Developments of a new mirror technology for the Chevernov Telescope Array

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ABSTRACT
Here we present a novel technology for the production of IACT mirrors that has been developed in the Institute of Nuclear Physics PAS in Krakow, Poland. The mirrors are made by cold-slumping of the front reflecting aluminium-coated panel and the rear panel interspaced with aluminium spacers. Each panel is built of two glass panels laminated with a layer of a fibreglass tissue in between for reinforcement of the structure against mechanical damage. Full-size hexagonal prototype mirrors produced for the medium-sized CTA telescopes will be presented together with the results of recent comprehensive optical tests. Their design will be compared to the earlier technology developed at INP PAS that used a rigid flat open support structure with a reflective layer made by cold-slumping of the coated glass panel to the cast-in-mould spherical epoxy resin layer.

Introduction
Current operating imaging atmospheric Cherenkov telescopes (IACTs): H.E.S.S., MAGIC and VERITAS, have reflective dishes segmented into mirror facets. The effective mirror area and the quality of the Cherenkov light shower images play a key role in the performance of these telescopes.

An open-structure mirror technology has been developed at INP PAS since 2008. Recently, mirror prototypes have been designed for the medium-sized telescopes (MST), which have a classical Davies-Cotton construction. The basic feature of our mirror technology used so far is to use a flat, rigid support structure for the mirrors. It represents a novel approach, different from commonly applied solutions with closed aluminium honeycomb supports which requires that the side walls of the mirror be sealed perfectly to protect the structure against water penetration inside the honeycomb, which can cause damage to the structure.

The MST mirrors should have a focal length of 16.07 m, radius of curvature should be 32.14 m. The CTA requirement is that more than 90% of the reflected Cherenkov light should be focused within 1/3 of the pixel size which is ~17 mm.

The sandwich support structure consists of two convex glass panels separated by spacers, which are aluminium tubes. These tubes are glued to the convex panels with epoxy resin. The mirror is hexagonal in shape with size 1.2 m flat-to-flat as in previously. Both panels are made of ordinary float glass and their thickness is 2 mm. The aluminium tube spacers have a diameter of 40 mm and length of 50 mm. To ensure the free flow of water inside of the mirror, six slots are cut at both ends of the tubes (see Figure 2).

The front panel is produced by laminating a glass sheet of thickness 2 mm with epoxy resin, with a special reflective layer. A fibreglass tissue of thickness 0.4 mm is placed between these two layers to reinforce the structure. The rear panel: the two ordinary glass sheets with another fibreglass layer are simultaneously cold-slumped. All the layers are glued together on a final vacuum mould. Three stainless steel pads are glued to the rear panel to enable mounting of the actuators designed for the CTA mirrors. Stainless steel mesh is attached to the sidewalls as shown in Figure 2. In the last step the special silicone rubber, which is resistant over a wide temperature range, from -60 to +260 °C, is attached to the mirror sidewalls to protect the mirror against damage during the transportation and mounting processes.

Technology Description
The open-structure mirror consists of a sandwich support structure and a spherical glass reflecting layer. In 2014, the INP PAS team, taking into account previous experience, designed and manufactured the first new open-structure mirror support structure prototype, as shown in Figure 1. The reflective layer is made of Borofloat 33 glass sheet and it was coated with Al₂SiO₄·2H₂O·3SiO₂, by the German company BTE prior to gluing.

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Test Results
Preliminary tests are performed on mirror prototype to measure the Point Spread Function (PSF). The measurements were done using a test bench, which was designed and manufactured at INP PAS. The test bench consists of a red laser, a jig to mount the mirrors and a CCD camera with software for image capture and processing. The CCD camera is equipped with a set of filters, which allows for measurements during daytime. The focal length of a mirror can be determined from its PSF measurement, since at focal length the mirror PSF will be at its minimum. The results of a scan at twice the focal length are shown in Figure 3.

The inferred value of twice the focal length for this mirror prototype is 32.15 ± 0.09 m (statistical error only), in very good agreement with the nominal value of 32.14 m. The PSF spot - Δθ₀, (the radius of the circle in which 80% of the reflected light energy is contained) is 10.2 mm, which compares well with the CTA requirement for the MST mirrors, that Δθ₀ < 17 mm. At present, the mirror prototype is under extensive durability tests in a climate chamber at INP PAS.

Conclusions
A novel mirror technology for Cherenkov telescopes has been proposed. The advantage of this technology is that the manufacturing steps are independent of the coating processes and hence different reflective layers can be used. The other important advantage of the mirror technology presented here is its open architecture, which does not face the well-known problems of other closed structures and honeycomb technologies. A fully-equipped production line has been built at INP PAS, with a production capacity of two mirrors per week.