

Developments for coating, testing, and the alignment of CTA mirrors

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Abstract: The telescopes of the Cherenkov Telescope Array (CTA) will have segmented mirrors, with mirror facets of $\sim 1\text{-}2.5\text{ m}^2$ area. In the framework of the CTA mirror work package, the Institute for Astronomy and Astrophysics in Tübingen (IAAT) is participating in the developments for procedures to coat glass-substrate based mirror facets, is preparing a mirror facet test facility, and is prototyping Active Mirror Control (AMC) alignment mechanics and electronics. The developments are based upon the experiences the group has gained through its participation in the preparations for the 27 m dish of H.E.S.S. phase II. We will present the current status of our work and plans for future developments. The devices and procedures will be relevant for all classes of telescopes that will finally form CTA.

Keywords: Cherenkov Telescope, Optics

1 Introduction

The Cherenkov Telescope Array (CTA) consortium aims at deploying two arrays of Imaging Atmospheric Cherenkov Telescopes (IACT), in the Southern and in the Northern hemisphere, with a surface covering $\sim 3\text{-}5\text{ km}^2$. At least three different telescope types are foreseen: A large size telescope (LST) type with $\sim 24\text{ m}$ dish diameter, a medium size (MST) with $\sim 12\text{ m}$, and a small size (SST) with $\sim 4\text{-}7\text{ m}$. The reflective surface of each telescope primary mirror will consist of segmented mirror facets of $\sim 1\text{-}2.5\text{ m}^2$ area. The baseline design for the MST (a close to Davies-Cotton design with camera in the primary focus) foresees hexagonal segments with 1.2 m flat-to-flat diameter, and 84 mirrors per telescope.

The total reflective mirror surface of the entire CTA is huge ($\sim 10^4\text{ m}^2$), with hence several thousands of mirror segments. High efficiency during testing and alignment of the segments is therefore necessary. High durability of the mirror reflective surface is equally necessary to avoid the need for frequent re-coating. In general, segments should persist with sufficient reflectivity for at least 10 years. In this paper, activities by the Institute for Astronomy and Astrophysics Tübingen (IAAT) conducted in the field of mirror alignment, mirror testing, and mirror coating are reported. The work is performed in the framework of the CTA mirror work package.

2 Mirror coating

Current mirror facet specifications demand that the reflected light should largely be contained in a 1 mrad diameter area, the reflectance in the $300\text{ nm} \leq \lambda \leq 600\text{ nm}$ (hereafter $\text{WR}_{300-600}$) range should be $\geq 80\%$, and facets should be robust against aging for several years [1]. The goal is of course to provide coatings with the highest possible reflectivity and longest lifetime that is economically possible.

Currently, various designs for mirror facets are under study, including aluminum or carbon fiber honeycomb structures. The focus of the study presented here is on mirror types where a reflective layer on top of a glass substrate is needed. Such coating consists of a thin ($100\text{-}1000\text{ nm}$) single or multiple reflective layer plus, possibly, a protective overcoating.

2.1 Mirror coating study

The aim of our study is to obtain a mirror coating solution with reflectance $> 90\%$ (measured vertically close to the mirror surface) for the entire $\text{WR}_{300-600}$, with long term endurance. At the same time, it should be as simple as possible to be suitable for mass production. We currently use the McLeod [2] simulation software for optimizing the coating design. Coating of small glass samples is performed in the recently refurbished IAAT coating chamber (shown in Fig. 1).

The IAAT coating chamber is equipped with:

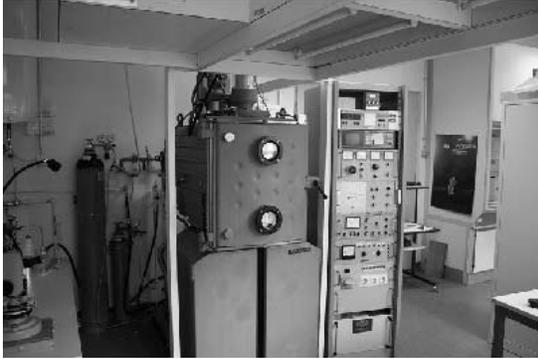


Figure 1: Coating chamber of the IAAT

- a rotative pump for vacuum production (10^{-6} mbar);
- Nitrogen and Argon flooding system for humidity and impurities removal;
- water warming-cooling system (15-65 °C);
- one resistor crucible for metals evaporation;
- a 4-fold electron beam crucible for dielectric materials evaporation;
- a single-sensor quartz micro-balance for measuring the deposited layer thickness.

For the coating, we focus along three main directions:

1. one metallic reflective layer plus a very robust protective overcoating;
2. one metallic reflective layer plus a multilayer interferometric overcoating for both protection and reflectance improvement;
3. a purely dielectric multilayer interferometric coating.

The first solution usually consists of an Al layer with a protective coating made of SiO_2 or Al_2O_3 , widely in use for current IACT mirror facets because of its good performance, easiness, and low cost. The biggest drawback of this approach is that the long term reliability achieved so far is probably not suitable for CTA scales.

The second solution is an intermediate solution enhancing a simple reflective layer with a protective coating, which will not only provide a protection to the metallic layer but also improve the reflectance in the $\text{WR}_{300-600}$.

The third solution is the most interesting and so far the least explored one. Light, passing from a material to another one with different refractive index, is reflected according to Fresnel's law

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2$$

where R is the reflection coefficient, n_1 and n_2 the refractive index of the first and second material.

For a light ray passing from one layer to another one, the reflectance depends also on its wavelength. The maximum value is for

$$\lambda = \frac{4 \cdot n_1 \cdot L_1}{\sin(\theta)}$$

where λ is the reflected wavelength in vacuum, L_1 and n_1 the thickness and the refractive index of the first layer, and θ the impinging angle. By alternating many dielectric layers with different thickness and refraction index, it is possible to achieve very high reflectance inside the $\text{WR}_{300-600}$, with very low reflectance outside this WR. In this way, the Cherenkov light collection will be maximized, and at the same time the pollution by the Night Sky Background (NSB) – mostly at large wavelength – will be minimized. Furthermore, since no metallic layer will be used for the mirror coating, deterioration e.g. due to oxidation will not occur. On the other hand, a large number (> 30) of layers is required. This could result in layer deterioration in the field, because of thermally induced stress between different layers.

2.2 First results from mirror coating

For the first solution we focus on improving the resistance of the protective overcoating, on which the long term mirror reliability depends on. We have produced several samples in the coating chamber with different coating procedures (coating chamber and glass substrate cleaning, pumping time, deposition rate) in order to find the optimum one. Furthermore, we checked the agreement between simulation prediction and experimental measurement on the coated samples.

In Fig. 2 we report the experimental and simulated reflectance curve for almost vertical ($\theta = 83$ degrees) light of a glass sample coated with one 116 nm thick Al layer plus one 100 nm thick SiO_2 layer. The two lines show reasonably good agreement especially in $\text{WR}_{300-600}$, while for $\lambda < 300$ nm the agreement worsens to some extent. Whether this is a limitation of the software or due to variations in the coating procedure is still under investigation.

For a dielectric multilayer coating we found several solutions applying commonly used materials, like HfO_2 , ZrO_2 , MgF_2 and ZnS . In Fig. 3, the reflectance and transmittance for a multilayer coating as obtained by the McLeod simulation software [2] is shown. Such a design could not yet be realized in the current stage of completion of our coating chamber, since a multi-sensor quartz micro-balance is needed together with a substrate warming system, in particular for the ZnS deposition.

For the intermediate solution, we are about to realize different samples of ~ 100 nm thick Al coating with a protective overcoating made of SiO_2 - HfO_2 - SiO_2 . This solution is not

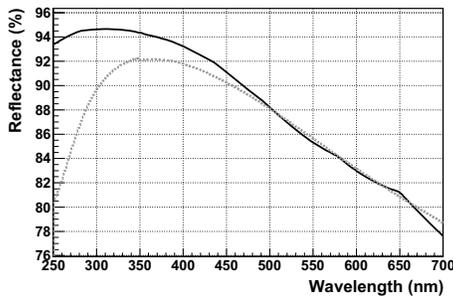


Figure 2: Reflectivity vs. wavelength for 83 degrees impinging angle light for a glass substrate coated with one Al layer 116 nm thick plus one SiO₂ layer 100 nm thick, simulation (black) and real data (grey dotted).

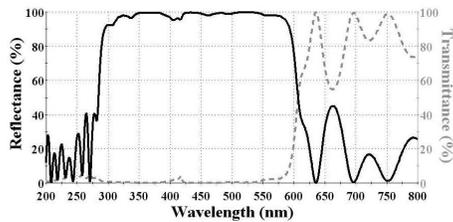


Figure 3: Simulation of reflectivity (black line) and transmittance (grey dotted line) vs. wavelength for normally impinging light for a 35 layer ZrO₂, MgF₂ and ZnS coated glass substrate.

completely new, since it is long time used by industry and it has been recently applied for the the Hess I mirror re-coating.

Our aim is to put the realized samples through long term reliability tests. If the results will be positive, such a design might present a good alternative to the more complicated and expensive pure dielectric coating.

3 Mirror reflectivity and psf testing

Using a mirror test stand developed by the MPI-K Heidelberg, the reflectivity and spot size of all the mirror facets for the H.E.S.S. II telescope have been tested at IAAT. The setup is shown in Fig. 4 and summarized in the following:

- a halogen lamp lights up the mirror facet from a distance two times its focal distance;
- the reflected light converges on a target, placed at two times the mirror facet focal distance, producing a light spot;
- the reflected light spot is monitored with a digital camera to measure the spot size;
- the total reflectance at different wavelengths is measured with a photo-diode which is scanned across the light spot, using different optical filters.

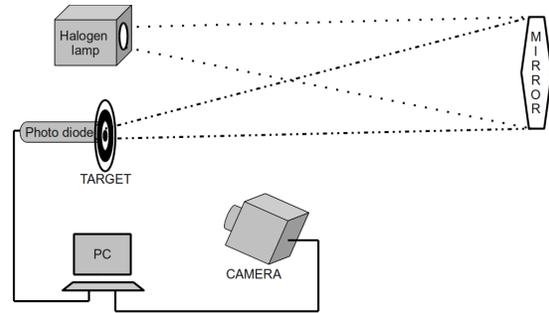


Figure 4: Current 2f mirror test setup based at IAAT.

We are working towards an improvement of such a mirror test setup by making the following changes:

- replacing the present digital camera with a new one sensitive additionally in the UV region. In this way the global reflectance can be measured avoiding the photo-diode;
- replacing the halogen lamp with four monochromatic high power LEDs with different wavelengths, covering the entire WR₃₀₀₋₆₀₀. The light source will be much more point-like and its time stability will be considerably improved. Furthermore, the optical filters and the lamp cooling system will not be needed anymore;
- installing an optical fiber system for monitoring the four LEDs, using the same digital camera used for observing the reflected light spot. Information about the emitted light, camera stability, and target aging will be constantly acquired, allowing a more precise measurement of the mirror reflectance.

The improved IAAT mirror test setup could be used for testing mirror prototypes as well as perhaps a good fraction of the total number of the CTA mirror facets.

4 Mirror alignment system

The large number of mirror facets, especially for the MST and LST types, demand motorized control of the mirror actuators, even if the mirror dish is stiff enough so that only an initial alignment after mirror mounting or mirror exchange is needed. In the current baseline design for the MST, the dish is expected to be indeed stiff enough so that an active alignment (i.e. frequent realignment during telescope observation time) is not needed. On the other hand, the LST structure will most likely require such active alignment. While the demand on mirror actuators is certainly lower for initial alignment procedures, nevertheless options which might be suited for both types of alignment are currently pursued.

The design which the IAAT is currently developing and testing is based on the actuator mechanics developed for

the large, 27 m telescope of H.E.S.S. phase II [3]. Mirror facets are supported by two motor driven actuators and one freely-rotating bolt which is fixed to the telescope structure. Several of these actuators are currently being prepared to be tested in the course of the MST prototype development project led by DESY. Here, the actuators are connected to a supporting triangle, which is fixed to the structure of the telescope dish by two clamps. One actuator is tightly anchored to the supporting triangle not allowing any tilting movement; the second one is equipped with a pivot allowing a free rotation along a tilting angle. The motor of each actuator is housed in a watertight box vented by a sintered bronze valve. Based on the results of outdoor testing performed already at IAAT and also during the MST prototyping phase, any necessary improvements on the actuator mechanics will be made.

Compared to the electronics which is used to control the actuators at H.E.S.S. II [3], a new architecture based on the Controller Area Network (CAN) interface [4] will be employed. For each mirror there is a electronic control board, composed by a driver for each motor and a microcontroller (Atmel AT90CANxx), which is placed in one of the two actuator boxes. The other actuator is connected to the control electronics by an external cable. For each mirror, the two actuators plus the electronic control board form a Mirror Control Unit (MCU). In Fig. 5, an actuator with its motor and electronic control board are shown.

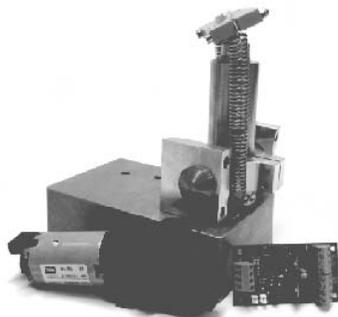


Figure 5: Mirror actuator together with its motor (normally housed in the bottom box) and the CAN control board.

MCUs are serially connected to a central unit. Each such unit serves one telescope, and can be placed in the center of the dish. The connection is realized with a four-wire shielded cable: two wires are used for transmitting the CAN signal, the other two for the power supply. A limitation of the chain length is not imposed by the CAN interface, but by the Ohmic power loss of the cables transmitting the motor current. As an alternative, more expensive cables could be used, but we found the best solution will consist of a distribution of the MCUs along different CAN chains, each of them serving 7-8 MCUs. The central unit, an embedded PC working as a TCP/IP to CAN gateway, is controlled by a PC. The control PC could be Client or Server and be placed in the telescope tower or in the central control room, depending on the architecture of

the telescope control system. A power gate for the AMC DC power supply is also present in the telescope tower. The scheme of the actuator control system is shown in Fig. 6.

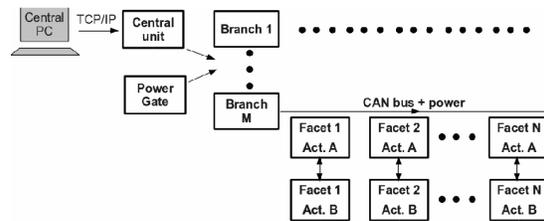


Figure 6: Scheme of the actuator control system developed for CTA telescopes.

While in the H.E.S.S. II control frame only one mirror facet can be aligned at a time[3], with our new frame it will be possible to align a large number of mirror facets at the same time. The only limitation will be given by the AMC power consumption.

Furthermore, such control frame is extremely simple and robust as evidenced by our laboratory and external tests. During different tests, we transmitted various millions of CAN commands without experiencing any transmission failure. It is also extremely flexible and can be easily adapted to any of the CTA telescope types requiring motorized actuators.

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