Applicability of iTIRM for roughness reduction monitoring

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ABSTRACT

The results obtained with iTIRM during polishing are presented. It is shown that iTIRM unites the working ranges of several other techniques where iTIRM can be used during production where the others can not. The applicable range of iTIRM is shown to be at least 1 μm down to 0.1 nm rms.

Keywords: roughness, in-situ monitoring, optical fabrication

1. INTRODUCTION

The final stage of the production of optical surfaces is polishing. Before this stage starts the surface is ground into the correct shape. The time required for the polishing step depends on two things, the starting roughness (the end roughness of the grinding process) and the required end roughness. Recently we proposed a non-destructive method to monitor the process of the grinding and polishing process, which goes by the name of iTIRM[1] (intensity-detecting Total Internal Reflection Microscopy), after the well known method TIRM (Total Internal Reflection Microscopy[2]). Being able to monitor the process during the production shortens the production time since it can be detected when a process has reached its end roughness level. Apart from this, it can also be used as a tool to optimize the process and to compare different processes in terms of production time and surface finish.

It has already been shown[3] that iTIRM can be used to monitor the change in roughness from #800 ground surfaces to #1200 ground surfaces, during processing. What still had to be determined is the working range of the method, which is the topic of the present paper. Here we will report on the change of surface roughness from brittle mode grinding to polishing. As a comparison we also analyzed the surface for each roughness stage with an α-step and a profilometer.

2. EXPERIMENT

In this section the iTIRM method will be explained and the other setups used will be specified. After that, the performed experiment will be described.

The iTIRM system is shown in Figure 1. Light from a HeNe laser is coupled into the sample, such that it will be reflected by the surface that is being processed. Care has to be taken that the angle of incidence of the laser beam (with respect to the surface normal) is larger than the critical angle of total internal reflection. In the case of a perfectly smooth surface, 100% of the light will be reflected. Surface roughness and subsurface damage will attenuate the intensity of the reflected beam such that by monitoring the intensity of this beam information is obtained on the surface characteristics.

In the case of an angle below the critical angle of total reflection, part of the light will be transmitted through the interface where the transmitted amount strongly depends on the properties of the substances on top of the surface. The grinding/polishing liquid and the presence of the pad will change the characteristics and thereby the transmittance. It should be noted that for in-process measurements the angle of total internal reflection has to be determined for the situation that the grinding/polishing compound is present on the surface.

The iTIRM method differs from the TIRM method (see Figure 2), in that it measures the intensity of the throughput where in TIRM the reflection spot is visually inspected via a microscope. Roughness and subsurface damage will give rise to scattering and will thus show up as bright spots in an otherwise dark microscope image. This system can not be used for in-process monitoring but is very well suited for post process characterization.

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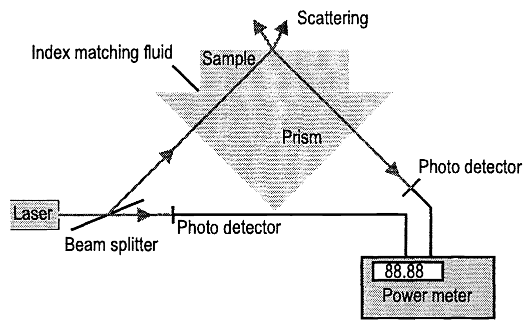


Figure 1 Layout of the iTIRM setup as used for off-line testing of optical surfaces.

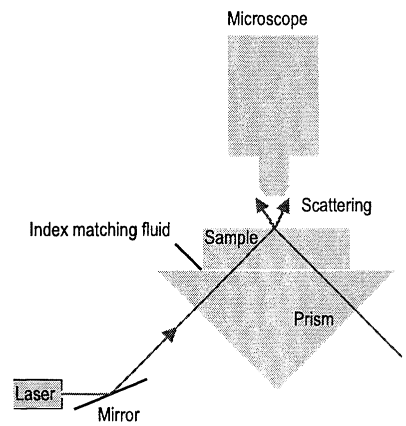


Figure 2 Layout of the traditional TIRM setup as used for off-line testing of optical surfaces by observing the scattered light through a microscope.

We will present an experiment in which we follow the roughness reduction by polishing in time. Apart from our home-made iTIRM setup, which yields a signal that is only an indication of the roughness, we also used commercially obtained systems to get a more `certified' number on the roughness. The used systems are a Wyko (RST500), an α-step (Tencor Instruments alphastep-200), and a hand held profiler (Mitutoyo Surftest 301).

3. MEASUREMENTS

In the following the results of the mentioned experiment will be presented and discussed.

The experiment started with a ground BK7 sample (flat, ground with #800 SiC). This sample was measured with all mentioned techniques. The initial roughness was about 300 nm rms. The sample was polished for two hours and after each ten minutes measured. Measurements of the results are given in Table 1. In order to be able to compare all measurement results, we conducted all measurements after cleaning (removing the slurry from the surface). This means that we did not use iTIRM as an in-process tool, which is one of the main features of it. The polishing technique used was pitch polishing with water and HPC (a Cerium Oxide based material) as polishing compound.

Table 1 Roughness of the sample measured by the Mitutoyo profiler, the α-step, the Wyko interferometer and iTIRM after various intervals in the polishing process.

time (min)	mass (g)	Mitutoyo R_q (nm)	α-step 80 (nm)	α-step 400 (nm)	Wyko R_q (nm)	iTIRM (dB)
0	49.3936	310	299.0	282.0		-25.385
10	49.3917	150	77.5	55.5		-3.723
20	49.3900	90	57.0	48.5	13.65	-1.473
30	49.3887	50	6.5	2.0	4.30	-0.346
40	49.3874	50	6.0	7.5	2.77	-0.189
50	49.3859		2.5	2.5	1.23	-0.073
60	49.3843		2.5	2.5	0.95	-0.035
70	49.3824		3.0	3.5	0.79	-0.027
80	49.3802		3.5	3.5	0.80	-0.022
90	49.3785		3.0	2.0	0.79	-0.021
100	49.3766		3.5	1.0	0.87	-0.018
110	49.3747		3.0	1.0	0.77	-0.018
120	49.3731		2.0	1.5	0.88	-0.022

First thing to be noted from Table 1 is that the conventional systems have a more restricted working range than iTIRM has. The Mitutoyo can be used for rough surfaces but can not be used for roughness below 50 nm rms. The α-step showed to be applicable for roughness values down to about 1 to 2 nm rms. A clear difference is observed when the scan length is changed. The Wyko could not be used for the initial roughness but was able to measure down to the final stage. The iTIRM signal can be used over the full range. It is to be expected that even rougher and smoother surfaces can be measured by using iTIRM.

The results obtained with the WYKO and the iTIRM setups are shown in Figure 3.

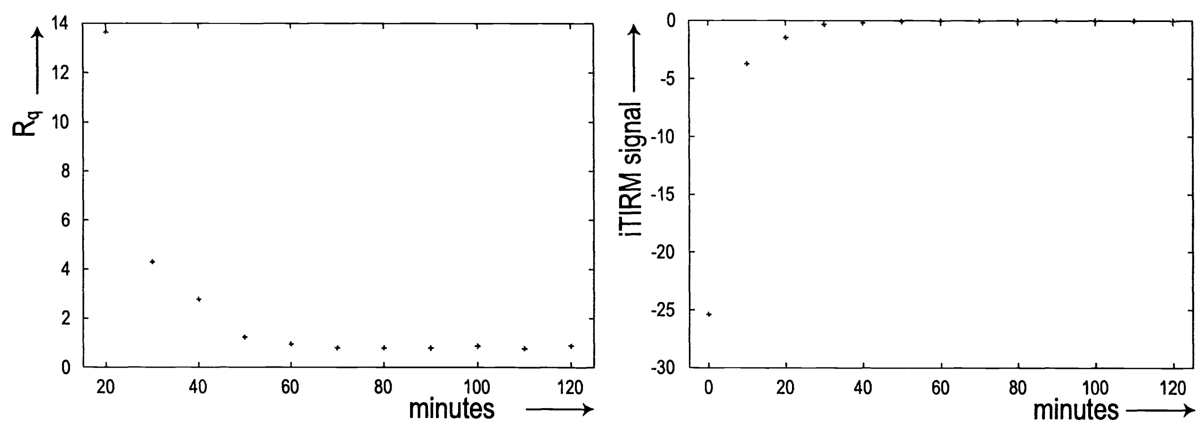


Figure 3 Results of roughness measurements as obtained with the WYKO (left) setup and the iTIRM (right) setup. The iTIRM results are shown on a logarithmic scale

To ensure that the process removed material from the sample, we monitored its mass reduction due to processing. After each ten minutes of processing the sample was weighed. The results are shown in Figure 4. It seems that although the roughness reduces with time, the removal rate was about constant.

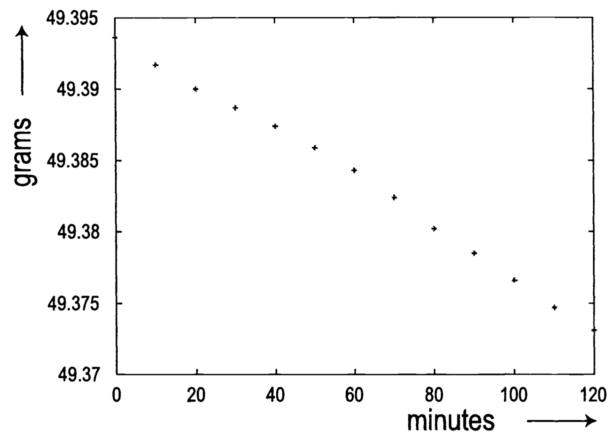
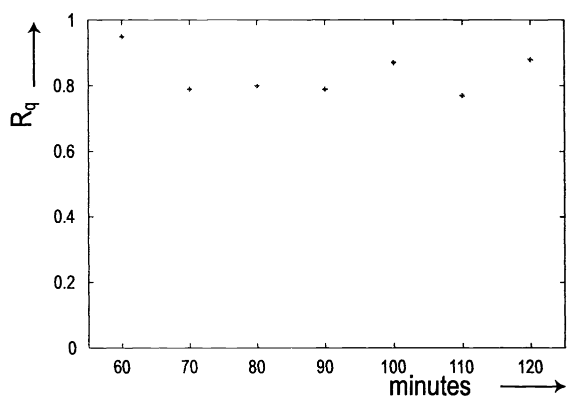


Figure 4 Weight of the sample as a function of the time that it has been processed.

4. DISCUSSION

From Table 1, it can be seen that both the WYKO and iTIRM can be used for the characterization of the roughness in the final stages of the processing, i.e. for low roughness values. When we zoom in to these final stages, see Figure 5, we see that using the WYKO we can no longer see any improvement after 70 minutes of processing, where using iTIRM we can monitor the improvements up to 110 minutes. The conclusion can be that iTIRM is more sensitive to small changes in the roughness, but it should of course be noted that the results for the WYKO setup is only valid for the type we have which is already relatively old. Newer types of WYKO profilometers are known to be capable to measure roughness values down to the 0.1 nm region.



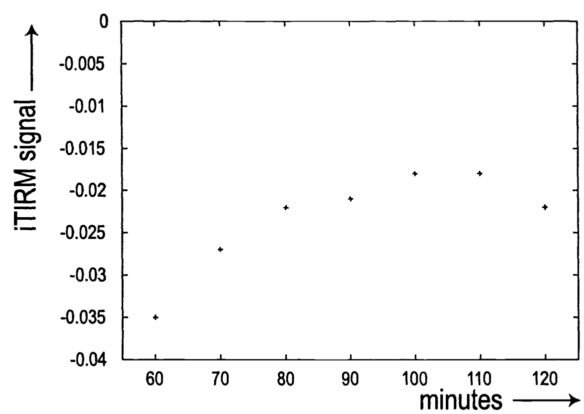


Figure 5 Results of roughness measurements as obtained with the WYKO (left) setup and the iTIRM (right) setup, zoomed in to the final stages of the processing for which the sample is relatively smooth. The iTIRM results are shown on a logarithmic scale

For the iTIRM result, all features (e.g. R_z and R_q) are comprised in a single number. This is on one hand a drawback, on the other hand it can be thought of as a positive feature of the method. During fabrication the only thing of interest is whether the surface quality is improving or not. As long as the iTIRM signal is increasing the surface is getting smoother, either owing to the reducing roughness, or because the number (or size) of pits and scratches is decreasing.

At present, iTIRM is not an absolute measurement. Surface changes can be observed but it is not possible yet to link the iTIRM outcome to a surface roughness figure. The strongest point of iTIRM is that it can be used during fabrication. Where other methods can only be used to measure the static status of a surface, iTIRM can be used to monitor changes during grinding and polishing.

Suppose that the intensity coming from the laser equals I_0. Just prior to reflection the intensity will be reduced to I_1 due to losses caused by e.g. transmission through the air-to-sample interface (reduction factor R_1). Upon reflection by the surface under inspection the intensity will reduce further down to I_2 due to the surface roughness and possible sub-surface damage (reduction factor R_2), and finally I_3 is the intensity that is measured by the photo detector which again will be lower than I_2 due to reduction factor R_3, i.e. absorption and transmission losses.

During an iTIRM experiment the quantity R_2 is the one that is of interest. The quantity that is obtained is $(1\text{-}R_1)(1\text{-}R_2)(1\text{-}R_3)$, most likely with changes due to laser intensity fluctuations and errors due to ambient illumination changes.

If the facets where the laser light enters and exits the sample are polished, the reduction in intensity due to passage through those facets can be expected to be nearly constant. In that case the observed iTIRM signal can be written as

$$I_{iTIRM} = \text{const} \cdot \text{noise} \cdot (1 - R_2)\,. \tag{1}$$

The constant comprises all the intensity loss components that are caused by passage through the air to glass interfaces and reflections by mirrors in the setup. The noise term pertains to laser fluctuations, position dependent transmission through the facets due to facet roughness and all other possible intensity changing contributions. From the measurement results as shown in this paper it can be concluded that the noise term is small enough to allow the detection of roughness changes in the regime below 1 nm (rms). The roughness of the sample at the end of the two hours polishing was well below the 1 nm (rms) value. We are convinced that using iTIRM roughness levels between 0.1 and 1 nm (rms) can be distinguished. From an observation of the line width during an iTIRM scan, and the change in iTIRM signal during polishing, it becomes apparent that the working range is very large. It is even to be expected that iTIRM allows for the monitoring of roughly ground to super polished, i.e. roughness values of some μm down to 0.1 nm.

5. CONCLUSIONS

The iTIRM system can be used to quantify the rms surface roughness of ground surfaces. The surface quality of polished surfaces can be quantified, where the influence of R_q and R_z are captured in a single figure. Surface improvements of 0.1 nm rms can be detected and the working range is at least from 1 μm down to 0.8 nm. Finally it can be repeated that iTIRM is especially suitable for in-process measurements.

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