High-reflectance, High-durability Coatings for IACT Mirrors

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Abstract: Increased reflectance and longterm durability are major goals in the development of mirrors for CTA, the future observatory for very-high energy gamma-ray astronomy. Multilayer protective coatings on top of an aluminium coating and especially purely dielectric coatings show an increase in reflectance by 5 to 10% and a significantly better resistance to environmental impact simulations in the laboratory than aluminium coatings with a single SiO_2 protective layer as are used in present day experiments.

Keywords: CTA, Imaging Atmospheric Cherenkov Telescope, Gamma-rays, Optics

1 Introduction

Imaging Atmospheric Cherenkov Telescopes (IACTs) for very-high energy (VHE) gamma-ray astronomy image Cherenkov light of particle showers in the atmosphere onto a photosensitive detector. The wavelength range of interest is roughly between 300 and 600 nm. Typically IACTs have tesselated mirror areas of the order 100 m^2 and larger. The current standard (e.g. in H.E.S.S., VERITAS and partially MAGIC) are mirrors with glass surfaces, coated on the front surface with aluminium (Al) and a single protective layer (e.g. SiO_2, Al_2O_3). Not being protected by a dome, the mirrors are constantly exposed to the environment and show a loss of reflectance of a few per cent per year. This requires re-coating of all mirrors after approximately 5 years. For the future CTA observatory (see [1]) with a total planned mirror area of about 10000 m^2 this would mean a significant maintenance effort. Coatings which increase the lifetime of the mirrors can therefore play a major role in keeping the maintenance costs of the observatory lower. If new coatings in addition show a better reflectance than the classical Al + SiO_2 coatings the sensitivity of the instrument will be increased.

2 New Coating Options

Aluminium coatings with a single SiO_2 layer typically show a reflectance of 80 to 90% between 300 and 600 nm. To enhance this reflectance and the durability of the coatings two commercially available options are currently under investigation:

(a) A three-layer protective coating (SiO_2 + HfO_2 + SiO_2) on top of an Al coating. Already this enhances the reflectance by about 5% as can be seen in Fig. 1 in comparison to the reflectance of an Al + SiO_2 coating.

(b) A dielectric coating, consisting of a stack of many alternating layers of two materials with different refractive indices, without any metallic layer. This allows to custom-taylor a box-shaped reflectance curve with ¿95% reflectance between 300 and 600nm, and ¡30% elsewhere. The reflectance curve of this coating is as well shown in Fig. 1. The design could be adjusted to the required wavelength range such, that e.g. a cut-off at 550nm allows to reduce the night-sky background (first emission line around 556nm). The latter might become important in combination with a possible future replacement of the current photomultiplier tubes (which are less succeptible to night sky background) by silicon detectors that have a good quantum efficiency as well for wavelengths above 600 nm.

3 Durability Testing

A series of durability tests have been performed with small glass sample that have been coated with the different coatings to evaluate their resistance to environmental impact in the laboratory.

Temperature and humidity cycling: The samples have been exposed to overlapping cycles in temperature (-10° C $<$ T $<$ 60° C; 5 h cycle duration) and in humidity (5% to 95%; 8h cycle duration) for a total of approximately 8000h. The different cycle duration was chosen to expose the sam-

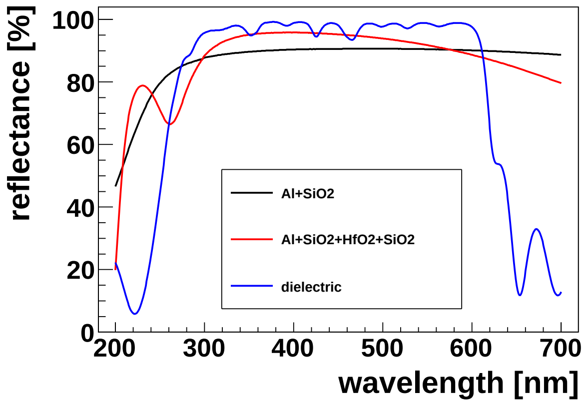

Figure 1: Comparsion of the spectral reflectance of the two newly investigated coatings (Al + SiO_2 + HfO_2 + SiO_2 and dielectric) relative to Al + SiO_2.

ples to all possible combinations of temperatures and humidity. The reflectance as a function of wavelength of the samples has been measured with a spectrophotometer (angle of incidence 7°) before and after the cycling. The results of these measurements are shown in Fig. 2

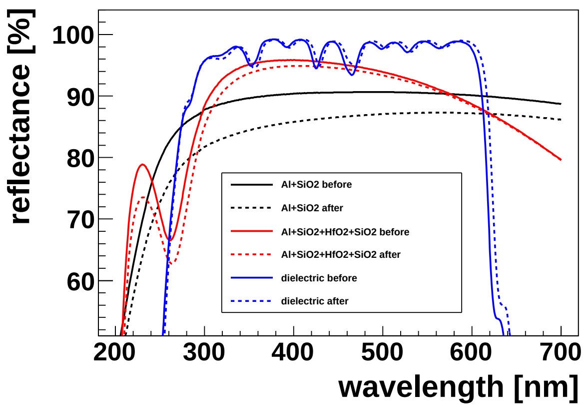

Figure 2: Comparsion of the spectral reflectance before (full lines) and after (dashed lines) temperature and humidity cycling for all three coatings.

The classical Al + SiO_2 coating shows a significant loss of refelctance. The Al coating with the three layer protective coating exhibts a much smaller change in reflectance after the cycling and the dielectric coating has not changed its reflective properties at all within the accuracy of the measurement.

Salt-fog test: All samples have been exposed for 72 hours to a salt-fog atmosphere at a temperature of about 20° C with a salt concentration of 5%. The samples with Al + SiO_2 showed small spots of damaged coating at the sample edges visible by eye, the other two coatings did not exhibit any damage in the visual inspection. Figure 3 shows the reflectance before and after the test, measured in the center of the samples where no obvious damage was visible.

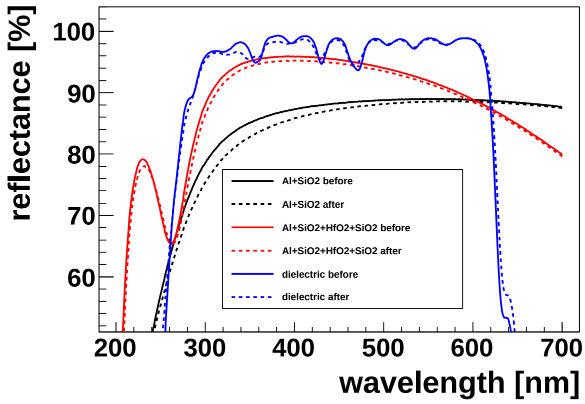

Figure 3: Comparsion of the spectral reflectance before (full lines) and after (dashed lines) a 72 h salt fog test for all three coatings.

The changes in reflectance are less pronounced as for the temperature and humidity cycling. Neverthess, again the standard Al + SiO_2 coating shows the strongest decrease.

Abrasion tests: Three different abrasion tests have been on samples with all three caotings:

a) A standard cheesecloth test using a force of 5 N and 50 strokes on the coated surface does not show scratches on all coatings. After increasing the force to 10 N a significant amount of fine scratches were created on the samples with the Al + SiO_2 coating. The depth of these scratches was determined to be of the order of 10 nm (with the SiO_2 coating having a thickness of 70 to 100 nm) using a Zygo profilometer. Figur 4 shows the results of the measurement of the depth of such a scratch.

The samples with the three layer overcoating and with the dielectric coating were hardly affected by this test also at a force of 10 N.

b) In a more severe test an eraser was used and 20 strokes with a force of 10 N were performed. After this test all three coatings showed scratches, the samples coated with SiO_2 significantly more than the those with the three-layer overcoat and those more than the dielectric samples. The scratches were deeper (up to 30 nm) than for the cheesecloth test, for the dielectric coatings the width was narrower than for the other two coatings.

c) Samples with all three coatings were exposed to a sandblasting test. The abrading medium used was silicon carbide with a grade of 220 μm. The flow rate was approximately 25 g/min and the test duration 5 min. The setup was

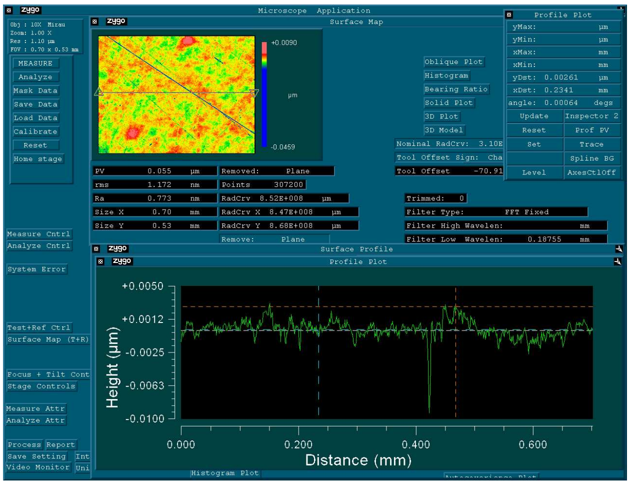

Figure 4: Measurement of the depth of a scratch in an Al + SiO_2 coating after the cheesecloth abrasion test.

operated using an air pressure of 15 kPa and the air was fed in at a rate of 50 l/min. The sample was placed under an angle of 45° under the abrasive jet nozzle. The test results into an ellipse on the coated surface in which the coating is fully removed. The size of this ellipse is a measure how easy or not the coating is abraded. Figure 5 shows three samples after the sand-blasting test, on the left with the Al + SiO_2 coating, in the middle with the Al + SiO_2 + HfO_2 + SiO_2 coating and on the right with the dielectric coating.

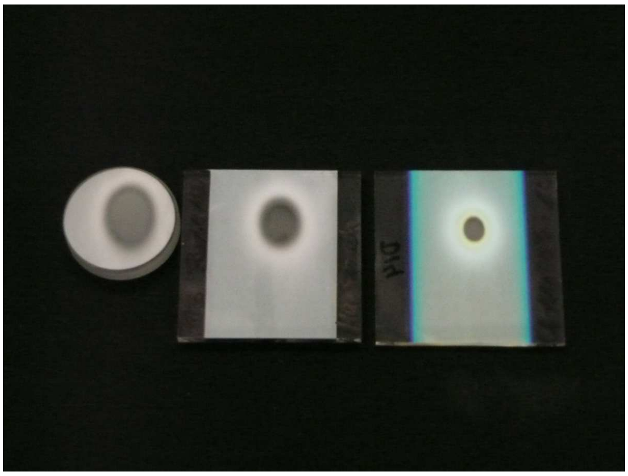

Figure 5: Coating samples after the sand-blasting test. Left:Al + SiO_2. Middle: Al + SiO_2 + HfO_2 + SiO_2. Right: dielectric coating.

The areas of the ellipses in Fig. 5 are 150 mm^2 for the sample with the SiO_2 coating, 85 mm^2 for the sample with the three-layer overcoating and 35 mm^2 for the dielectric coating. The test has been performed with similar results for 5 samples of each type of coating.

Artificial Bird Faeces: Samples of all coatings have been treated with pancreatin, a pancreas enzyme that is regularly used to simulate the effects of bird feaces on lacquers and other material. A 1:2 mixture of pancreatin and de-ionized water has been applied to the coated surfaces of the samples and they have been “baked” for 4 weeks at 40° C in a climate chamber to simulate the effekt of the bird faeces staying on the mirror surface for some time in a hot and dry environment as is typical for locations of Cherenkov telescope experiments. No influence on either of the the three coatings was observed after cleaning the samples.

4 Conclusions and Outlook

In laboratory tests like temperature and humidity cycling, exposure to salt fog atmospheres or simulated abrasion the three layer protective coating on top of an aluminium coating performs slightly better than the standard Al + SiO_2 coating. The dielectric coating shows even a significantly better performance. Nevertheless, the predictive power of these laboratory tests for the real outdoor performance is not clearly established. Currently the approximately 1800 mirrors of the H.E.S.S. experiment in Namibia are being re-coated. The Al + SiO_2 + HfO_2 + SiO_2 coating was chosen for most mirrors of this project. The first 280 mirrors with the three layer overcoatimg have been deployed in autumn 2010, another 380 mirrors in spring 2011. Further 380 mirrors will follow in autumn 2011. In addition, 100 mirrors with the dielectric coating have been installed in autumn 2010. Further, one telesope was refurbished with 380 mirrors with a classical Al + SiO_2 coating and can serve as a baseline for comparison. So far no negative influence on the performance of the experiment has been recorded. Detailed data on the performance of the three different coatings in a realistic outdoor application will become available soon.

Concernig the reflectance the three-layer overcoating shows an increase by approximately 5% compared to Al + SiO_2, the dielectric coating of the order of 10%. The latter has the additional advantage of a box-shaped reflectance curve of tunable width might help to reduce the night-sky background, especially in case of the possible future use silicon based detectors that are more sensitive at longer wavelengths as the currently used photomultipliers.

Costwise there is not significant difference between the classical Al + SiO_2 and the Al + three layer coating since costs for relatively simple coatings are mainly driven by the time the coating chamber is occupied rather than material costs (for the types of materials used here). The dielectric coatings are currently more expensive, but this is based on orders of much smaller quantities.

Both, the Al + SiO_2 and the Al + three layer coating can be applied at low substrate temperature during the coating process. This was not of importance for classical glass mirrors as used in H.E.S.S. but might become an issue for CTA, since most mirror substrate technologies currently under investigation are sandwich structures that consist of different materials that are glued together, mostly with a thin cold-slumped glass sheet as the front surface (see for example [2, 3, 4, 5] for details). The dielectric coating currently needs a substrate temperature of 150° C which is too high for most of these sandwich structures. The plan for the near future is to develop an improved coating design that keeps the performance of the currently investigated dielectric coating and can be applied at significantly lower temperatures. In parallel, the possibility of coating the glass sheets (at high temperatures) before mounting the sandwich structure should be investigated.

Both, the Al + SiO_2 and the Al + three layer coating are available “out of the shelf” for substrate sizes as currently envisaged for CTA (up to 2 m^2). For the type of dielectric coating investigated here the largest mirrors we have tested so far are the H.E.S.S. mirrors (circular, 60 cm diameter). Since for this type of coatings a very precise control of the film thickness of all layers over the full mirror area is essential, further investigations are needed to proof that mirrors up to 2 m^2 can be successfully coated.

To conclude, the Al + SiO_2 + HfO_2 + SiO_2 is a readily available alternative to the standard Al + SiO_2 coating that provides an about 5% better reflectance and a slightly better performance in durability tests in the laboratory at no significant extra cost. The dielectric coating provides a significantly better reflectance in the desired wavelength range, the possibility to suppress night-sky background and a significantly better performances in the durability tests, but it needs further investigation concerning the application on large mirror surfaces and a possible application at lower substrate temperatures for future sandwich mirrors.

Acknowledgements

We gratefully acknowledge support from the agencies and organisations listed in this page: http://www.cta-observatory.org/?q=node/22.

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