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Maintenance and testing of anodized aluminum mirrors on the 10-m Whipple gamma-ray telescope

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Abstract. Threshold energy sensitivity depends not only on the high reflectivity of the mirrors used in atmospheric Cherenkov telescopes but also on the maintenance of this reflectivity over months/years. The successful application of a mirror maintenance technique depends on the type of mirror coating and the contamination that must be removed. The uncovered mirrors in use on the 10-m Whipple gamma-ray telescope are anodized aluminum mirrors. A standard cleaning technique for such mirrors is not available. With the aim of extending the life of the aluminum coating exposed to the MtḢopkins environment, several cleaning procedures were tested on mirrors that had been exposed for three years. Evaluation of the most effective cleaners is presented. Preliminary results are also presented from a long-term experiment using newly coated mirrors at the proposed VERITAS site and at the current 10 m site. This experiment is designed to reveal the rates at which the reflectance degrades as a function of time, depth of anodization, storage direction, degree of covering, and maintenance procedures.

1 Introduction

Numerous telescope designs exist for a wide variety of applications in ground-based astronomy. One of the most important parts of any telescope is its mirrors. These have to be kept in the best possible condition. In almost all astronomical applications, mirrors are subjected to the environment only during the course of the observations and are covered during non-working time. The observations are normally carried out in good atmospheric conditions. An exception is the VHE gamma-ray atmospheric Cherenkov telescope. In this case, the mirrors are subject to high contamination due to the fact that they are normally not covered. This results in them being subjected to all environmental impacts. To reduce the effect of the environment on the mirrors, anodized mirrors or mirrors with protective overcoatings are normally used. The original coating used on the mirrors of the 10 m reflector were aluminized with a quartz overcoating (Liberty Mirror 747). After 3-4 years it was found that the reflectivity had decreased to 40%. A detailed study of the mirrors showed that the deterioration in the Arizona mountain desert environment was due to chemical action from many small holes in the overcoating probably caused by sand blasting in high winds (Meinel and Meinel, 1976). The commercial overcoating of quartz is expensive, difficult to clean and of limited lifetime. Hence in 1992 the Whipple group switched to anodized Al coatings; the aluminization and anodization are done in house (Harris et al., 1992).

Aluminum is widely used as a coating because of its superior reflectivity especially at the UV and the blue range of the spectrum. This range of wavelengths is particularly important in the detection of atmospheric Cherenkov light generated by very high energy gamma-rays. The mirrors in use on the 10-m optical dish now are anodized to protect against deterioration. The anodization process causes some loss in the reflectivity (of the order of few percent) but increases the hardness of the mirror.

Some of the most exciting astronomical discoveries of this century have come from gamma-ray astronomy (e.g. Weekes, 1999). An extension of the present ground base experiments will be the operation of a multi-telescope array in order to reduce the energy threshold and increase the sensitivity to weaker sources. The VERITAS experiment (Weekes et al., 2001) will come into operation over the next few years. The proposed experiment should have seven times the mirror area of the 10-m telescope. A cleaning technique for the 10-m mirrors is not generally available. There are no standard test procedures for this coating under these environmental conditions. The cleaning technique may be different from those developed for different optics in less severe environments. It is the aim of this study to develop in situ, a safe, efficient, method applicable for very large telescope optics, and an inexpensive cleaning technique for mirrors continuously exposed to the open air.

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2 Reflectivity Degradation

The factors degrading optical performance of the telescope optics are the deterioration of the reflective coating and the accumulation of contamination on the mirror surface. The loss of Al layer from the substrate can be due to residual mounting stress and relaxation of structural materials. It can also be a result of environmental exposure. In this case the recovery of the reflectivity is achieved by stripping the Al layer and recoating the substrate. Contaminants on the reflecting surface cause significant degradation of its reflectivity and increase the scattered light. Sources of pollution are many and depend on the site (local environment) and season. Among the pollutants are dust, molecular contaminants (pollens, oil films, and water spots), air contaminates (SO_2, NO, H_2S, and NO_2), bird dropping, and insects attracted by the light reflected from the mirrors. Common contaminants are diorite and amphiboles. Diorite is generally composed of feldspars (mineral composition based on Si) and amphiboles (silicates having a complex formula associating Al, Fe, Mg, Ca, and Na). Some diorites contain quartz.

3 Mirror Cleaning Techniques

The appropriate cleaning technique and cleaner depends upon the optical material, coating and contaminant. Based on investigations carried out for telescopes in other fields of astronomy, there are a number of methods aiming to achieve surface cleaning without damaging the aluminum coating and the mirror substrate. They can be divided into contact (C) and noncontact (N) methods.

1. Electrostatic cleaning device (C). The results are not satisfactory.
2. Self-adhesive roller (C). This method is unusable on curved surfaces.
3. Peel-off technique (C). It is a polyurethane dispersion in water of white coloration. The material is poured or sprayed onto the optical surface, allowed to dry, and then stripped off the surface. It is well suited for cleaning both small and large Al coated mirrors but an appropriate masking of mechanical surroundings is advisable. It can also be used as a protective layer.
4. CO_2 sweeping (snow-flake technique) (N). The method relies on impulsive force from CO_2 crystals to knock particulates from the surface. The snow quickly sublimates, so the particulates glide over the mirror surface on a cushion of gas. It is effective in removing dust. It was found that it is better than dry air or nitrogen blowing [ref]. The mirror should be tilted by around 60 degrees and the injection of CO_2 snow-flakes takes place from the top to the bottom of the mirror. The application of CO_2 snow depends on the local humidity (Zito, 1990). The CO_2 cleaning works very well as long as the mirror stays dry. If the mirror gets wet when dirt is present, it will stick and the cleaning will not remove it. In such case washing is necessary. Molecular contaminants and very small dust particles, which adhere with a relatively high force per mass, can lie under the cushion of the gaseous CO_2, and are not effectively removed.
5. UV laser (N). This is a relatively new technique. Laser cleaning delivers photons directly to the surface where bonds between contaminants are broken. Photoacoustic stress waves from the pulsed beam and photothermal vaporization are important at removing particulates, molecules, and thin films of water or oils. The UV-laser cleaning outperforms CO_2 snow cleaning by a factor of two (Kimura et al., 1995). It covers an area of about 52 m^2 in 10 hours. There are a number of disadvantage of using this method. To achieve a maximum cleaning efficiency, spraying of water close to the laser impact is needed. This method requires extra safety precautions during cleaning because of UV laser reflections. Operation and maintenance of the laser may need skilled technicians. Complicated optics is necessary to scan the whole surface of each mirror. The equipment used in this method is relatively heavy.
6. Washing methods (C). Washing the mirrors includes many cleaners; e.g. soap, isopropyl alcohol, actone, methanol, ethyl alcohol, lens cleaner. In one method (Barney washing method), lens cleaner in solution with deionized water is used with cotton in a drag only method. This is followed by a deionized water rinse and then by blowing the water off with dry nitrogen. The advantages of this method is that the solution rinses very well and because of the lack of rubbing there is very little measurable increase in the mirror scatter even with many washes.

4 Reflectivity Measurements

The reflectivity measurements were performed using a Deuterium lamp, an f/1.5 condenser lens, an f/4.6 focusing lens, and a monochromator with UV grating. Two liquid optical fibers are used to guide the incident and reflected light into and from the mirror, respectively. The reflected light is passed through the monochromator to the UV enhanced Si detector. A standard mirror is used to calibrate the reflectometer. In addition, comparative measurements of the reflectometer are made from time to time using a specular reflectometer. Mirrors were evaluated outdoors on the 10-m dish using a cherry picker to access all the mirrors and two compact hand-held reflectometers (DYN-Optics 262) were used to measure the reflectivity at 430 and 550 nm. Each reflector is calibrated with an on-board reflector. This allows fast scanning of the mirrors on the telescope.

5 Preliminary Test of Cleaning Methods

A few broken pieces of mirrors were used to test the efficiency of the following cleaners: 1) blue spray protective coating, 2) universal cleaner/degreaser; this cleaner is used

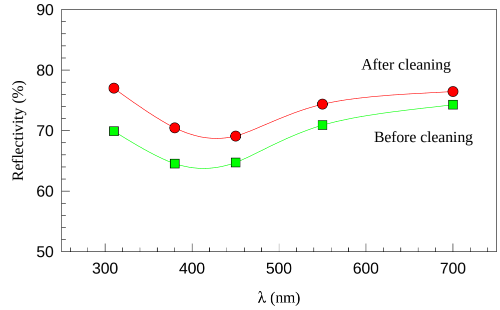

Fig. 1. The average measured reflectivity of 11 three-years old mirrors before and after cleaning with Universal cleaners.

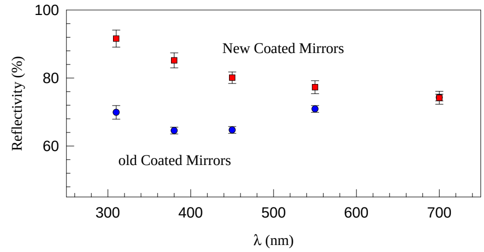

Fig. 2. Measured reflectivity of the three year old and fresh anodized aluminum mirrors.

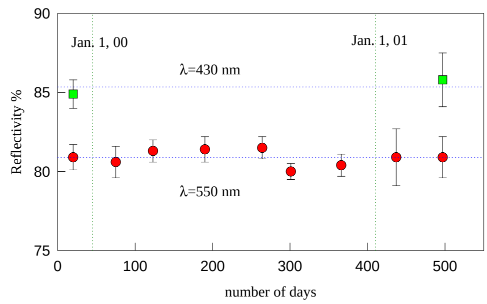

Fig. 3. Mirrors reflectivity measurements at 430 and 550 nm over a 17 month time period. The reflectivity in both wavelengths seem to stay constant during the testing period.

to clean silicon wafers in the production process in the semiconductor industries as an alternative to the freon washing, 3) Lens cleaner, 4) Optical cleaner, 5) Liqui-nox, 6) Isopropyle alcohol, 7) Acetone, 8) Methanol, 9) Ethanol, 10) Front surface metallic reflector cleaning fluid, and 11) CO_2.

The reflectivity was measured at five positions on each mirror and the mean value was calculated. This was done before and after the cleaning. Generally, isopropyle alcohol, acetone, methanol, and ethanol with 25, 50, 75, and 100% concentrations did not provide any improvement. In some cases, it seemed that there is even a loss in the reflectivity after cleaning. No measurable effect was found by the application of CO_2 and front surface metallic reflector cleaning fluid. Some improvements was found by the application of blue spray protective coating, universal cleaner/degreaser, lens cleaner, optical cleaner, and Liqui-nox.

These five cleaners were then tested on mirrors on the telescope to determine the real improvement with good statistics and to see how long the improvement lasts. It should be kept in mind that the coating on these mirrors was about three years old and the improvement achieved should be taken as a lower limit. The effectiveness of the cleaning methods may vary if tested on freshly coated mirrors. Generally, the universal cleaner/degreaser improves the reflectivity at short wavelength. Fig. 1 shows the average of 11 mirrors before and after cleaning with universal cleaner/degreaser. On the average the method provides about 6% increase in reflectivity. These measurements indicate that universal cleaner is more effective especially at short wavelengths and lasts for a longer time. The second most effective cleaner is the lens cleaner. In contrast it provides more improvement at longer wavelengths. The results suggest that the reflectivity drops much faster with time at shorter wavelength (310 and 380nm) compared with at 450nm.

6 Long-Term Experiments

6.1 Testing Mirrors on the 10-m Telescope

Based on the previous measurements, a test was started in Nov. 1999 on the newly coated mirrors on the telescope. Fig. 2 shows the reflectivity measured of newly recoated and three year old mirrors. Four groups of mirrors were selected, each consisting of five mirrors. The four groups were cleaned bimonthly with water, water and Liqui-nox, universal cleaner, and lens cleaner. The mirrors were selected with positions in the lower part of the telescope and each group of mirrors was closely located to make sure that they are not affected by the cleaning method applied on an other group of mirrors. The rest of the mirrors on the 10-m telescope are cleaned with water without application of any cleaner either bi-monthly or when necessary. The reflectivity measurements are carried out immediately after the cleaning. The application of the cleaning technique involves only spraying the cleaner on the mirror. It does not include hard washing or rubbing.

6.2 Testing Small Mirrors at Two Sites

The direction from which contaminants are more likely to come not only depends on the direction of the wind but also strongly depends on the nature of the site. Two mirror test boxes were designed; one was placed close to the 10-m telescope (2,300 m a.s.l) and the other one at the proposed VERITAS site (1,300 m a.s.l). The box sides are arranged to face up, down, East, West, North, and South. 15 flat mirrors with dimensions of 5cm$\times$5cm are placed on each side. Those mirrors are divided into three groups (five each) which were anodized using currents of 2, 6, and 10 Amp. Four mirrors of the group of mirrors with the same anodization current are

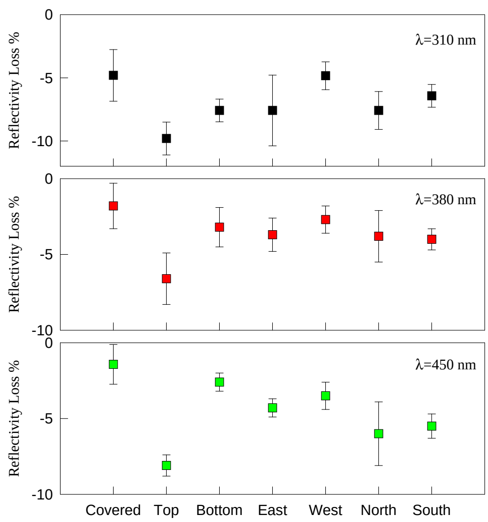

Fig. 4. Reflectivity at 310, 380 and 450 nm of flat test mirror (uncleaned) at the bascamp after being subjected to the environment for about 15 months.

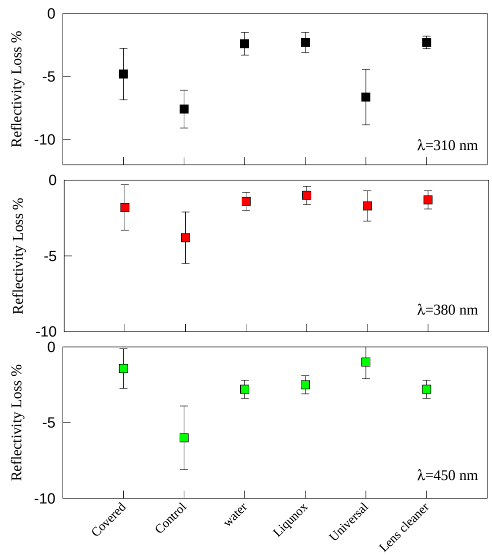

Fig. 5. Reflectivity at 310, 380 and 450 nm of flat test mirror cleaned with different methods at the bascamp after being subjected to the environment for about 15 months. Also shown are the reflectivity of control and covered mirrors.

cleaned bi-monthly with one of the four cleaning methods and one mirror is monitored as a control. In addition, three mirrors with different anodization currents were put on the North side of each box and covered partly with aluminum sheet. These mirrors should serve to provide information about the effectiveness of loosely covering the mirrors on the telescope. The North direction is chosen because it is the stowed position for the gamma-ray telescope. Both boxes were installed on site on Feb. 2000. This test is designed to give information about the most probable direction of pollutants and about the effectiveness of the four methods of cleaning. This arrangement should also serve as a test for the best condition for anodization.

6.3 Preliminary Results

Fig. 3 shows the average reflectivity of some mirrors on the telescope at 430 and 550 nm. For a period of time of 18 months, the reflectivity was constant. This is a good indication that regular washing with water helps remove contaminants. Results of four groups of mirrors cleaned with different cleaners do not show any difference from those cleaned with water. Continuing this program should provide evidence of any possible difference between the cleaners used in the future.

On the other hand, measurements at both sites do not yet give a statistically significant result about a more preferred direction for contaminants, or a difference between mirrors with various anodization current, or a comparison of the two sites. Despite this, there is some indication that there is less contamination from the West relative to the other directions and slightly more from the North. This is shown in Fig. 4 which also illustrates the fact that the uncleaned mirrors on the top lost more reflectivity because they are continuously subjected to sunlight. Also shown in Fig. 5 is that partly covered mirrors have some protection. On the other hand, cleaning the mirrors seems to be equal or more efficient than covering them. The results do not give a strong preference of one cleaner over the other. There is some unexpected indication that applying the Universal cleaner provides less efficiency at 310 nm compared with the other cleaners.

Both the information gained from the preliminary test and the available results from the two long-term experiments are valuable towards our understanding of the degradation of the mirror reflectivity and the best way to avoid it. These programs are planned to continue over the next few years. It is the hope that future results will help to minimize the loss of reflectivity of the mirrors for a long period of time, which would be a great advantage for the VERITAS experiment.

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