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MEGARA Optics: stain removal in PBM2Y prisms

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Abstract. MEGARA is the new integral-field and multi-object optical spectrograph for the GTC. For medium and high resolution, the dispersive elements are volume phase holographic gratings, sandwiched between two flat windows and two prisms of high optical precision. The prisms are made of Ohara PBM2Y optical glass. After the prisms polishing process, some stains appeared on the surfaces. For this, in this work is shown the comparative study of five different products (muriatic acid, paint remover, sodium hydroxide, aqua regia and rare earth liquid polish) used for trying to eliminate the stains of the HR MEGARA prisms. It was found that by polishing with the hands the affected area, and using a towel like a kind of pad, and polish during five minutes using rare earth, the stains disappear completely affecting only a 5% the *rms* of the surface quality. Not so the use of the other products that did not show any apparent result.

1. Introduction

MEGARA is the acronym of Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía. It is the new generation optical spectrograph of the 10.4m Gran Telescopio CANARIAS. The instrument is being built by a consortium of public institutions lead by the Universidad Complutense de Madrid (UCM, Spain) and that includes the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE, México), the Instituto de Astrofísica de Andalucía (IAA, Spain), and the Universidad Politécnica de Madrid (UPM, Spain) [1-6].

To provide the 18 spectral configurations 60 optical elements are required, 36 windows: 12 for low resolution (LR), 20 for medium resolution (MR), 4 for high resolution (HR) and 24 prisms: 20 for MR and 4 for HR. These 73 optical elements are being built at INAOE optical workshop in Mexico. The diameters of the lenses vary between 110 mm and 272 mm. In the case of the pupil elements, the dimensions of the of VPH's windows are 220 mm x 180 mm x 30 mm for LR, and 240 mm x 190 mm x 25 mm for MR and HR, with similar dimensions for the MR and HR prisms apertures [1-5].

A pair of prisms is obtained from an Ohara PBM2Y blank [7], with dimensions of 247 mm x 149 mm x 195 mm, figure 1a.



An overview of the MEGARA project is presented by Gil de Paz et al. [1]. The manufacturing process is described by Carrasco et al. [2]. Specific processes in the optical fabrication are briefly described by Izazaga et al. [6].

In figure 1b, are shown the prisms mounting used during the polishing process. In the instrument design, the prisms have two polished surfaces. The required quality of the prisms HR are, for the first surface, 1 frg at the used aperture (180mm x 140 mm); and 0.5 frg at the central aperture (160 mm x 150 mm). For the second surface, the required quality is 2 frg at the used aperture (180 mm x 200 mm); and 1 frg at the central aperture (160mm x 200 mm). The first surface was designed to have an antireflective (AR) coating while the second surface will be cemented with a fused silica window.

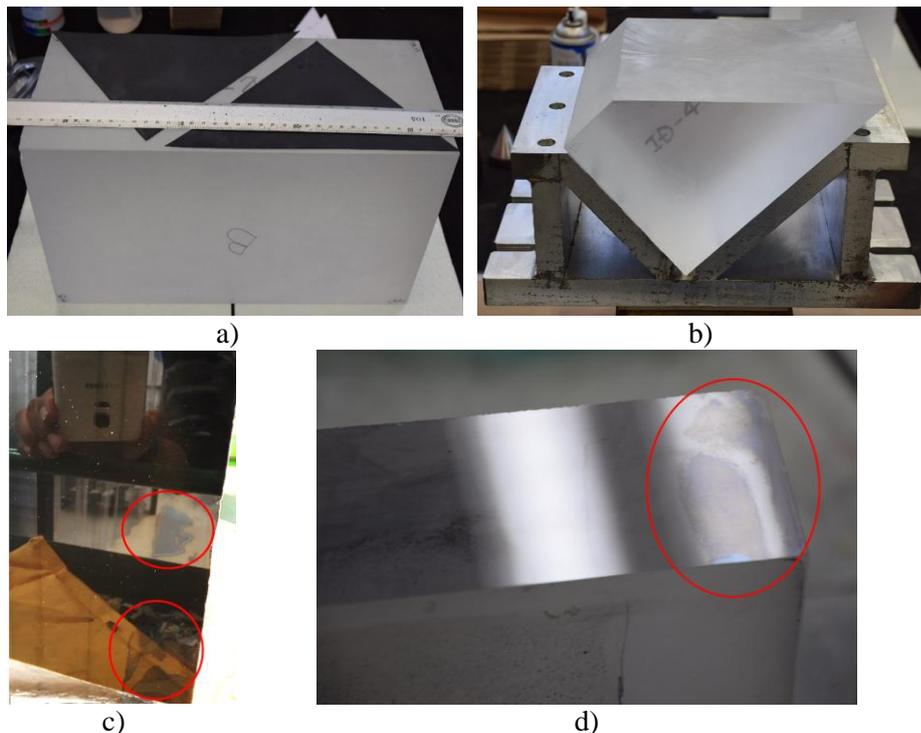


Figure 1. a) Ohara PBM2Y blank, b) HR prism mounted in a cast iron base, c) and d) stains on the polished surface.

During the polishing process, the prism is mounted in a cast iron base made in a CNC machine [7]. To clamp the prism in the base blocking wax was used. When the second surface of the prism is polished, the first surface is covered with a protecting coating to prevent scratches or digs. Then the prism is stuck to the base with wax. The stains problem appeared on the first surface when the polishing of the second surface was ended and the prism was removed from the mounting and it was cleaned [7], see figure 1c. It is believed that the stains were produced by the combination of the wax, the protected coating and the high temperature used to melt the blocking wax ($\approx 70^{\circ}\text{C}$). In figure 1d the stains are evident on the surface by using the reflection of a fluorescent lamp; we can compare the left side of the surface that it is free of stains. It is important to say that these stains appears only on a polished surface and are present in an optical glass with high acid resistance value.

These kind of stains on MEGARA prisms could produce diffused images, optical quality decreasing and maybe some problems with the AR coating or in the cementing with fused silica windows [1]. Thus, it is important that this optics do not have any kind of stains to avoid damages and guarantee the instrument performance.

From the above, the chemical products used are presented and also the techniques used for the stain removal at the INAOE's optical workshop.

2. Tests for stain removal

Due to the stain problem that appeared during the polishing process of the second surface of the HR prism, it was necessary to make some tests to eliminate these stains. Polished pieces of the prism, obtained from the cutting process of the PBM2Y blank, were used for these tests, figure 1a. These

pieces of glass have the same stains problem as the principal prism on the polished surface (large basis of the prism, figure 2).



Figure 2. PBM2Y polished piece used for the cleaning tests.

The piece of glass was divided into three parts and the cleaning test was made on the ends of each surface. Figure 3 shows how the glass was divided.

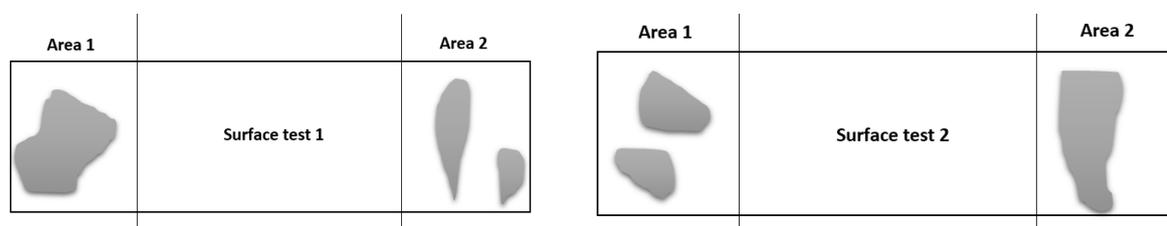


Figure 3. Scheme of the pieces used for the cleaning tests.

In Table 1 are shown the thermal and chemical properties of the glass.

Table 1. Properties of Ohara PBM2Y optical glass.

<i>Thermal properties</i>		<i>Chemical properties</i>	
Strain Point StP (°C)	385	Water Resistance(Powder) Group RW(P)	2
Annealing Point AP (°C)	418	Acid Resistance(Powder) Group RA(P)	1
Transformation Temperature Tg (°C)	436	Weathering Resistance(Surface) Group W(S)	1
Yield Point At (°C)	470	Acid Resistance(Surface) Group SR	1

2.1 Commercial products

The first tests were made with two different commercial products. The first product was Hydrochloric acid (muriatic acid), and the second product was paint remover (water + benzyl alcohol +titanium dioxide). These kinds of products were used because it was thought that the stains could be produced by a kind of thin film deposited on the surface because the chemical evaporation produced by the protecting coating and the blocking wax. Also these products are easy to get in any hardware store.

The first product was spread it above the stains of the surface test 1, area 1 figure 4a; the second product was spread it above the test surface 2, area 1 figure 4b. Both products were left act during 20 minutes but the results obtained were negatives and none of the products produced any perceptible change removing the stains.



Figure 4. Tests with a) hydrochloric acid, and b) paint remover.

2.2 High corrosive chemical products

Due to the results obtained in the previous test, it was decided to make some tests with products used to remove some kinds of thin films deposited on optical glasses, i.e. to remove the aluminum deposited on optical mirrors.

The first of these products was the sodium hydroxide (caustic soda), and the second product was aqua regia (nitric acid + hydrochloric acid). The sodium hydroxide is highly corrosive and is used in the soap industry and for the cleaning and whitening in the textile industry. As solid, the sodium hydroxide has a white color. The aqua regia is also a highly corrosive solution and is composed with a ratio of one-to-three parts of nitric acid and hydrochloric acid mixture that has a yellow color.

The first surface test was left soaking in aqua regia, figure 5a, and the second test surface was left soaking in sodium hydroxide, figure 5b. This procedure was done similar to the process that is followed when a thin film of aluminum coating is removed from optical mirrors.

The two products were left act during 4 hours and the areas under test were checked every 20 minutes to see the progress. During that time was observed that the sodium hydroxide did not cause any apparent change on the surface stains. Whereas that, a little change or vanishing on the surface stains after two hours was observed with the aqua regia, but the stain did not disappear completely.



Figure 5. Tests glasses into a) aqua regia and b) sodium hydroxide.

2.3 Cerium oxide polishing test

Because the results obtained in the last section, it was decided to use the solution that is applied in the majority of the cases when these kinds of troubles appear in optical fabrication, which is re-polish the damaged surface, with the polish machine. This alternative has some problems, one of them is that the grinding and polishing process has to be re-done, but this is time-consuming. Another problem is that, since the stain problem is not controlled, to polish the first surface implies to cover with a protecting coating the second surface, stick it to the base with blocking wax and heating again the material. As we know, the stains appeared when the prism was removed from the base, so risk exists with stains that could appear on the other surface making this a cycle without end. To avoid this problem, it was decided to hand polish the surface with stains. These tests were done using cerium oxide (Universal Photonics rare-earth polishing compound).

In order to follow the figure behavior of the surface during the hand polishing we did an interferometric analysis of the surface irregularity. This analysis was done by using a Newton interferometer with a wavelength of 546.1 nm and an Edmund Optics lambda/10 reference flat. An interferogram was taken before and after the hand polishing. The interferogram was analyzed with the Durango interferometry software (Diffraction International Inc.). With this analysis, we can know the influence of the hand polishing on the surface irregularity in terms of PV and *rms* values. The results obtained in these tests are shown next.

2.3.1 Results for surface 1

Before polishing the area 2 of the first surface, the interferogram of figure 6a was captured. The values obtained when this interferogram was analyzed were 0.9158 frg PV and 0.1190 frg *rms*. The polishing process was done as follow: the area of interest was polished following a path of circles and using a smooth cotton towel similar to a polishing pad, this was done until the stains disappeared completely. This process took about 5 minutes.

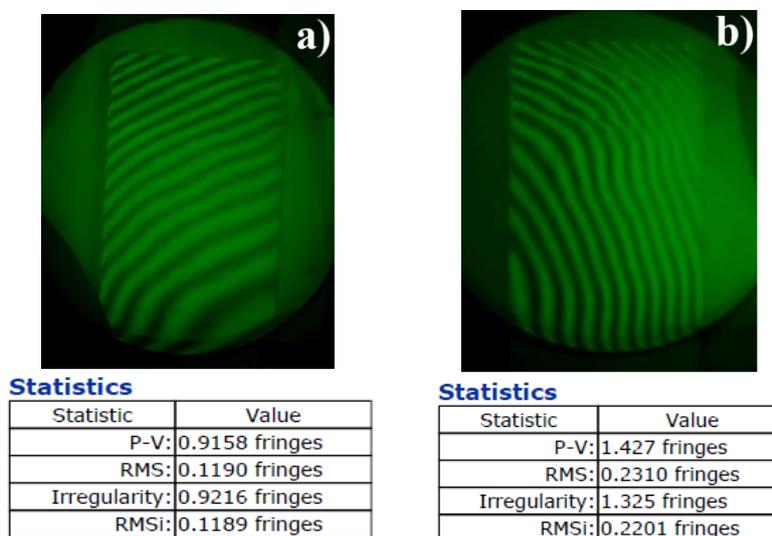


Figure 6. Data and interferogram a) before and b) after polishing surface 1.

Figure 6b shows the surface interferogram after hand polishing. As can be seen, the values of PV and rms were 1.427 frg and 0.2310 frg, respectively. It is observed that two values increased more or less 55% and 94%, respectively. This can be corroborated by observing the interferograms of figure 6b where the fringes are irregular compared with the interferogram fringes of figure 6a.

Although the stains almost disappeared, the problem of scratch and digs appeared on the surface. This effect is attributed to the aqua regia which caused damage to the surface due to its highly corrosive nature.

2.3.2 Results for surface 2

The interferogram that is shown in figure 7a was taken before polishing the area 2 of surface 2. In this figure it can be seen a horizontal gray shadow in the fringe pattern. This shadow corresponds to one of the stains on the surface. The values obtained from the analysis of this interferogram were 1.069 frg PV and 0.2125 frg *rms*.

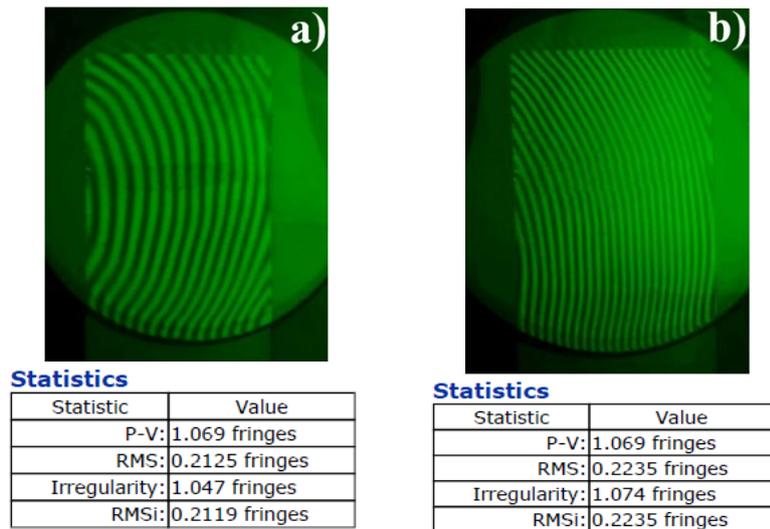


Figure 7. Data and interferogram a) before and b) after polishing surface 2.

The hand polishing time consuming for surface 2 to get stains vanishing was 5 minutes, the same of the last test. Comparing these results against the results for surface 1, this test the scratch and dig defects did not appear because the caustic soda is not more aggressive than the aqua regia. After the hand polishing, the values obtained for the interferogram shown in figure 7b were 1.069 frg PV and 0.2235 *rms*. In this test, the variation in PV and *rms* was 0% and 5%, respectively. Also, it can be seen in figure 7b that the shadow of figure 7a disappeared completely without affecting the irregularity of the interference pattern.

3. Conclusions

In this work was shown the comparative study of different commercial products used for the stain removal in the HR prisms for the MEGARA spectrograph. The results with hydrochloric acid, paint remover, and caustic soda were not satisfactory. The results obtained with aqua regia after 2 hours of treatment were not perceptible, besides this substance produced serious damages on the surface (scratch and digs). On the other hand, the use of cerium oxide for hand polishing worked very well. After 5 minutes of polish all the stains disappeared completely without produce significant changes in the quality of the surface (*rms* 5% and 0% PV, approx.). It is important to remark that these stains appears only in a polished surface, and are present in an optical glass with high acid resistance value.

Due the results obtained in this work, the hand polishing is used at the INAOE's optical workshop for the stains removal in the MEGARA prisms. Besides this technique is used for the stain removal in the COLL-D2 and COLL-D3 lenses, which are part of the collimator system of the instrument.

With this study we can guarantee the instrument performance and avoid damages, i.e., diffused images, optical quality decreasing and maybe some problems with the AR coating or in the cementing process for fused silica windows.

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