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PHOTONICS & IMAGING TECHNOLOGY

Developing a Laser System to Decrease the Rate of Neurodevelopment Issues

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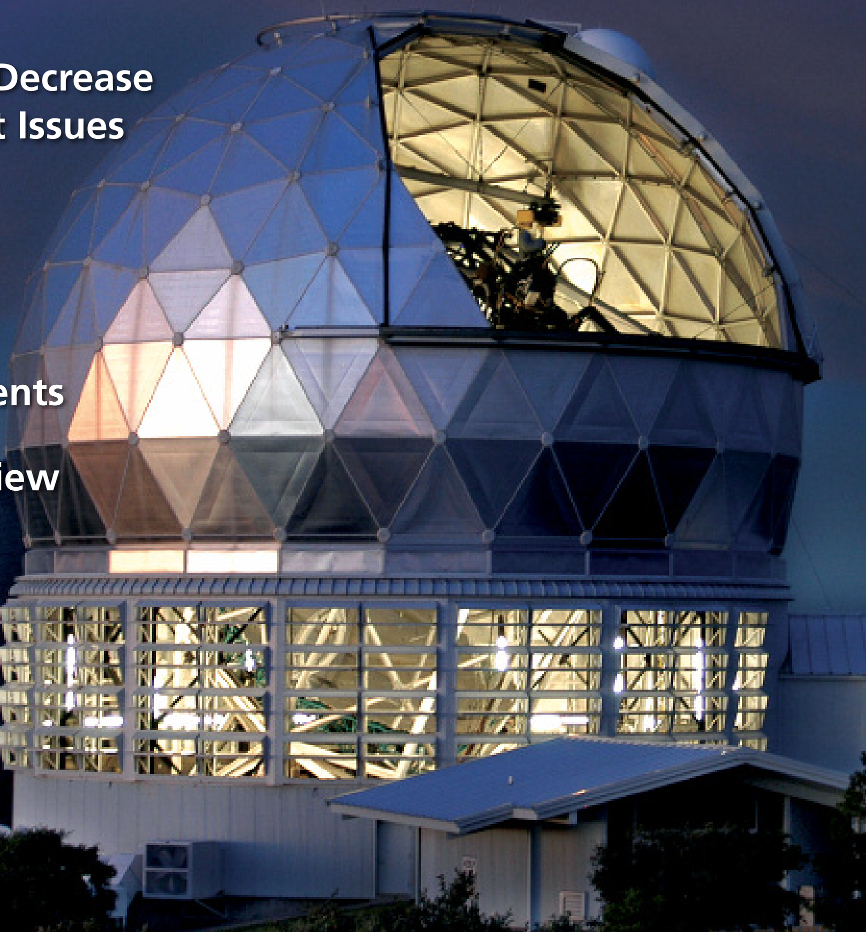
Fabricating Optical Mirrors for Use in Outer Space Measurements

SPIE Photonics West 2017 Preview



Supplement to *NASA Tech Briefs*

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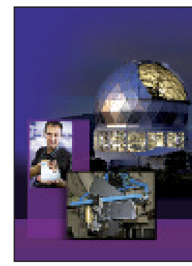

The mirror of the 9.2-meter Hobby-Eberly Telescope is visible through the open louvers in this twilight view of the installation. The Visible Integral-field Replicable Unit Spectrograph (VIRUS), shown beneath it, is a key part of the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX), as are the custom-made mirrors being shown here by Dan Bukaty, Jr., president of Precision Glass & Optics. For more information on how these mirrors were made, see the application brief on page 12.

(Photos of Hobby-Eberly Telescope and Visible Integral-field Replicable Unit Spectrograph courtesy of Marty Harris/McDonald Obs./University of Texas-Austin. Photo of Dan Bukaty, Jr. courtesy of SCHOTT and PG&O.)

APPLICATION BRIEFS

Fabricating Optical Mirrors for Use in Outer Space Measurements

There are many ways to manufacture an optic depending on the complexity of the component and the application. From choosing the best substrate, to detailing the numerous operations required to make the optic, all the while considering tight tolerances and other specifications. This article highlights the precision needed to successfully fabricate the mirrors for the Hobby-Eberly Telescope Dark Energy Experiment's (HETDEX's) Visible Integral Field Replicable Unit Spectrographs (VIRUS) unit which was designed to measure dark energy in outer space.

Review the Specs

The first part of the process is the engineering overview and quoting the part to the customer. We began by going through the customer's specifications and verifying that all the specifications could be achieved.

In this case, they were looking for a borosilicate glass substrate with a flatness of ¼ wave in RMS over the clear aperture (CA), surface quality of 60/40 scratch/dig, and <10 angstroms RMS over the CA. All other surfaces were to be ground with beveled edges and were to include a serial number on each part.

The coating requirements were for a dielectric reflector with an average reflection of >99% from 345-700 nm and an absolute reflection of >98% from 345-700 nm with an angle of incidence (AOI) of 12.5° ± 5°. After the initial review, it was determined that our manufacturing capabilities were a good fit and we proceeded to provide a quote to the customer, which was accepted.

Figure 1. Machining was done on a Haas CNC machine using a custom-made fixture that held the part in place at 12.5°.

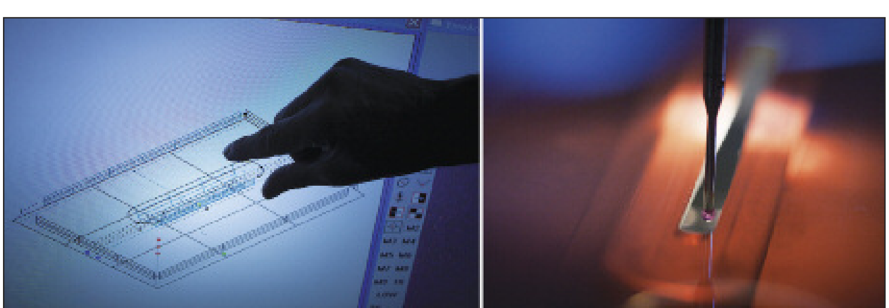

Figure 2. After machining, all dimensions are verified using a Starrett computer measurement machine (CMM) equipped with a touch probe that measures parts to within 2 microns.

Choosing the Substrate

The customer specified Corning Pyrex 7740 as the substrate material. The issue was that Corning no longer manufactures Pyrex 7740, so a suitable substitute had to be found. After much consideration of all the requirements (size, thickness, surface finish, and coating), it was decided to make the part from 25 mm SCHOTT SUPREMAX® 33. The physical and chemical properties of this revolutionary, rolled borosilicate glass include low thermal expansion, high thermal resistance, excellent light transmission, and superior chemical durability. The versatile, low-density glass is 12% lighter than soda-lime glass, making it particularly useful for applications where weight is a critical factor.

Fabricating the Substrate

The customer's specification was for a 216 × 138 × 20 mm mirror. What made this part particularly tricky to fabricate, though, was the 20 × 100 mm pocket centered on the backside of the part that had 10° tapered walls and a 4.6 mm slot that went through to the mirror surface — and the whole feature was 12.5° off axis. We had to decide if we were going to polish the part before or after machining this feature; we decided to machine the part first because sometimes when you polish a part to the flatness requirement and then machine it, the flatness changes.

We started by taking a sheet of 25 mm Supremax and cutting the blanks oversized on our Flow Waterjet. Next, the parts were Blanchard ground to length and width, leaving the thickness oversized. We sent the parts to be precision ground 0.1 mm over the finished thickness plus flat and parallel to within .025 mm. Now the parts were ready to have the center pocket feature prepared.

First, we had to make the CNC program in MasterCAM, which is a CAD/CAM software that allowed us to write the program G codes for our Haas CNC machines. We had special diamond tooling made that would also allow us to machine the 10°

tapered walls of the feature. We custom-made a fixture that went on to our Haas CNC machine that held the part in place at 12.5°. After indicating the part parameters to within .012 mm, we began the machining process (Figure 1).

It is interesting to note here that when we machine glass, we typically use standard equipment that is used in the metal fabrication industry; the difference is that we use diamond tooling and we are actually grinding the glass away. We used a series of diamond grains, starting with a 100-grit metal bond and finishing with a 320-grit metal/resin bond. Diamond wheels are available in different bonds; metal is very tough and can withstand the rough grinding process where metal/resin diamond bonds are softer and leave a smoother finish on glass.

After each part was machined, it was sent to our quality control station to measure the part and verify all the dimensions using a Starrett computer measurement machine (CMM) which uses a touch probe to measure parts to within 2 microns (Figure 2). Once all of the dimensions were verified, the part was sent for polishing.

Polishing the Optic

The polishing had its own set of challenges. To polish an optic with a flatness of ¼ wave in RMS over the clear aperture, surface quality of 60/40 scratch/dig, and <10 angstroms RMS over the CA requires special lapping machines called continuous polishers (CP). After completing a light grind with 9-micron aluminum oxide, we brought the part thickness right to the top of the thickness tolerance.

We then began the polishing process. First, we polished on a pitch lap using Opaline® cerium oxide to polish out the “grey,” which is an optics term describing pits that are left over from the grinding process, and began smoothing out the surface. Once all of the grey was removed, we switched the polishing compound to Hastilite PO cerium oxide and began finishing the surface. We then ran the part, constantly checked the flatness, parallelism, and surface quality, and made minor adjustments with weight and amount of polishing compound to get the final results. We used a 6" Zygo interferometer to verify that the surfaces met the specification (Figure 3).

Depositing the Optical Coating

The final operation was to deposit the coating onto the polished surface. As noted earlier, the dielectric reflector coating parameters ranged from an average reflection of >99% from 345-700 nm to an absolute reflection of >98% from 345-700 nm with an AOI of 12.5° ± 5° (Figure 4). Although the coating is the final process for this part, we actually started the design work many weeks earlier.

We began by designing the coating using TFCalc, which is a thin-film design software that allows you to design coatings using different dielectric and metal materials. The critical first step is deciding which materials to use. Since this design needed high reflection, it was important to find a high-index material and a low-index material. Ideally, you want the separation between these materials to be as great as possible to achieve the highest reflection with the lowest number of layers. Because the coating had to perform down to 345 nm, we decided to use tantalum oxide (Ta_2O_5) with an index of 2.1 @ 550 nm and silicon dioxide (SiO_2) with an index of 1.45 @ 550 nm. The finished optical coating design ended up being 57 layers (Figure 4).

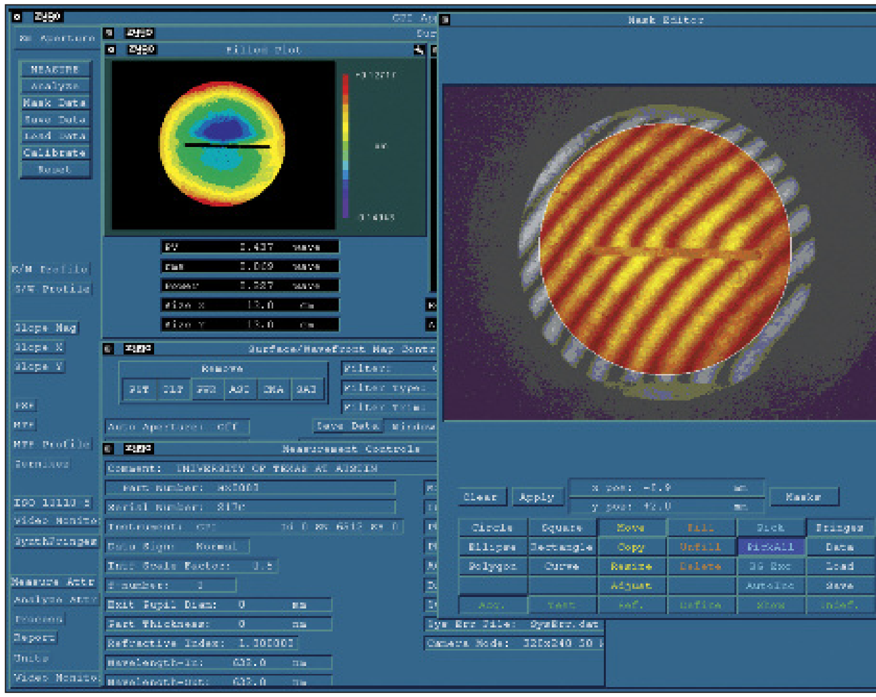

Figure 3. A 6-inch Zygo interferometer was used to verify that the surfaces met the specifications.

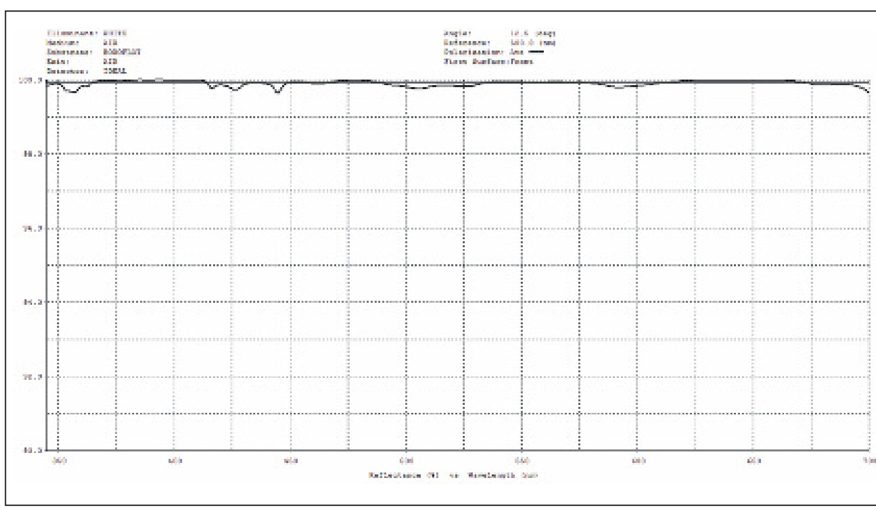

Figure 4. Optical Mirror - Reflectance vs. Wavelength Graph


Figure 5. After verifying that the coating results met the customer's stringent specifications, each individual part was moved to final QC for cleaning, packaging, and shipping.

Testing the Coating Design

With the design phase complete, we performed a test run to verify that the optical coating design would yield the correct results. We loaded the test run and pumped the chamber down to 1×10^{-6} Torr. Using ION-assisted electron-beam evaporation, we coated our test sample using quarter-wave optical monitoring with overshoots to control our layer thickness. When the coating was completed and subjected to all of the environmental testing, we measured the sample using a PerkinElmer Lambda 950 Spectrophotometer. Once we verified that we had a good design and a proven coating process, we were ready to coat the actual parts.

Cleaning the Parts Before Coating

Once the parts were received from inspection and cleaning, we needed to clean them again before coating. We used a multi-step process for cleaning the parts prior to coating, scrubbing them with cerium oxide, then with calcium carbonate before washing them in a mild detergent. A final scrub with di-water was followed by a di-water rinse, and then parts were placed into the acetone vapor dryer.

From there, we moved the parts into our class 1000 laminar flow bench and gave them a final wipe with acetone. All parts were visually inspected for any defects and then placed into the coating tooling. Utilizing our 72" chamber, we were able to coat 32 parts in a single run. After verifying that the coating results met the customer's stringent specifications, each individual part was moved to final QC for cleaning, packaging, and shipping (Figure 5).

It was challenging every step of the way to fabricate these specialized mirrors for the HETDEX project. But it was also an exciting opportunity to be part of a team that enables scientists to study and measure the role of dark energy in outer space.

This article was written by Dan Bukaty, Jr., President, Precision Glass & Optics (PG&O®) (Santa Ana, CA). For more information, contact Mr. Bukaty at danjr@pgo.com or visit ***http://info.hotims.com/65847-202.***