First results of the two square meters multilayer glass composite mirror design proposed for the Cherenkov Telescope Array developed at INFN

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cta cherenkov telescope array

ABSTRACT

The Cherenkov Telescope Array (CTA) is a future ground-based gamma-ray astronomy detector that will consist of more than 100 Imaging Atmospheric Cherenkov Telescopes of different sizes. The total reflective surface of roughly 10 000 m^2 requires unprecedented technological efforts towards a cost-efficient production of light-weight and reliable mirror substrates at high production rate. We report on a new concept of mirror production proposed for CTA developed by INFN, which is based on the replication from a spherical convex mold under low pressure. The mirror substrate is an open structure design made by thin glass layers at the mirror's front and rear interspaced by steel cylinders. A first series of nominal size mirrors has been produced, for which we discuss the optical properties in terms of radius of curvature and focusing power.

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INTRODUCTION

An Imaging Atmospheric Cherenkov Telescope (IACT) is a detector that is suited for the study of the very high energy (VHE) gamma-ray component of the cosmic radiation. The future generation of IACTs is represented by the Cherenkov Telescope Array (CTA) project [1,2] that aims at a further improved performance with respect to the current generation of such instruments. The CTA design foresees the installation of IACTs of different sizes, sensitive to different energies of the VHE band. In total, CTA will consist of more than 100 telescopes comprising several tens of small size telescopes (SSTs) of 6 m diameter, few tens of medium size telescopes (MSTs) of 12 m diameter and few large size telescopes (LSTs [3]) of 23 m diameter that will be split across two sites - one in the Northern and one in the Southern hemisphere. Besides conventional layouts based on the so-called Davies-Cotton single-mirror configuration, which are adapted for the MST and the LST, some alternative designs based on dual-mirror layouts that adopt the Schwarzschild-Couder configuration for the MST and the SST are investigated. For such dual-mirror designs, the requirements on the primary and secondary mirror are more constraining than for the MST and LST demanding short radii of curvature and high asphericity elements [4].

The primary mirror of each telescope requires a dish tessellated with many light-weight (<50 kg for the LST), robust and reliable mirror facets of adequate reflectance (>85% into the focal spot from 300 to 550 nm) and focusing quality (the point spread function (PSF) in terms of D_{80}, i.e. the diameter of 80% light containment, but demanding very little maintenance [4,5]. In the case of the LST the D_{80} of the individual mirror facets is required to be less than 1/3 of the pixel diameter at the focal length of the telescope, which is 16.6 mm (0.59 mrad for *f* = 28 m) for a pixel diameter of 2 inch (~50 mm) including the light concentrator [5]. Usually, IACTs are not protected by domes meaning that the mirrors are continuously exposed to the environment. The challenge for CTA is to develop low-cost, mirrors of 1 to 2 m^2 area, hexagonal geometry, high optical performance in the wavelength range of interest and long-term durability, with the potential for a high production rate.

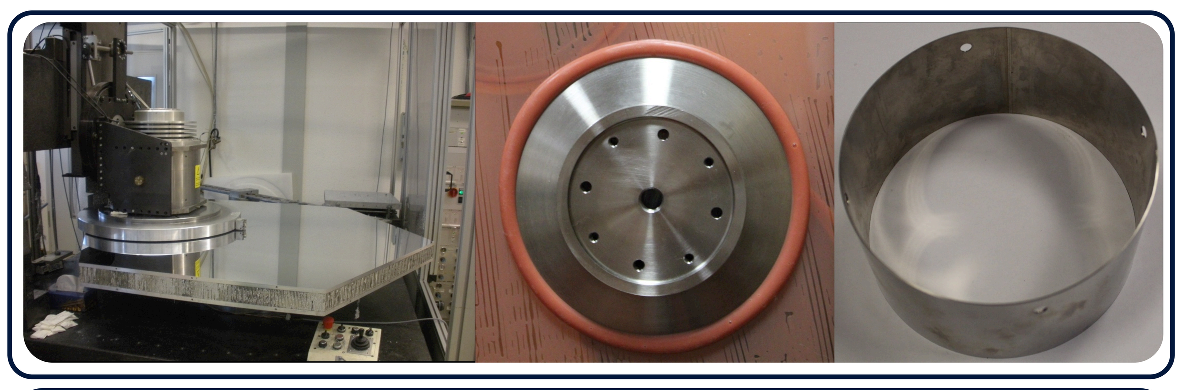

Fig. 2: Left: Diamond-milled 1.5 flat-to-flat (FTF) diameter aluminum mold. Center: Pad for the active mirror control attachment. Right: Image of a stainless steel cylinder.

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PRODUCTION TECHNIQUE UNDER DEVELOPMENT

The multilayer glass composite mirror has an open structure design and consists of a thin rear and front glass multilayer interspaced by steel cylinders (Figure 1). A similar mirror design is developed at the INP PAS and proposed for the MST [7]. The technique is based on the curvature replication under low pressure from a convex diamond-milled aluminum mold (Figure 2 left panel), with a nominal radius of curvature of (57.9 ± 0.5) m a microroughness of <30 nm. To ensure a good surface contact between the mold and the glass sheets, small channels have been incised into the mold after its polishing, allowing the evacuation of entrapped air via a vacuum pump that is attached through a central hole creating a pressure of (0.8 ± 0.04) bar.

In a first step, the mirror rear glass multilayer is assembled, i.e. the glass sheets are spherically shaped on the mold under low pressure and are glued together, curing the glue, a two component epoxy paste, at room temperature. Contemporaneously, the pads (Figure 2) for the Active Mirror Control (AMC, [3]) are glued to the back of the mirror rear. Similarly, the mirror front is assembled on the mold with the difference that the reflective surface is composed by equilateral triangles produced by the BTE [8] company whose reflective surfaces, an Al+3-layer coating with a reflectance >85% in the wavelength of interest [9], are protected by a residual free removable foil.

RESULTS

Several prototypes (Figure 3) of a weight of roughly 42 kg have been produced. Optical measurements were performed with a 2*f*-setup [3,4]. The radius of curvature was consistent with the nominal radius of curvature of the mold with variations up to ~+40 cm (~0.7%), while the PSF was calculated to be as good as ~0.75 mrad, taking the dimension of the light source (~1.5 mm in diameter) of the 2*f*-setup into account (Figure 3).

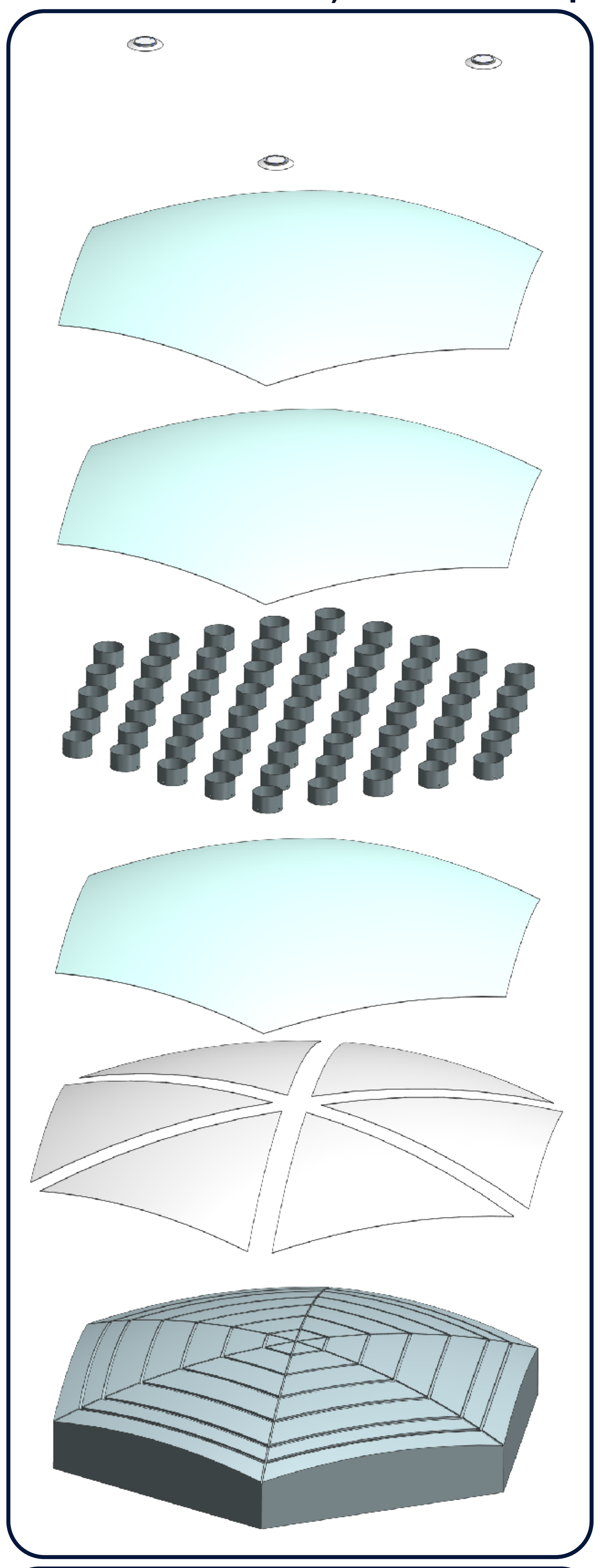

Fig. 1: Production scheme of the multilayer glass composite mirror based on the replication from a spherical convex mold.

Fig. 3: Front (left) and rear (right) of one of the first 1.5 FTF diameter mirror prototypes proposed to be used for the LST.

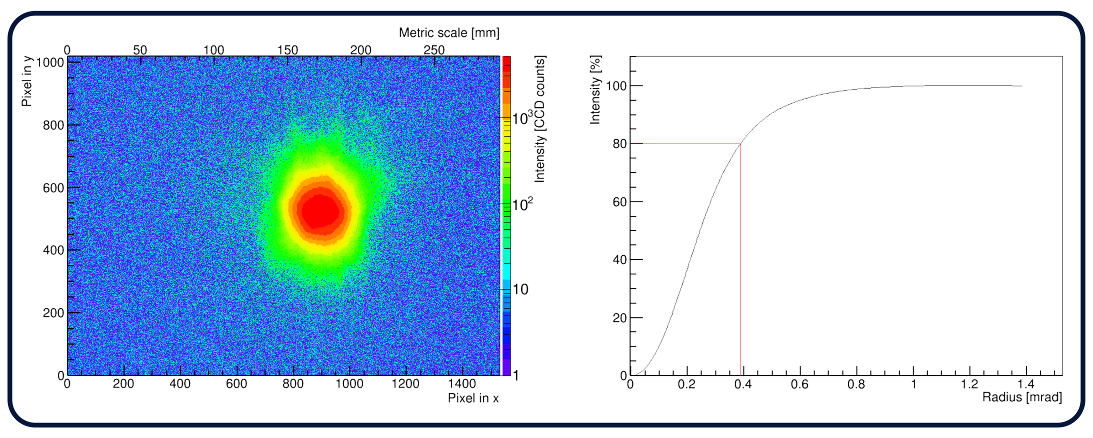

Fig. 4: Left: CCD image of the minimum focal spot at the distance of 58.3 m. On top a metric scale is drawn. Right: Focal spot profile. The red vertical line indicates the R_{80}.

The deviations of the radii of curvature with respect to the mold are rather small and are no issue for a parabolic optical design as foreseen for the LST, requiring different radii of curvature [4,6]. The PSF is most likely affected by local variations from the mold geometry due to dust and due to the surface waviness of the reflective surface glass leading to variations of ~+0.16 mrad (~27%) with respect to the CTA specifications of the LST.

CONCLUSION & OUTLOOK

We are currently finalizing the development of an open structure composite layout for mirrors suited for IACTs based on the shape replication from a spherical mold. The design consists of thin rear and front glass multilayers interspaced by steel cylinders ensuring the mirror to be rigid and light-weight.

For the LST, part of the AMC system is designed to be integrated in one of the mirror corners [6], which still has to be implemented in the mirror design presented here.
The mirror prototypes show a good agreement with the nominal radius of curvature, with variations of few tens of centimeters. The PSF achieved is slightly higher than the CTA specifications for the LST, which is mostly limited by the surface waviness of the reflective surface glass and dust on the mold. Improvements of the PSF could be to use a front glass of higher quality and different segmentation geometries.

Durability test of some of the prototypes produced at a dedicated outdoor facility are planned. Mechanical and further optical testing are foreseen to be carried out at adequate facilities accessible to the CTA Consortium [4].

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