Mirror Facets for the VERITAS Telescopes

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Abstract

Each of the VERITAS telescopes has 345 glass facets. These were manufactured by D.O.T.I. (Roundrock, Texas), by slumping and grinding to obtain the desired optical figure. The facets were aluminized and anodized at the Whipple Observatory. The reflectivity, radius of curvature and spot size were measured. The design specifications for reflectivity (90% at $320\ nm$ and $\geq 85\%$ between $280\ nm$ and $450\ nm$), radius of curvature ($24\ m < \pm 1\%$) and spot size ($< 10\ mm$ at Radius of Curvature) were easily met. The aluminizing and anodizing process are described as well as the effects of exposure at the VERITAS site on the reflectivity.

Glass

VERITAS mirror facets measure $60.96 \pm 0.3cm$ across the flat sides (width) with a radius of curvature (RoC) measuring $24\ m \pm 1\%$. The mirrors are slumped glass $11.5 \pm 1.0\ mm$ thick and aluminized on the front surface.

- The energy concentration of each mirror allows for more than 90% of the reflected light to fall within a 10mm diameter circle located at the radius of curvature.
- An alignment of all mirrors on the telescope produces a point spread function of $0.06°$, which is well within the pixel size of the camera.

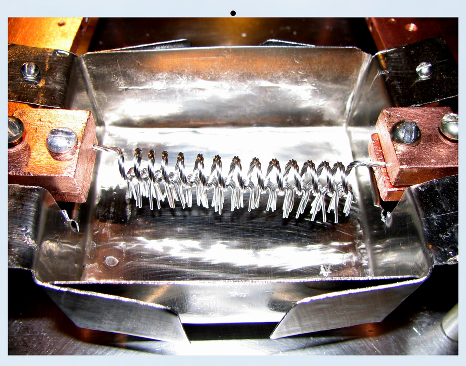
To achieve a high quality aluminum coating, it is essential that the glass be thoroughly cleaned. The glass is washed with a phosphate-free mild detergent (Liquinox) to remove the surface dirt. This is followed by a rinsing with tap water and a final rinsing with distilled water. The glass is then dried in an upright position to help keep it clean. Prior to loading the glass into the aluminizing chamber, the glass is wiped with isopropyl alcohol (99% electronic grade). Once in the chamber, the glass is "dusted" with carbon dioxide snow, which removes any lint or dust present on the glass surface. A final microscopic cleaning using ionized argon is performed under vacuum just prior to the deposition of aluminum [4].

Aluminizing

Aluminizing is the process of evaporating aluminum onto the glass surface to create a mirror. The evaporation must be done under vacuum to ensure the purity of the coating, which is important for optical properties and strong adhesion [3].

- The glass is suspended from the top, facing downwards.
- $75\ cm$ below the glass is a $7.5\ cm$ long tungsten filament.
- The filament supports $30 - 40$ aluminum staples consisting of 99.999% pure, $1\ mm$ diameter aluminum cut to a length of approximately $4\ cm$.
- The final vacuum needed for deposition is in the mid 10^{-5} Torr range. This is the optimal vacuum to ensure both time and quality requirements are met.
- The thickness of the coating is measured using a 5 MHz quartz crystal oscillator mounted inside the chamber adjacent to the glass facet [2].
- **The average aluminum coating is $180\ nm$ thick, deposited at a rate of between 3 and $8\ nm$ per second.**
- **The entire coating process (per mirror) takes about one hour.**

Interior of the aluminizing chamber.



Tungsten filament with aluminum staples.

Anodizing

Anodization is a process in which the top layer of the pure aluminum coating is converted into a harder and more durable layer of aluminum oxide. This is accomplished by passing an electrical current through the aluminum coating while it is submerged in an electrolyte solution. Compared to a quartz overcoat, the anodized surface is much less prone to deterioration, is less costly to produce and can be washed as needed.

- The electrical circuit consists of the cathode (mirror surface), electrolyte solution and the anode (aluminum coil).
- The electrolyte is a weak acidic solution (pH 5.5) containing ammonium hydroxide, tartaric acid, distilled water and ethylene glycol.
- The anode is an aluminum wire of $1.5\ mm$ diameter and approximately $15\ m$ long laid out in a spiral pattern 10cm above the mirror, but fully submerged in the electrolyte [2].

The Anodizing Tank

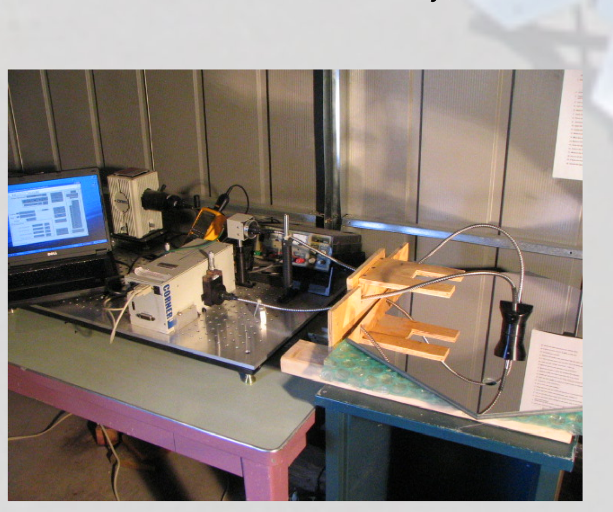
Quality anodized coatings are very sensitive to the cleanliness of both the glass and evaporated aluminum. During anodization any impurities present create high electrical fields which accelerates the reaction, breaking the aluminum surface bonding and causing pinholes. It is important to anodize the mirror immediately after coating as some amount of oxidation occurs naturally in the atmosphere and this oxide will crack as the new layer forms underneath.

The thickness of the anodized layer determines the wavelength at which peak reflectivity of the mirror is obtained. This thickness is controlled by adjusting the voltage across the electrolyte [1]. Typically, $60\ V$ is used at a current of $8\ A$ which oxidizes the top $80\ nm$ of the aluminum coating. This gives a reflectance of 92% at approximately $320\ nm$. It takes less than 5 minutes to anodize a mirror.

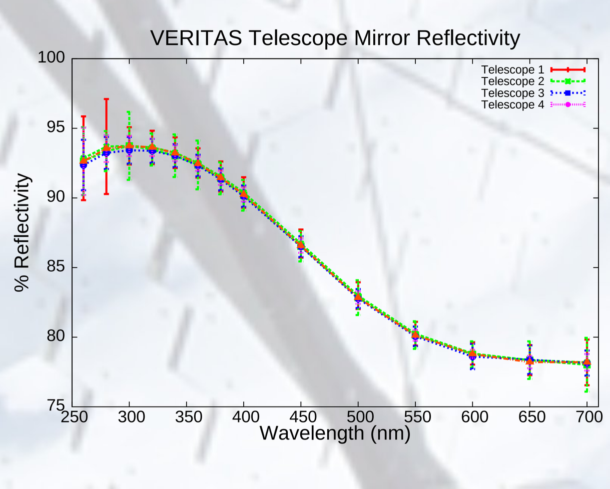
Testing and Validation

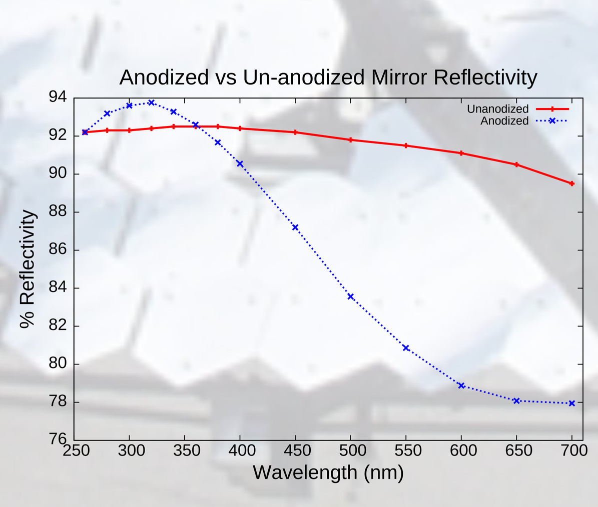
On-site testing includes measurements of reflectivity, spot size and radius of curvature after coating.

- Reflectivity is measured using a broad-spectrum light source, an adjustable filter wheel and a photometer (Oriel 71610).
- All reflectivity measurements are referenced to a calibration mirror of pure aluminum (which is periodically recoated to ensure consistency).



Reflectivity Measurement Lab



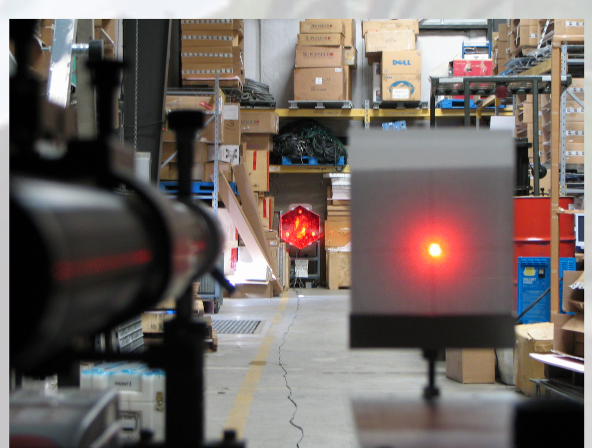


Minimum specifications are 90% at $320\ nm$ and $\geq 85\%$ between 280 and $450\ nm$.

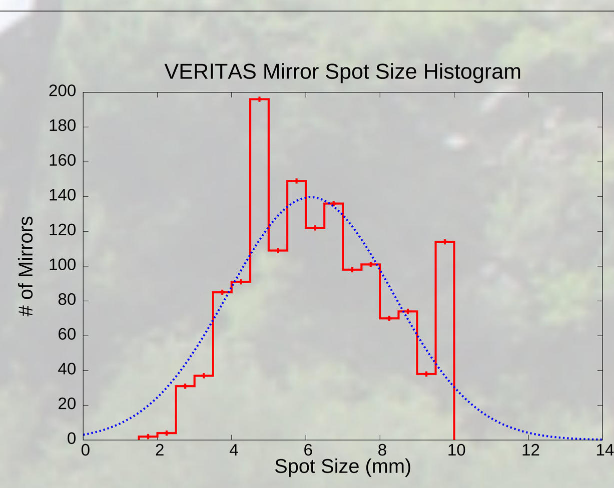
For spot size and radius of curvature measurements a laser beam is passed through a diffuser to illuminate the entire mirror surface and reflected light is viewed on a screen located $24\ m$ from the mirror. We measure:

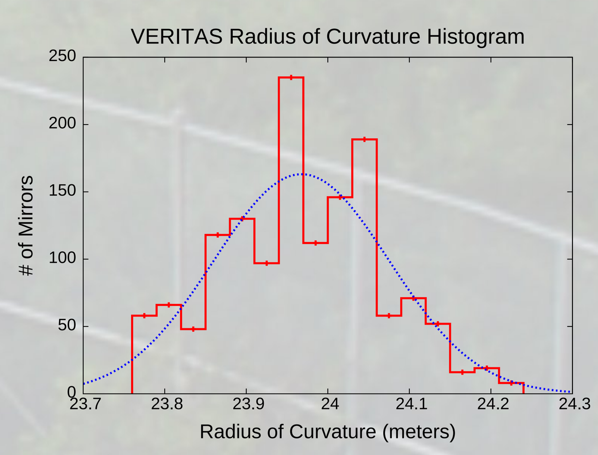
- the image size at $24\ m$ (the nominal RoC) and
- by adjusting the target distance, the minimum spot size.

The minimum spot size corresponds to the actual RoC and is defined by the smallest circle into which 90% of the reflected light falls.



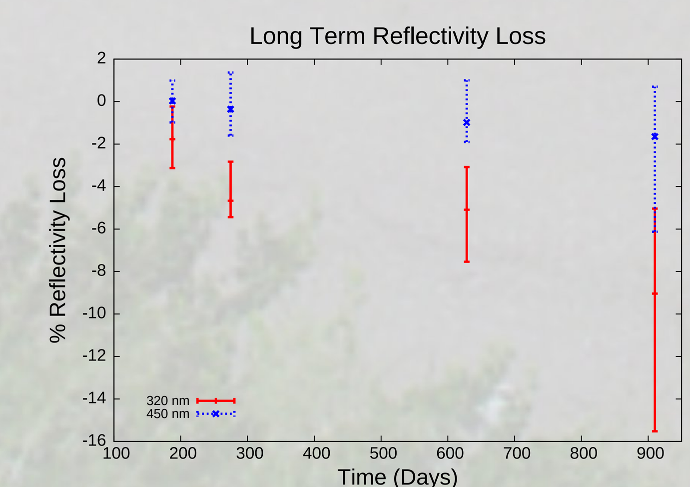
RoC and Spot Size Measurement





Design specifications established a RoC equal to $24\ m \pm 1\%$ and a spot size $< 10\ mm$ at RoC. The mirrors had an average RoC of $23.97 \pm 0.01\ m$ and an average spot size of $6.0 \pm 0.5\ mm$.

Effects of Exposure on Reflectivity



Preliminary reflectivity measurements taken at the beginning of 2007 on the first two telescopes showed an overall loss of 3% reflectivity per year at $320\ nm$. More recently we have begun regular testing of four mirrors per telescope (two in the upper region and two in the lower region) which will be repeated every three months. Using the first of these long-term measurements we can show the beginning of a trend of reflectivity loss over time. Given the amount of degradation seen on the first telescope, we plan on recoating those mirrors in the summer of 2007.

Conclusions

On-site aluminization and anodization of the glass facets have produced quality mirrors for all four VERITAS telescopes. All design specifications for optics and reflectivity were met. While any reduction in reflectivity is undesirable; the apparent rate of loss is acceptable and should not adversely affect the quality of data produced by the array. Ongoing studies of the degradation of mirror reflectivity over time will help us to optimize the use of our coating facility as well as understand the environment in which our mirrors reside.

References

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