Optical filters designed for the fluorescence detector of the AUGER project with transmittance in the range 300 nm – 400 nm

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Abstract

The fluorescence detector, a component of the AUGER project, is designed to observe fluorescent light generated in interactions of high energy cosmic rays with nitrogen atoms in the Earth's atmosphere. This article presents several designs of optical filters transmitting in the range 300 nm – 400 nm, where the fluorescent light is emitted. Two approaches are proposed - a system of thin dielectric layers and a combination of suitable glass plates. Quality of different filters is determined accoring to the value of transmittance in the required wavelength range, the shape of the transmittance curve at the edge of the transmitting window, long-term stability as well as feasibility and cost of their mass production. Selected types of filters were prepared, their parameters measured and compared with predicted values.
Keywords: cosmic radiation, optical filters

1 Introduction

The aim of the AUGER project is the search for cosmic radiation in the energy range above 10^{19} eV, where the information regarding its origin and propagation is very limited. More than 20 particles with energy above 10^{20} eV were observed so far, yet no known mechanism can produce particles of such energy. Flux of cosmic ray particles decreases dramatically with increasing energy. Estimated rate of particles entering the atmosphere with the energy of 10^{20} eV is only about one per square kilometer per century, which urges consstruction of experiments with enormous detecting surface.

Project AUGER combines two methods of cosmic ray air shower detection mastered by previous ground based experiments. The first component is the *surface array* formed by 1600 water tanks on the area of 3000 km^2 with 1.5 km spacing between individual stations. Čerenkov light produced by charged shower particles in each 11000 litre tank is recorded by three photomultipliers at the top of the tank. Intensity and relative time of arrival of the signal at each tank is used to determine energy and arrival directions of the primary particle.

The *fluorescence detector* representing the second component of the project exploits the fact that shower particles passing through the atmosphere excite the atoms of nitrogen in the air, which then produce a faint light. The light is recorded by telescopes that constitute of spherical segmented mirror (3.4 m radius of curvature) and a camera formed by 440 photomultipliers in its focal plane. Each telescope is further equipped with a corrector plate allowing 30° by 30° field of view and with an optical filter. Clusters of telescopes overlook the surface array so that each shower seen by a fluorescence telescope is also recorded by a number of surface stations. The fluorescence detector provides additional information about the shower development profile so that simultaneous observations of the two detectors allow to determine properties of primary particles with unprecedented precision.

2 Filters for fluorescent detector

The Earth's atmosphere is a source of optical signals which differ in their intensity and wavelength. The cosmic radiation under study causes fluorescence of the atmospheric nitrogen atoms in the wavelength range 300 nm – 400 nm. The signal produced is very weak and short in comparison with all the atmospheric radiation and it is therefore hidden in the background noise. The simplest method of suppressing the unwanted noise is implementation of an optical filter with transmittance tuned to the wavelength interval 300 nm – 420 nm.

Two positions of the filter come into consideration. The first possibility is to place the filter at the entrance aperture of the telescope, which implies production of large filters 2.2 m in diameter. The second alternative is to mount smaller filters of the size of the photomultiplier entrance window. With respect to the technological and economical reguirements we prefer using a relatively large numbers of small pieces.

There are several methods of fabrication of filters with transmittance in the desired range. We compare dielectric multilayer filters produced by evaporating and/or sputtering with suitably chosen glass filters.

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2.1 Vacuum deposited filters

A periodic structure of dielectric thin films reflecting the visible light is numerically modified so that its transmittance in the wavelength interval 300 nm – 420 nm is maximally enhanced. A suitable substrate glass FK-5, also contributing to the desirable filtering function, comes from the Schott company. The system composed from 29 layers alternating Ta_2O_5 and MgF_2 materials was proposed. From Fig. 1 we can see the theoretical transmittance of this filter without filtering effect of the glass substrate.

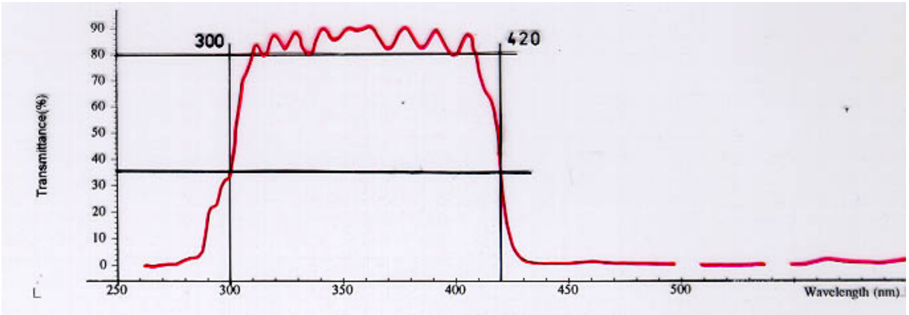

Figure 1: Transmittance of the evaporated filter composed from 29 thin layers Ta_2O_5 and MgF_2.

2.2 Sputtered filters

Design og the scattered filter is similar to the design of vacuum deposited filters. Physical principles of the sputtering and vacuum evaaporation processes differ but their results are similar. A trial filter composed of 41 layers of Ta_2O_5 and SiO_2 was deposited and measured. This filter meets the requirements nearly ideally as it can be seen from the Fig. 2.

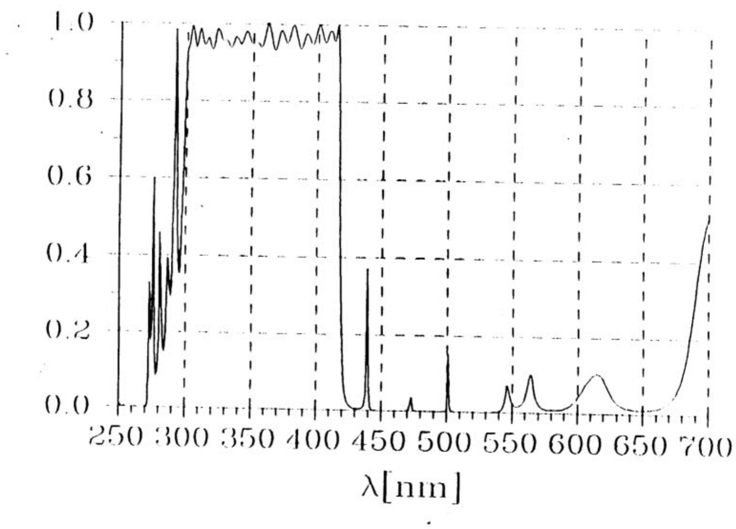

Figure 2: Transmittance of the system of 41 thin layers (Ta_2O_5 and SiO_2).

2.3 Glass filters

The glass additives (usually chemical elements) are selected so that they cause an absorption of light in the desired part of the spectrum. This type of filter requires browsing through catalogues in order to find a suitable filter glass and to choose an appropriate filter thickness as absorption is an increasing function of thickness.

Looking through glass catalougues of several producers no satisfactory result was obtained. Therefore a combination of two types of glass was proposed: optical glass FK-5 and filter glass BG24A, both produced by Schott company. The result of the measured transmittance can be seen in the Fig. 3.

2.4 Hybrid filters

During the development of filters for the AUGER project another possibility meeting the detector needs emerged. It is a hybrid combination of cemented absorbing and sputtered filters. The first step of the produc-

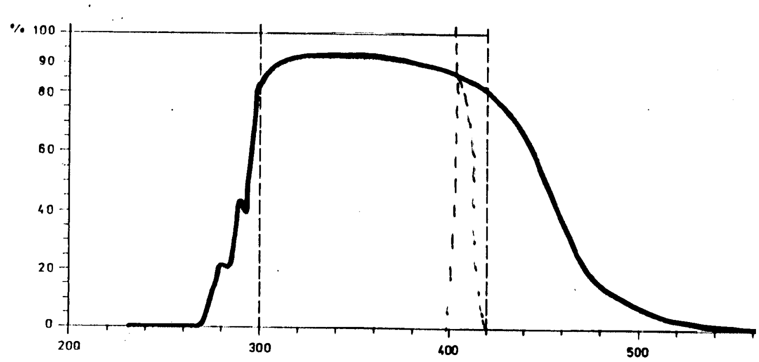

Figure 3: Transmittance of the bonded filter from FK-5 and BG24A glass.

tion is sputtering of dielectric layers with a transmittance edge at 400 nm and the second step is cementing with a filter glass BG24A. The result of the computed transmittance of this hybrid filter is given in the Fig. 4.

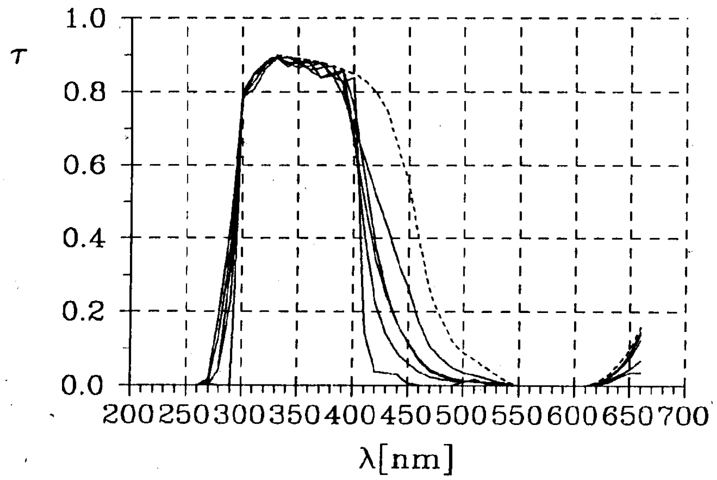

Figure 4: Transmittance of the hybrid filters composed from filter glass FK-5/BG24A and various number of thin layers.

3 Conclusions

All tested methods used for filter production are able to provide a satisfactory solution which meets solution that provides transmittance in the range specified by AUGER project. In view of the relatively high number of the filters (13200 pieces) it is necessary to take into account the capability of filters to maintain their transmittance and the available financial resources. Considering all arguments the recommendation follows to use the cemented absorbing filter composed of the FK-5 and BG24A glasses.

4 Acknowledgements

This work was supported by the project LN00A006 of the Ministry of Education of the Czech Republic.

References

[1] *The Pierre Auger Project Design Report*, November, 1996.

[2] Z. Knittl: *Optics of Thin Films*, John Wiley & Sons, London - New York - Sydney - Toronto, 1976.

[3] Walter G. Driscoll: *Handbook of Otics*, McGraw Hill, 1978.