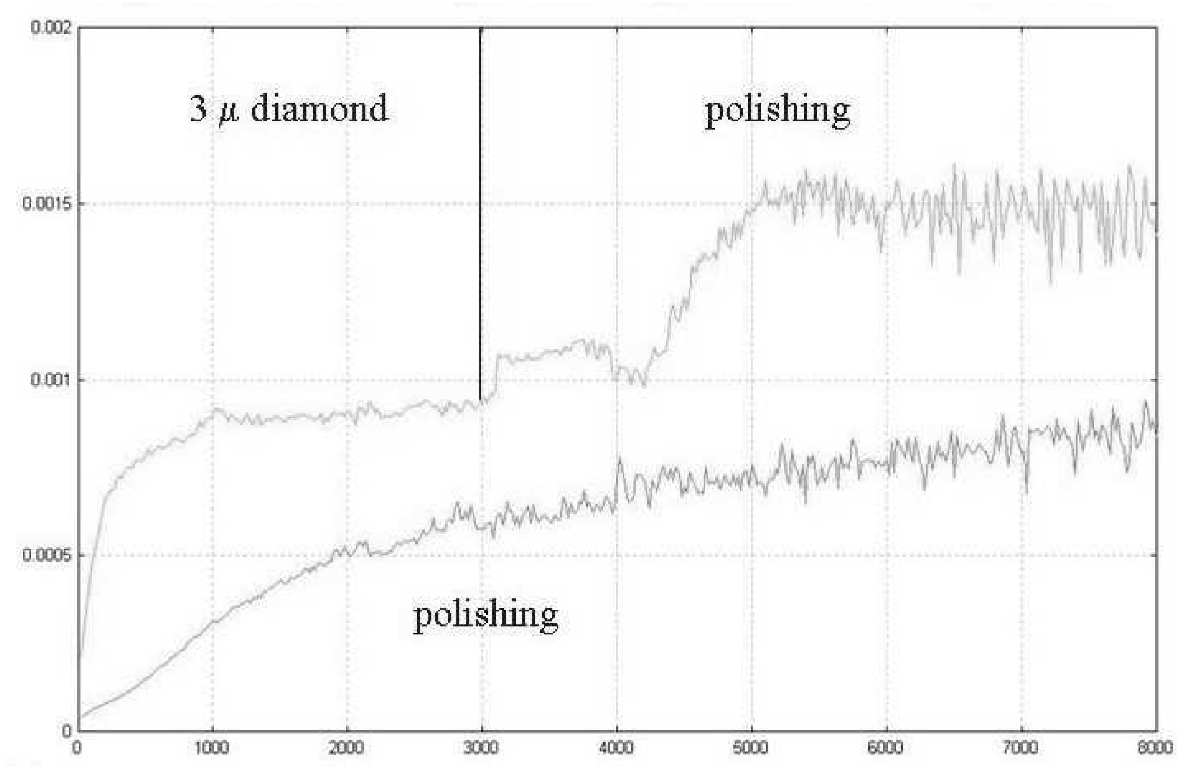


Figure 6: Comparison of ductile grinding plus polishing to polishing only. Vertical axis: iTIRM power value in W. Horizontal axis: elapsed time in s. A SCHOTT N-LASF31 surface is processed in both cases. The polishing agent is water based 10% Cerium Oxide slurry. For the ductile grinding step, water based 1% 3μm diamond slurry is used.

4. DISCUSSION

The results of the experiments described in Section 3.1 show that iTIRM has the ability to differentiate between polishing processes in-situ. As a result one could qualify polishing processes and after thorough calibration even "value" a surface finish without disturbing the polishing process. Section 3.2 has shown another application of iTIRM: optimising surface finishing processes. The use of ductile grinding was effectively shown in Figure 6. The measurement setup, however, could still use significant improvement. As it is, it does not allow adjusting the laser in such a way that the beam's incident angle is "safely" above the critical angle for the glass-slurry interface. The measurement data do not seem to suffer from that but it would probably make the different experiments better comparable. Furthermore, the scattered measurement data when using polishing agent B in Figure 5 are not explainable with certainty. On the whole it can be concluded that iTIRM provides interesting R&D opportunities for the optical workshop but is not (yet) suited as a production tool.

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