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Process Characterisation and Key Tasks for Cost-effective 3D Figuring of Specular Surfaces Using RAP

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Abstract:

Recently established the Helios 1200 (Rapt™) is a unique facility designed for the figuring of large optical surfaces [1]. It combines a CNC machine tool with a reactive atom plasma (RAP) process. This provides a unique rapid surface figuring capability with tool size and tool path motion flexibility. RAP is a proven technology for processing silicon based optical materials [2]. The aim with this technique is to achieve figuring correction of metre size optical components in 10 hours - a much reduced process time compared to the 100 hours currently needed. This paper focuses on key technical tasks to achieve a cost-effective figuring method using RAP. Classically a figuring process is carried out iteratively by analyzing surface figure error and removing material using an optimum tool path algorithm. In this work, the material removal is achieved by decomposing the compound SF_6 in a plasma jet to obtain free fluorine radicals which etch away silicon based material. In this paper, measurements of the specific material removal rate and footprint of the plume over a range of substrate temperatures are presented. Then the authors present a base-line process for the neutral removal of material over a large area. Various tool path algorithms are investigated some of which include time-dwell adaptation based on substrate temperature. Finally, the issue of heat transfer is discussed, and both experimental and finite element analysis results are presented. The processed surfaces are analyzed using coherence probe and phase-shifting interferometers for surface morphology and 3D surface form respectively. Surface roughness (Sq) is reported within the 2-3 nanometre range on fused silica and surface flatness is within the +/-50 nanometre range after 0.5 micrometre deep material neutral removal (Typical processed area: 70x200millimetre).

1 Material removal rate (MRR)

Experimental work to assess the change in material removal rate due to substrate temperature has been carried out on ultra-low-expansion glass ULE® samples (50mm diameter and 5mm thickness). The polished ULE substrate is first mounted on a 5mm thick aluminium disc using thermal paste to ensure a consistent temperature distribution and a thermocouple is embedded between the two to ensure accurate temperature measurement. "Sandwich" samples are pre-heated using a hot plate and the temperature is logged. The disc surface is exposed to a static plasma plume (sulphur hexafluoride/argon gas mixture) for one second duration. Results show that there is a significant material removal rate increase with temperature of about 38% between 20 and 105°C.

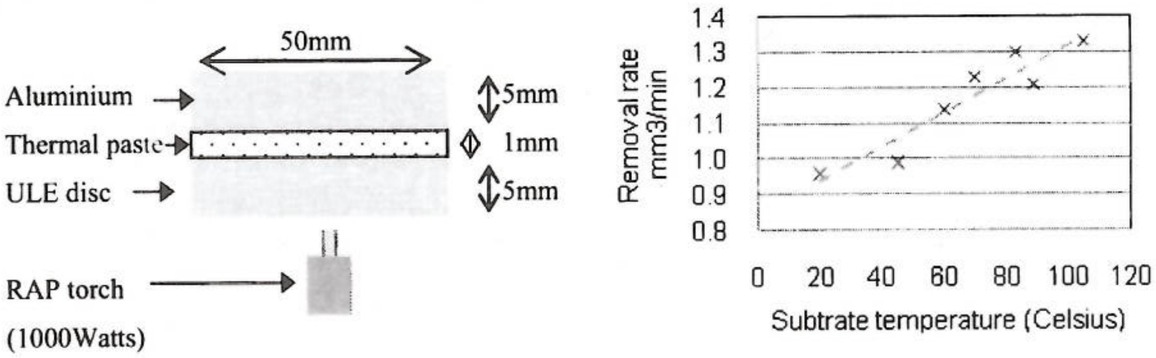

Figure 1. Sandwich structure (left) MRR dependency on substrate temperature (right)

2 Tool path algorithm for neutral material removal over large area

With the specific machine design, surface processing is carried out by raster scanning the torch [1]. To identify the main trends in the etching process, a design of experiments was carried out using two variables, travel speed and raster pitch, and two levels for each, 2 and 6m/min and 1 and 2mm respectively. This work identified the high speed level and larger pitch value as the preferred combination for further investigation to achieve neutral removal. Two scanning methods have been used, whose results are shown in figure 2. In the iterative method (Fig.2 left), the surface is etched twice using identical machine parameters, but with the sample turned 180 degrees after the first process. In the alternating raster (Fig.2 right), the torch travels across the entire sample surface at constant velocity, but for the following scan line the farthest available within the 70mm range is selected. Finally the test is repeated on a fresh surface but with the surface temperature measured and travel speed tuned based on material removal rate dependency on surface temperature (see results presented in the previous section).

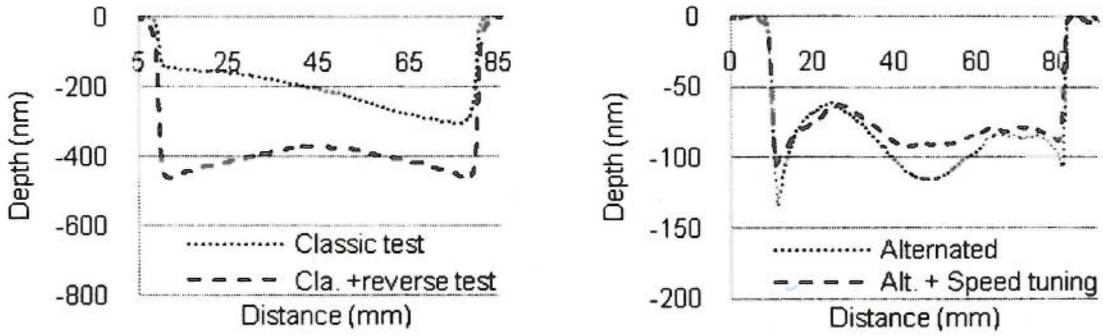

Figure 2. Iterative method (left) Feed speed tuning based on substrate temp (right)

3 Heat transfer

In light of the results presented in the first section, the surface temperature changes due to heat transfer from the plasma plume were investigated for torch travel speeds in the range 2 to 4m/min. Single passes were carried out on a 200mm diameter 0.75mm thick silicon wafer with four thermocouples attached to it. These were calibrated using an oven set to 100°C and positioned on the back side of the silicon wafer to avoid RF perturbation, in intimate contact with it. A USB Pico TC-08 Thermocouple Data Logger was used to record the temperature changes. For finite element modelling purposes, the heat source was assumed to follow a Gaussian distribution law. Both intensity and full width half maximum parameters were determined using Ansys software version 10.

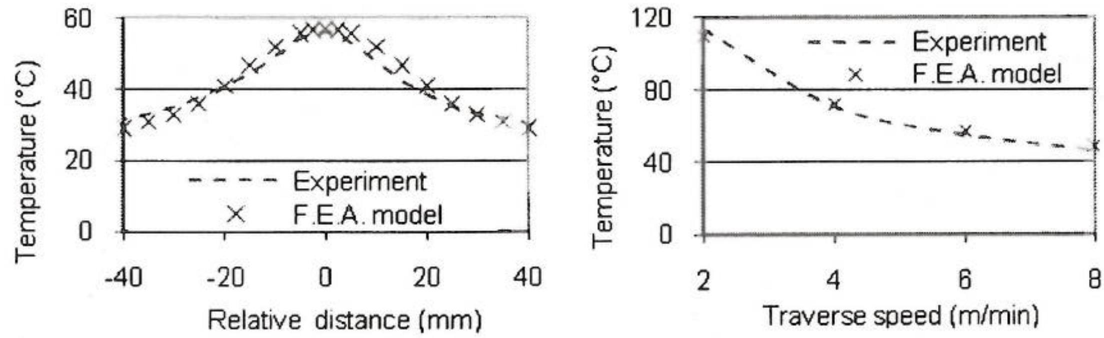

Figure 3. Induced temperature rise across plasma plume due to single pass (left) Maximum temperature due to single pass at various travel speed (right)

Firstly the temperature profile due to a torch plume (heat source) was measured for a travel speed of 4m/min and Gaussian parameters of the numerical heat source were identified using a reverse engineering technique. Secondly, the torch travel speeds were varied for both experimental conditions and the numerical model. Measured and predicted results were in good agreement.

4 Surface roughness

Surface roughness changes on Lithosil[(r)] Q1 (synthetic fused silica) surfaces were investigated for a 70x200 millimetre area using a white light coherence probe interferometer with lateral resolution of 0.4 micrometre. Firstly, surfaces were polished and characterised then exposed to a 4% SF_6/Ar plasma plume using a raster scan type tool path algorithm (see Table 1 for the range of travel speeds and pitches). RF generator power of 1000 W, and standoff distance of 7.5mm are constant process parameters. Post process surfaces were cleaned using a Baikalox emulsion containing 20nm alumina oxide particles. The results (Table: 1) demonstrate the excellent potential of SF_6/Ar gas mixture for figuring optical surfaces.

Table 1. Surface roughness of synthetic fused silica sample

Travel speed (mm/min)	Pitch (mm)	Sq(nm) Pre-processing	Sq(nm) Post-processing	Material removal depth (nm)
4000	1	1.663	3.321	300
4000	2	1.621	2.444	150
6000	1	1.695	2.125	175
6000	2	1.657	2.056	125

5 Conclusion

These results confirm the capability of the RAP process to remove the required amount of material for the figuring of metre size optical components within a 10 hours period. The work also shows that thermal energy can be measured and exploited to increase and control advantageously the material removal rate.

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