Fabrication and Implementation of a New Ceramic Material in an Adaptive Optics System

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Abstract: A CNC machine optical polishing protocol for ZrB_2 ceramics has been established. The first optic is a deformable mirror facesheet. Light-weight athermal systems with optical and structural components fabricated from the same material will follow.
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1. Introduction

A key component of adaptive optical systems is the deformable mirror (DM). Through the use of actuators the DM corrects aberrations present in the wavefront being examined [1]. Generally, the DM and the components used to hold it in place are comprised of different materials. This creates engineering challenges to avoid thermally induced aberration or worse as the parts will generally have different coefficients of thermal expansion.

If the components were made out of the same material this could be prevented. In order to accomplish this a ceramic material, made of 75% ZrB_2 and 25% SiC, is being examined for potential use in an adaptive optics system. Our near-term goal is to design a process to manufacture large thin aspheric ceramic facesheets for deformable mirrors that may be incorporated as the primary or secondary mirrors of adaptively corrected telescopes. The facesheets will be light weight and robust, being just 0.8 mm thick, and will be capable of handling high power density: the material's primary application is in the nose cones of hypersonic rockets. Here we report that a sample of the material has been successfully polished to an optical finish and a protocol for replication of the polishing process has been produced. This is a major milestone in the development of the deformable mirrors. The material is also tough, and has a bulk modulus roughly 5× that of glass meaning that complete optical systems can potentially be built that are robust and substantially lighter than their traditional glass and metal counterparts.

2. Fabrication and Polishing

In order to generate a set of procedures that could be replicated, a sample of the material was used to test polishing methods. The sample, a disk 30 mm in diameter and 6 mm thick, was manufactured in-house in a sintering furnace. We then proceeded to optical processing. Once the initial shape of an optic is defined by coarse grinding, the goal is to reduce surface roughness through polishing: a high-quality mirror will typically have no more than 2 nm rms surface deformation on spatial scales below about a millimeter. In our case, the ceramic sample initially underwent fine grinding on a CNC machine driven by a custom code written in Matlab. Multiple different parameters such as the polishing compound, speed, and pressure were explored. After many dozens of trials the sample's surface roughness decreased from its starting point of 0.265 μm to 0.133 μm rms. This was accomplished using a Trizact diamond pad at diamond grit sizes of 20, 9, and 3 μm at 2.552 PSI and a speed of 500 mm/min [2]. A slurry of Sabre coolant and 5 μm Al_2O_3 was used in conjunction with the Trizact.

Following the CNC machining, a Strasbaugh machine was used for finer polishing. For this step, a diamond powder was mixed with olive oil and deionized water. This slurry was applied to a pellon pad and used in successive particle sizes of 1.5 and 0.5 μm. This proved to be very effective and lowered the surface roughness to about 7 nm rms. Under the polishing conditions tested this appeared to be the best possible result, but with finer tools and more trials we believe lower values may be attainable. For optical system prototyping, however, the surface quality achieved is quite sufficient, as it is for many practical applications where reaching the very lowest optical scattering is not a primary concern.

Throughout the polishing process other forms of polishing compound, such as SiC and Al_2O_3, were used but were found to be ineffective. The details of the final grinding and polishing prescription are listed below in Table 1. Additionally, in Figure 1 both polishing setups (CNC and Strasbaugh) are displayed. In Figure 2 a photograph of the polished sample is shown.

Table 1. Polishing parameters.

Machine	Polishing Compound	Pressure (PSI)	Speed	Polishing Radius (mm)	Resulting RMS (nm)
CNC	Trizact (20 µm), Al_2O_3 (5 µm), Sabre Coolant	2.552	500 mm/min	3	328
CNC	Trizact (9 µm), Al_2O_3 (5 µm), Sabre Coolant	2.552	500 mm/min	3	184
CNC	Trizact (3 µm), Al_2O_3 (5 µm), Sabre Coolant	2.552	500 mm/min	3	133
Strasbaugh	Diamond (1.5 µm), Olive Oil, Deionized Water	2.552	Eccentric: 35 RPM Spindle: 50 RPM	30	20
Strasbaugh	Diamond (0.5 µm), Olive Oil, Deionized Water	2.552	Eccentric: 30 RPM Spindle: 50 RPM	30	7

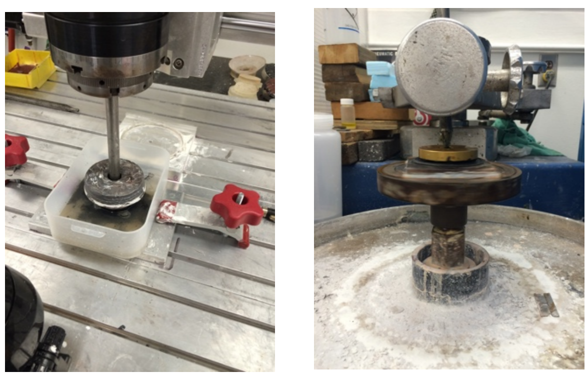

Fig. 1. The two setups used to grind and polish the ceramic sample. (Left) Initial work with a CNC machine. (Right) Final polishing with a Strasbaugh machine.

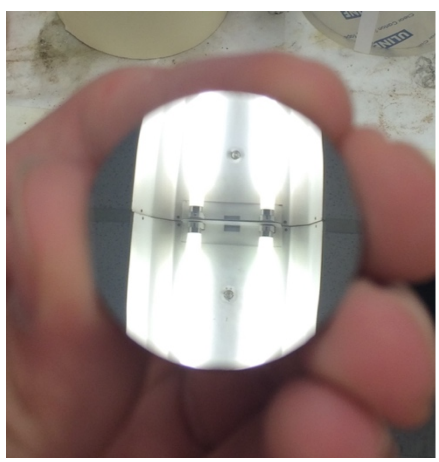

Fig. 2. Polished ceramic sample.

3. Measurements

The surface roughness was measured at many points during the polishing process. This was done using a Zygo white-light interferometer. In addition, surface maps were generated. Below in Figure 3 are some of these maps made at key points in the polishing process. In Figure 4 a map of the whole surface was stitched together by taking hundreds of successive measurements across the entirety of the sample using the white-light interferometer. This map shows significant power in the surface. This is caused by edge roll-down from the Strasbaugh machine. Now that the correct protocol to polish the material has been identified the shape can be better controlled by using the CNC machine throughout the whole process.

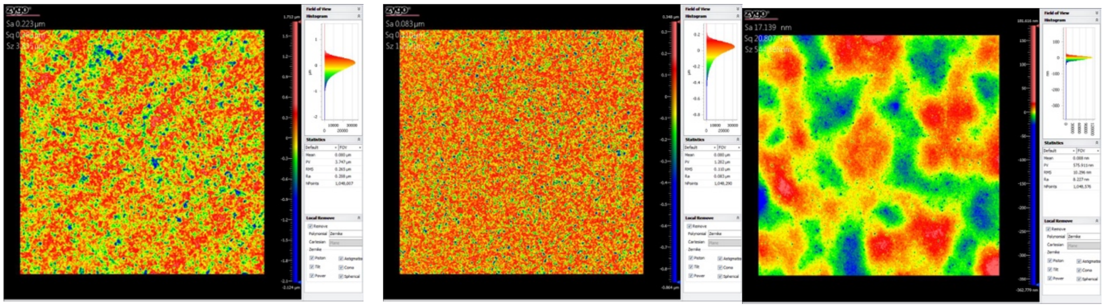

Fig. 3. Surface maps of a small portion of the ceramic sample, approximately 0.8 mm on a side. (Left) At the beginning of the polishing process the rms surface error is 265 nm. (Center) Following Trizact polishing, the error is reduced to 110 nm. (Right) Towards the end of polishing, the surface quality is 10 nm rms.

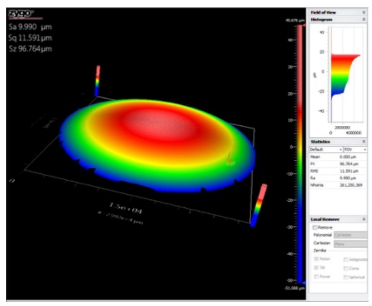

Fig. 4. 3-D full surface map after polishing.

4. Conclusions and Future Work

The ceramic material has been polished to a low surface roughness and a set of procedures to repeat the process has been generated. A 3 inch diameter flat disk is currently being ground down to 0.8 mm thickness. The disk will then be polished using the same protocol described in this paper. To maintain the flat figure, the polishing can be held under much more control with the use of the CNC machine. For these first tests, the Strasbaugh was used because of its speed, but it allows for easy deterioration of the shape of the material being polished. The finer control possible with the CNC machine will limit this error and the shape can be held to a higher standard.

Once polished down to a surface roughness of 10 nm rms or less the mirror will be optically and mechanically tested. A custom mount has been made for the mirror and actuators have been built into it [3]. The mirror will be bonded to the mount with epoxy. The ZrB_2 materials are of interest for more than their athermal properties. They are also relatively light-weight, durable, and very strong. This allows for adaptation to many different optical systems. Going forward we are also developing prototype monolithic systems that, once rigidly assembled, are robust and largely immune to internal misalignment. Such systems will be ideal for operation in challenging thermal, shock, and vibrational environments.

5. References

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