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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 get 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.

Introduction

In early 2003 work began on the first of the four VERITAS telescopes at the Whipple Observatory. Displays and Optical Technologies Inc. (D.O.T.I.) of Roundrock, TX supplied the 1,470 VERITAS glass facets. To produce the best quality mirror facets as quickly as possible the gamma ray mirror coating facility was moved from Mt. Hopkins to the Observatory basecamp. With a new, cleaner, mirror lab, an upgraded vacuum pump and new glass from D.O.T.I., we were able to produce mirror coatings of a quality exceeding any on the 10m telescope. Continuing the decision made in 1992 we no longer use a quartz overcoat. Our aluminum coatings are anodized and have a hard aluminum oxide surface. This anodized surface is much less prone to deterioration than the quartz treatment, is less costly to produce and can be washed as needed.

Glass

VERITAS mirrors are hexagonal facets which measure 60.96 ± 0.3 cm across the flat sides (width) with a radius of curvature (RoC) measuring 24 m $\pm 1\%$. The mirrors are slumped glass 11.5 ± 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 10 mm diameter circle located at the radius of curvature. An alignment of all mirrors on the telescope produces a point spread function of $0.06°$(at $70°$ elevation, with a bias alignment), 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, to remove 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 [5].

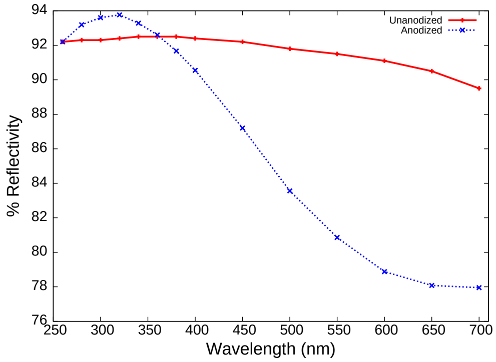

Figure 1: Anodized and un-anodized mirror reflectivity versus wavelength. The un-anodized mirror has a relatively flat wavelength response compared to the anodized mirror. However, anodization greatly increases the lifetime of the mirror.

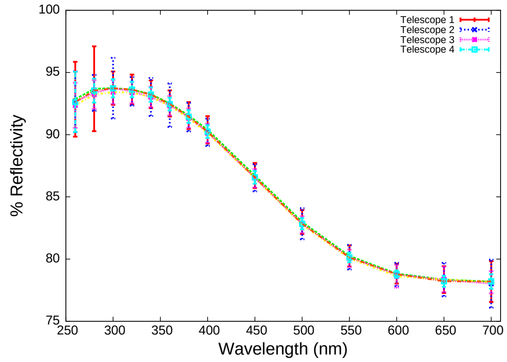

Figure 2: VERITAS telescope mirror reflectivity versus wavelength broken down by telescope. The design specified reflectivties of 90% at 320 nm and $\geq 85\%$ between 280 nm and 450 nm.

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 [4]. The aluminizing chamber measures roughly one cubic meter internally and easily accommodates a single facet. The glass is suspended from the top of the chamber, facing downwards. About 75 cm below the glass is a 7.5 cm long tungsten filament supporting $30-40$ aluminum staples. These staples consist of 99.999% pure, 1 mm diameter aluminum cut to a length of approximately 4 cm. The pressure inside the chamber is reduced first by a 150 cfm Stokes fore pump and then by a Varian Turbo Molecular pump. 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 [3]. The average aluminum coating is 180 nm thick, deposited at a rate of between 3 and 8 nm per second. A minimum allowed coating of 135 nm was established to ensure a uniform reflectivity across the surface of the mirror. The entire coating process (per mirror) takes about one hour.

Anodization

Traditional telescope mirrors are coated with pure aluminum. As aluminum is easily weathered, most telescopes are protected by a dome. Unfortunately, this is not feasible for air Cherenkov telescopes. Previously, a protective quartz overcoating was used on the 10 m telescope. However, pitting in the overcoating led to rapid deterioration of the aluminum reflectivity, and this method was abandoned in 1992 in favor of anodization [3].

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 a current of electricity through the aluminum coating while it is submerged in an electrolyte solution. The electrical circuit consists of the cathode (mirror surface), electrolyte solution and the anode (aluminum coil). The cathode makes contact with the aluminum coating at the three mounting holes to produce an even current distribution and minimize the un-anodized surface area. The contact material is 000-steel wool which is kept dry by compressing rubber o-rings against the aluminum coating. 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 10 cm above the mirror, but fully submerged in the elec-

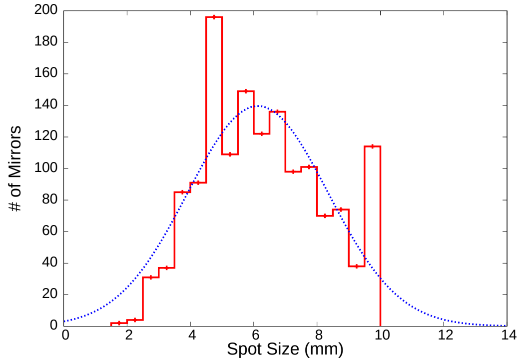

Figure 3: Histogram of the spot sizes of the VERITAS mirrors along with a Gaussian fit. The specifications established a spot size of < 10 mm at RoC. The mirrors had an average spot size of 6.0 ± 0.5 mm.

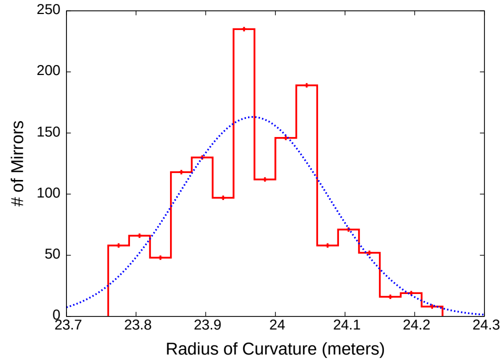

Figure 4: Histogram of the RoC of the VERITAS mirrors along with a Gaussian fit. Design specifications established a radius of curvature equal to 24 m $\pm$ 1%. The mirrors had an average RoC of 23.97 ± 0.01 m

trolyte. 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 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 [2]. 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 (Figure 1). It takes less than 5 minutes to anodize a mirror.

Testing

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). Minimum specifications are 90% at 320 nm and $\geq 85\%$ between 280 nm and 450 nm (Figure 2). The reflectivity data is acquired soon after mirror coating to provide a baseline for the determination of mirror quality degradation due to environmental effects.

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. The first measurement is the image size at exactly 24.000 m (the nominal RoC). Next, the absolute minimum spot size is determined by adjusting the target screen distance. The minimum spot size corresponds to the actual radius of curvature and is defined as the smallest circle into which 90% of the reflected light falls (Figures 3 and 4).

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

Effects of Exposure on Telescope Mirror Reflectivity

Preliminary reflectivity measurements taken at the beginning of 2007 on the first two telescopes built showed an overall loss of 3% reflectivity per year

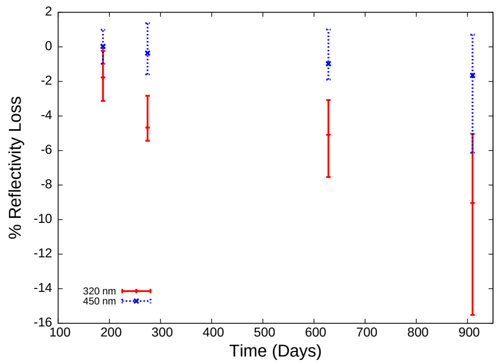

Figure 5: Long Term Reflectivity Loss. Preliminary reflectivity measurements taken at the beginning of 2007 on the first two telescopes built showed an overall loss of 3% reflectivity per year at 320 nm.

at 320 nm (Figure 5). See [1] for more information on the weathering of mirrors at the observatory.

As the telescopes are in stow position the majority of the time, uneven weathering of the mirrors occurs. Roughly, the upper third of the mirrors are mounted in an overhang, facing downward. These mirrors are less affected by rain and dirt build up. One mirror in this upper region was measured showing only a 1% loss (@320 nm) during the 2.5 years it had been in use. This mirror may be particularly shielded as it is mounted adjacent to the upper quad arm and therefore may not represent the average degradation of the upper telescope.

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 and variability of degradation seen on T1 and the possible corresponding effects that would be seen in the long-term drift of the energy threshold and event rate, we plan on recoating these mirrors during the summer of 2007.

Conclusions

On-site aluminization and anodization of the glass facets provided by D.O.T.I. 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.

Acknowledgments

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