Sintered silicon carbide mirror substrates surface finishing for embedded applications

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Abstract. Stiffness is the main reason to use SiC as a mirror substrate for aerospace applications. Also the SiC mechanical and thermal properties are superior to the optical material that is normally used for those applications. In this work, diamond tools and pastes were applied to obtain flat small diameter mirror substrates. The goals were to obtain flatness of $\lambda/10$ and Ra roughness of $\lambda/100$, for visible light.

1. Introduction
In this work, diamond tools and pastes were applied to obtain flat small diameter mirror substrates. The goals were to obtain flatness of $\lambda/10$ and Ra roughness of $\lambda/100$, for visible light [1,2].

Light weight is a main concern in aerospace applications. Vitroceramics, Be, Safire are materials used in this case. If low specific mass material is not available, hollowed stiff material can be used. On mirror substrates, the idea is to use a honeycomb structure or some blind holes in the back part, without losing the front surface profile. Stiffness is then a major property. SiC is a good candidate and it has been used in aerospace applications.

Normally it is easier to polish a hard material than a soft one. Soft materials are easily scratched and it is difficult to keep the substrate front surface shape during the polishing process. But SiC is a very hard material and the polishing process must use diamond tools and pastes. The SiC removing rate is 1/35 of the fused silica and 1/50 of vitroceramics. That is why the surface finishing processes is longer and more expensive [1, 3-5]. In general, it is not easy to find detailed information about the finishing processes on SiC, due to commercial interests.

This work presents the procedures and techniques applied to obtain low roughness and high flatness SiC mirror (sintered) substrates.

2. Materials and methods
The H. C. Starck Grade BF17 SiC powder was the starting material for the sintering process, having YAG as sintering additive. The mixture was processed by: ball milling, drying and deagglomeration, sif, uniaxial (40 MPa) and isostatic (300 MPa) pressing, and, finally, argon atmosphere sintering at 1950°C, figure 1. Part of the samples were uniaxially (80 Mpa) pressed only. The raw surface presented after sintering is quite irregular when viewed by a confocal laser microscope (Figure 2).
Figure 1. Sample preparation: (a) ball milling; (b) prepared for drying; (c) sifting; (d) filling the mold; (e) uniaxial pressing; (f) uniaxial pressed sample; (g) ready for isostatic pressing; (h) isostatic pressing and (i) isostatic pressed sample.

Figure 2. Confocal laser microphotography from a SiC surface after sintering.

Samples were prepared in groups of 20 units or more in order to have enough samples to compound a blockade and a few for characterization: hardness, X-Ray, number and size of open and closed porous.
3. Surface (curve) generation
There are three main steps to obtain an optical surface: curve generation (profile), grinding and polishing. In this work, a Karl Zeiss Curve Generator was used. The main parameters were: 200 mm diameter diamond tool of 3750 rpm and work piece rotation of 0.67 rpm, cooled by ethylene glycol. The lower Ra roughness (15 nm) was obtained after 8 hours of surface shaping.

4. Polishing
Due to high quality of the surface generation, the grinding process was discarded and the samples were immediately taken to polish. A 1 µm diamond paste polishing compound diluted in glycerin was the abrasive used to polish on a polyurethane work plate, in LOH PM-250 polishing machine. The whole polishing process lasts 24 hours. The flatness was measured on a Zygo Mark IV phase interferometer and the roughness on a Taylor Hobson PGI 1000. Those are calibrated instruments, traceable to the Brazilian Metrology Institute (INMETRO).

5. Results and discussion
The flatness measurement of a surface right after curve generation ranged from 1.1 µm and 1.7 µm, after 8h machining. One result is presented in figure 4. This shape is characteristic in this curve generation process.
After every 4 hours of polishing process, the flatness (and the roughness) was measured. The flatness results for sample number 6 are shown in figure 5.

![Flatness measurement after 8h machining on a curve generator.](image)

**Figure 4.** Flatness measurement after 8h machining on a curve generator.

The results for 6 samples polished in the same blockade are shown in table 1. It can be observed that the flatness range is a bit large for samples polished in the same blockade, but it is very hard material, having a very low material removal rate.

| Sample | Initial flatness | Flatness after 24 h polishing | Roughness (Ra) after 24 h polishing |
|--------|------------------|-------------------------------|-----------------------------------|
| 1      | 1749 nm          | 133 nm                        | 7,4 nm                            |
| 2      | 1546 nm          | 157 nm                        | 6,4 nm                            |
| 3      | 1066 nm          | 152 nm                        | 10,2 nm                           |
| 4      | 1665 nm          | 95 nm                         | 5,9 nm                            |
| 5      | 1102 nm          | 226 nm                        | 3,8 nm                            |
| 6      | 1226 nm          | 82 nm                         | 5,7 nm                            |

**Figure 5.** Flatness measurement of sample 6 during the polishing process.

**Table 1.** The results for 6 samples polished in the same blockade.
6. Conclusion
The procedures and techniques applied to obtain low roughness and high flatness SiC mirror (sintered) substrates were presented. The flatness of $\lambda/6$ and Ra roughness of $\lambda/100$, for visible light was obtained. These results were obtained on sinterized Grade BF17 SiC powder.

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References
[1] Torres R V 2006 Estudo de retificação de vidros ópticos (São Carlos: Universidade de São Paulo) Mastering thesis 104 f
[2] Damião A J 2002 Processo de deposição e propriedades de filmes de dióxido de titânio obtidos por Laser Ablation (Campinas: Instituto de Física Gleb Wataghin/Universidade Estadual de Campinas) PhD thesis 111f
[3] Johnson J S and Grobsky K Rapid fabrication of lightweight silicon carbide mirrors Zygo Corporation Donald J Bray, POCO Graphite, Inc. www.zygo.com/library/papers/proc_4771_243.pdf
[4] Konaka M et al Ultraprecision Polishing of CVD-SiC Mirrors. http://www.spring8.or.jp/pdf/en/ann_rep/96/P215-217.pdf
[5] Hu H et al 2011 Research on reducing the edge effect in magnetorheological finishing Appl. Opt. 50 1220-6. doi: 10.1364/AO.50.001220.