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Characteristics of Multi-Anode PhotoMultiplier Tube for the EUSO Focal Surface Detector

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The focal surface of the EUSO telescope consists of a few hundred thousand of pixels of photo-detectors and detects air showers as mosaic images. The strongest requirement for the focal surface detector is the maximization of the photon detection efficiency together with the uniformity over the focal surface. We have developed a new type of multi-anode photomultiplier tube (MAPMT). The tatal photon detection efficiency has improved than before by about 2.1 times.

1. Introduction

The Extreme Universe Space Observatory (EUSO) is being designed to detect fluorescence photons induced by extremely high energy cosmic ray airshowers by viewing down the atmosphere from the International Space Station in the wavelength region of 300-400nm [1]. The EUSO covers the field of view of $\pm 30°$ with angular resolution of about $0.1°$. The EUSO focal surface is a curved surface whose area is about $3.5m^2$. The focal surface detector should be capable of observing images at the sampling rate of the order of $1\mu s$ and capable of responding to single photoelectrons in the timescale of $10ns$. The detector should be radiation hard and its operation should be reliable and stable during 3 years mission period. The baseline choice of the photodetector is the multi-anode photomultiplier tube (MAPMT) with UV-glass entrance window. To enlarge the sensitive area ratio of the focal surface, we have developed a new type of MAPMT, R8900 series [2][3]. R8900 series is modified from ordinary series, R7600. By this development, the sensitive area ratio has improved to 83% from 45%. Finally, we have developed R8900-03-M36 (Figure 1) whose pixel size is suitable for optical spot size.

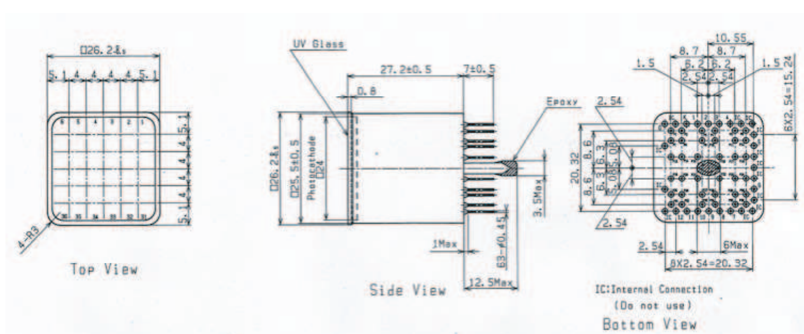

Figure 1. design view of R8900-M36.

2. Basic Characteristics

MAPMT R8900-03-M36 basic characteristics:

1. The physical dimension; the section is 26.2mm $\times$ 26.2mm and the length is 27.2mm. The mass is 27.3g.
2. The 6$\times$6 square pixels have a side of 4.0mm and a pitch of 4.0mm.
3. The tube is equipped with a bialkali photo-cathode and an UV glass window 0.8mm thick. This ensures good quantum efficiency for wavelengths well 330nm, with a peak over 20% at the wavelength of 420nm.
4. Detection efficiency (ε) as a function of the temperature ($T°C$):
$d\varepsilon/dT = a\varepsilon$ with $a = -0.37\%/°C$ and $\varepsilon(T = 30°C) = 0.158$
5. R8900 has a metal channel dynode structure with 12 stages, providing a gain of several $\times 10^6$ at 900V with a standard tapered voltage divider.
6. The anode pulse rise time and fall time are about 2.0ns.
7. The transit time spread is about 0.3ns.
8. The anode cross talk is about 7%.
9. Sensitivity non-uniformity between different anodes on the same MAPMT is 1:4.
10. The overall anode dark current after 30minutes storage in darkness is of the order 0.1nA.
11. Magnetic field effect; 0.1 relative gain variation at 2gauss.
12. Operating and storage temperature range is from -30$°C$ to +50$°C$.

As concerns the detection efficiency, it grows up to 13% (from 0.14 to 0.158) by improving the processing technology of the photo-cathode. Therefore, the total photon detection efficiency including geometrical effect has improved by about 2.1 times compared with that of R7600. Figure 2 shows the sensitive area by the detection efficiency for R8900 (right) and R7600 (left). The thick square surrounding the sensitive area represents the physical size of MAPMT.

3. Characteristics for Space mission

3.1 Vibration

The EUSO equipment will be launched using the National Space Transportation System (Space Shuttle) or other launch vehicle. The MAPMT must endure the vibration during the launch. We have checked the vibration limit of MAPMT itself using a vibration generator. The vibration environment is the random vibration, and its frequency profile is shown by Table 1.

R8900 endured the random vibration up to 20.0G(rms), and the vibration magnification was lower than 10 in any frequency (Figure 3,4).

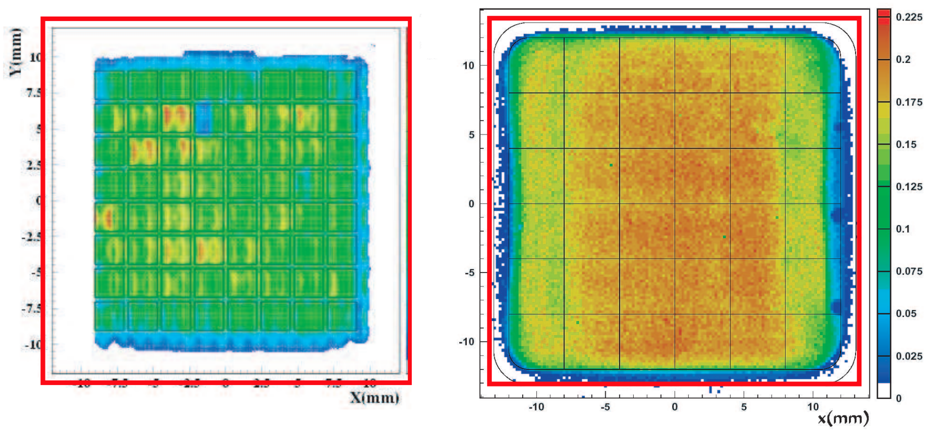

Figure 2. Comparison of sensitive area. The the right panel shows that of R8900-03-M36 and left panel shows that of R7600-03-M64. The color corresponds to the detection efficiency of each position.

Table 1. Frequency profile for MAPMT vibration test

20Hz - 100Hz	+6.00 dB/oct
100Hz - 500Hz	0.20 g^2/Hz (for 12.7G rms)
500Hz - 2000Hz	-6.00 dB/oct
vibration duration	2minutes

3.2 Radiation hardness

The influence of radiation is dominated by the degradation of entrance window transparency. The cathode sensitivity and electron amplification is negligibly small compared with the transparency degradation. The transparency is degraded to 90% beyond 1.4×10^5R for the gamma-rays in the energy region of MeV [4] . We have checked the transparency degradation for 70MeV proton beam.

We found almost no degradation beyond 30krad and 95% beyond 100krad. Because expected total dose during 3year mission time is a few krads, the degradation is negligible. More information about the radiation hardness is reported in Reference [5].

3.3 Long time reliability

Failure mode for MAPMT is roughly classified into gradual failure (ex. gain degradation) and breakdown failure (ex. cracks). The main failure mode is gradual failure. We estimated the reliability is over 99% for 3year operation, which is assumed 4.6μA average current and 50% operation ratio.

We have checked the gain degradation. No gain degradation was recognized over 8 times 3year mission time. The details are reported in Reference [6].

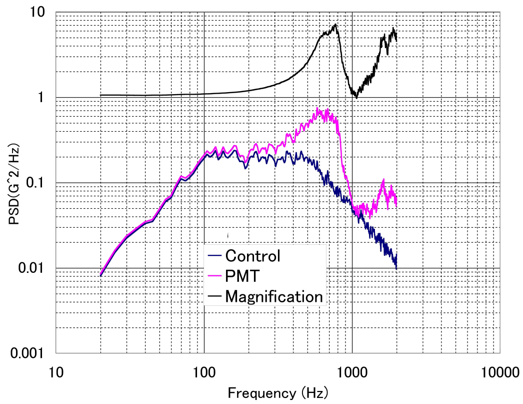

Figure 3. Frequency profile during vibration test

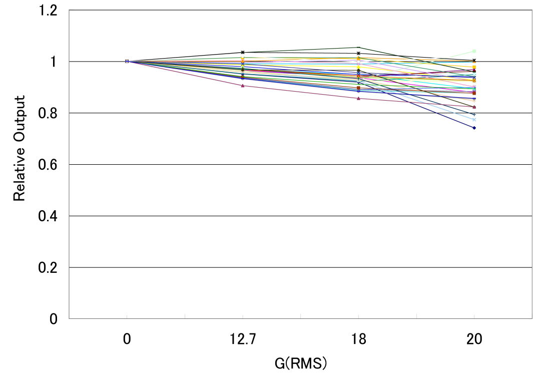

Figure 4. Output changes after vibration test

4. Summary

We have developed a new type of MAPMT R8900-03-M36 for EUSO mission. This MAPMT successfully fulfills most of the requirements for EUSO. In addition, we found an air shower detection power using this MAPMT is about 10% better than that using ideal MAPMT that satisfy EUSO requirements.

5. Acknowledgements

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