DEVELOPMENT OF AN ION FIGURING SYSTEM FOR CENTIMETER SCALE OPTICAL COMPONENTS

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An important step in the fabrication of an optical component involves the imparting of a precise contour on the optic, which can be expensive and time consuming. Ion beam figuring is the imparting of a contour on an optical component by removing material through the impingement of a broad beam of accelerated neutral particles, and provides a highly deterministic method for the final precision figuring (or correcting) of optical components with advantages over conventional methods. The high predictability allows the possibility of single step figuring, resulting in significant time and cost savings. And unlike grinding, polishing and lapping, ion figuring is non-contacting and so avoids several problems including: edge roll off effects, tool wear, and loading of the work piece. It has previously been demonstrated that ion figuring is effective for the correcting of large optical components [1][2]. These implementations typically use the process for final figure correction on meter class optical components. The work discussed here is the development of the Precision Ion Machining System (PIMS) at NASA's Marshall Space Flight Center, designed for the processing of smaller (less then 10 cm diameter) optics. Initial experiments using a Kaufman type ion source to figure 8 cm diameter fused silica and silicon carbide samples were successful. Experiments involved correcting flat samples and imparting spherical and aspherical contours.

In the figuring process, a surface contour map of the sample is measured using a ZYGO Mark IVxp interferometer. The desired surface contour is then subtracted from the map to give a map of the material to be removed. The beam is assumed spatially and temporally invariant and the removal distribution is Gaussian. Specific figures are achieved by varying the velocities of the beam as it is moved across the sample. The removal is used to determine the velocities for rastering the beam across a sample by a unique deconvolution algorithm developed for this application[3]. Using a series expansion to represent the removal map, the algorithm provides a series expansion for the velocities related by the statistical moments of the static removal rate. For the PIMS, the beam is rastered over the sample in concentric circle paths and angular velocities are varied within each annulus to account for non-axial symmetric removal.

The removal rate and distribution of the ion beam was determined by positioning the beam over the center of a flat sample for a known amount of time. The resulting removed shape was measured on the interferometer and the rate calculated by dividing by the duration of the beam operation. Several methods of linear curve fitting were used to match a Gaussian function to the resulting shape, but manual tweaking of the Gaussian parameters produced the most useful results. The function distribution is constant for a set of ion source parameters but a removal rate must be determined for each material

The results of the process for eleven cases are shown in Table 1 and Figure 1. Using a 3 cm diameter Ion Tech ion source, 8 cm fused silica samples were figured to spherical, parabolic

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Case	Target Profile	Part #	Initial rms	Final rms	Convergence
	Fused Silica (3 cm Beam Width)				
1	Parabola (radius: 100,000 mm)	FS2	1138 nm	80 nm	14.20
2	Parabola (radius: -100,000 mm)	FS8B	1071 nm	434 nm	2.47
3		FS8	1170 nm	380 nm	3.08
4		FS8	858 nm	359 nm	2.39
5	Spehere (radius: 100,000 mm)	FS6B	2279 nm	419 nm	5.44
6		FS6B	817 nm	256 nm	3.19
7	Saddle (radius: 160,000 mm)	FS7B	933 nm	638 nm	1.46
8		FS9	934 nm	456 nm	2.05
9	Saddle (radius: 140,000 mm)	FS10	934 nm	261 nm	3.58
			Average		4.21
	Silicon Carbide (3 cm Beam Width)				
10	Saddle	SC2	982 nm	324 nm	3.03
	Fused Silica (1cm Beam Width)				
11	Flat	FS2B	59 nm	24 nm	2.44

Table 1. Results of ion beam figuring 8 cm fused silica and silicon carbide samples. An Ion Tech 3 cm beam created parabolic, spherical, and saddle figures. In addition, a 1 cm aperture on the beam was used to correct a flat fused silica sample. The initial and final rms deviation from the desired figure is shown for each case. The convergence ratio represents the effectiveness of the process and is the inital over final rms deviation.

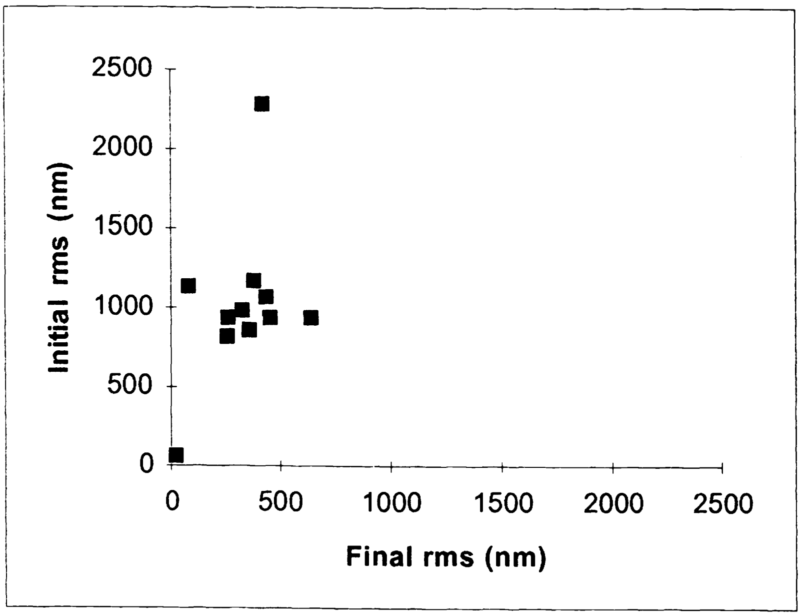

Figure 1. Results of ion figuring, displaying final rms figure error vs initial rms figure error for all eleven cases. The slope from the origin is the convergence ratio of each case.

(concave and convex), and saddle shapes. The saddle shapes demonstrated non-axial symmetric corrections. Initial deviations from the desired figures ranged from 1000 to 2000 nm rms and the ion figuring process corrected the figures to an average of 365 nm rms error. The average convergence ratio over nine cases was 4.21. Further iterations to process the samples did not improve the figures. This was found to be because of an axial symmetric variation in the beam removal rate over the samples. It is suspected that this is caused by errors in the operation off the rotational motor over a wide range of velocities. None of the samples experienced significant increases in surface roughness. The samples were expected to contain little subsurface damage that would be exposed and exacerbated during matching [4]. The best case involved imparting a shallow sphere(4 μm of sag) on a flat sample that had an initial surface error of 1138 nm rms error from the sphere to 80 nm rms. The final shape is shown in Figure 2. The process took a total of 121 minutes of beam operation and the surface roughness after machining was 10 A rms. A shallow saddle figured on a CVD Silicon Carbide sample resulted in improving the figure error from 982 to 324 nm rms.

In addition, a small 1 cm aperture was installed in the ion source to obtain higher frequency corrections. A simple non-magnetic stainless steel annulus was used as for the aperture. It was necessary to reduce the beam current, therefore the peak removal rate, in order to achieve a stable beam with the aperture in place. The resulting beam removal was still Gaussian shape but it had greatly reduced volumetric removal rates both because the overall footprint was smaller and the peak removal was reduced. This reduced removal rate makes the aperture source only useful for small (less than 100 nm rms) corrections. The process reduced an initial surface error of 59 nm rms to 24 nm rms on a flat fused silica sample.

The results demonstrate the feasibility of using the PIMS for final figuring of small optics with no appreciable increase in surface roughness. For the process, lower final rms error is expected when the beam removal variation is corrected. Finer corrections can be made with various apertured beam widths. The system currently uses concentric circle paths but other raster patterns will be tested.

References

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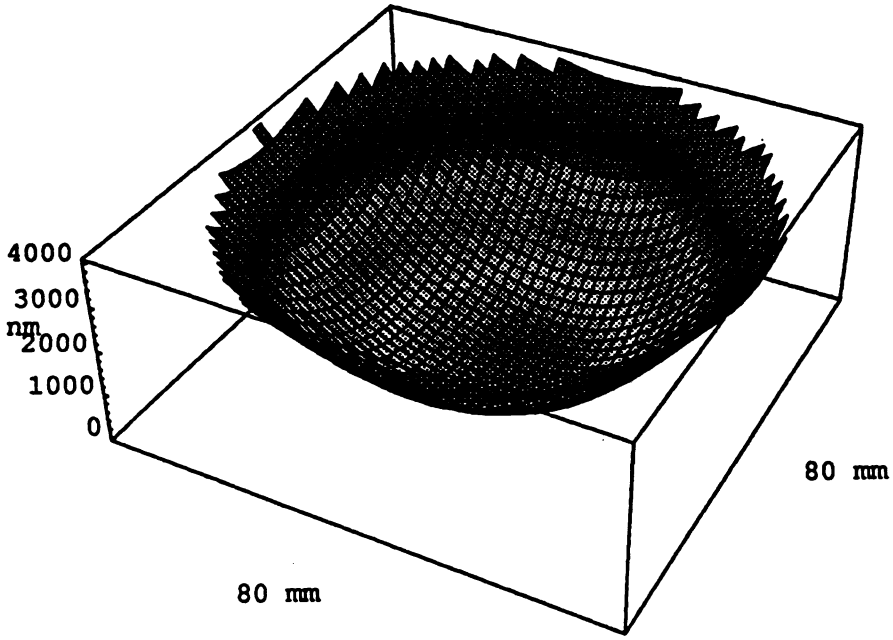

Figure 2. Final parabolic contour imparted on flat fused silica sample with 4 um sag.