Characterization of a multianode photomultiplier tube for use with scintillating fibers to detect gamma rays

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The performance of a multianode photomultiplier tube (MAPMT) with 64 anodes coupled to scintillating fibers has been examined. Such a detector system can be used in a pair- production gamma-ray telescope as well as in other applications. The characteristics of these tubes (Hamamatsu R5900-00-M64) are presented including single photoelectron sensitivity, electrical and optical cross-talk, and dark count. Environmental test results of these devices are also presented.

Introduction

When utilizing scintillating fibers to track singly charged, minimum ionizing particles, one must have sufficient light output and a readout device capable of detecting that light. In 1997, work began on the Scintillating Fiber Telescope for Energetic Radiation (SIFTER). Using orthogonal layers of scintillating fibers, a pair-production gamma-ray telescope was constructed to detect gamma rays with energy from 10 MeV to 300 GeV. The scintillating fiber tracker detects the path of the initial electron-positron pair created from the gamma ray's interaction with a high atomic number (Z) converter sheet and the subsequent electromagnetic cascade in the detector stack. Such a detector requires the scintillating fibers to detect the passage of electrons and positrons with greater than ninety percent detection efficiency. Initially, the scintillating fibers were read out using image intensified CCDs (IICCDs). However, the Hamamatsu Corporation has recently developed the R5900-00-M64 multianode photomultiplier tube (MAPMT) with a higher quantum efficiency than current IICCDs. Additionally, the faster time response of the MAPMTs was critical for a gamma-ray instrument designed in part to detect gamma-ray bursts [1]. Some of the important characteristics of these MAPMTs are described in this paper.

The MAPMT requires little power, is compact in size, has stable properties and is suitable for the harsh environment of space. Along with its other characteristics these properties make them suitable for use in a number of other experiments and fields. Some initial characterization of the sixty-four anode MAPMT have been presented by Enckelman, et al. [2], Rielage, et al. [3], and the Hamamatsu Corporation [4].

Description of the MAPMT

The Hamamatsu R5900-00-M64 photomultiplier tube (figure 1) uses a twelve stage metal channel dynode structure and has sixty-four anodes within a single vacuum housing. The anodes are arranged in an 8x8 array and have an effective area of 2 mm x 2 mm on a 2.3 mm pitch. The metal flange around the tube measures 2.8 cm x 2.8 cm and the tube body length is 2 cm from the photocathode window. The 0.8 mm thick photocathode window is made of borosilicate glass and is spaced 2 mm from the first dynode. The metal housing is held at cathode potential. Negative high voltage is used to allow direct coupling of the anode pins to readout electronics. The tubes use a bialkali photocathode with a quantum efficiency of ~25% at 420 nm. Each anode has two metal channel dynode chains with twelve dynode stages between the cathode and anode. This allows the tube to operate with a gain up to $3x10^6$.

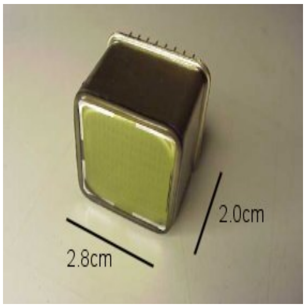

Figure 1

Single Photoelectron Sensitivity

Figure 2 shows the single photoelectron response for a typical anode. This single photoelectron spectrum was self-triggered by events with signal above 0.2 photoelectrons. Modifications made by Hamamatsu to the MAPMT in late 1999 have led to uniform single-photoelectron response on all anodes regardless of position in the tube.

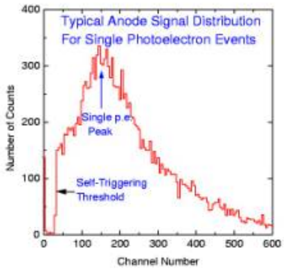

Figure 2

Cross-talk

There are two forms of cross-talk in the MAPMT: optical and electronic. Optical cross-talk occurs due to the divergence of light as it passes through the borosilicate glass window. The thickness of this window was originally designed to be 1.3 mm thick but was changed to 0.8 mm by Hamamatsu to reduce this effect. Electronic cross-talk occurs after the photocathode has produced an electron via the photoelectric effect and the electron is being steered toward a dynode chain. The electron can miss the dynode slit and hit the metal plate around the dynode causing the electron to “hop” a distance less than or equal to the cathode to first dynode separation (2 mm). The electron then begins the multiplication process in the wrong dynode chain leading to a signal in an incorrect anode. This cross-talk can thus appear on any one of the eight anodes around the original one. A second form of electronic cross-talk is being investigated that can occur in anodes that are not immediately around the original anode. This cross-talk is in the form of infrequent pulses which occur on anodes away from the anode being illuminated and can be thought of as correlated pulsing. This form of cross-talk contributes less than the other two forms and is currently being examined by the author and Hamamatsu.

Using a 1 mm blue-emitting square cross-section scintillating fiber as a collimated light guide for a blue LED, about twelve photoelectrons were produced at the photocathode. The fiber was centered on an anode and the signal from it and eight contiguous anodes were measured. For this 1 mm fiber centered on the anode, the average percent of cross-talked events above the 0.25 photoelectron level is ~13.4% in each of the anodes above and below, ~11.3% in each of the anodes to the right and left, and ~5% for each of the anodes located diagonally. A plot of the fraction of events detected versus the discriminator level (figure 3) shows that the fraction of events detected on each adjacent anode declines to < 7% at a setting of 1.0 photoelectron and to ~1% at a setting of 2.0 photoelectrons.

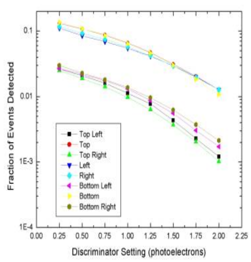

Figure 3

Dark Count

The dark count of the MAPMT is an important property since, for a given resolving time, it contributes to the number of anodes possessing a signal for a given event in an instrument. The dark count rate was measured to be ~1 count per second per anode at 25^{o} C after the tube has been kept in the dark for longer than six hours and the high voltage has been operating for one hour at –850 volts.

Environmental Testing

In order to consider using the MAPMT in the environment of space, it was subjected to thermal/vacuum tests and vibration tests to insure its ruggedness to survive typical loads experienced during and after launch. Several tubes were cycled between –40^{o} C and +40^{o} C and held in a vacuum of 10^{-7} Torr. Additionally, operational tests were performed over this same range. The tubes functioned without change after these tests. A total of seven tubes were subjected to vibrational tests performed at the Marshall Space Flight Center. All seven tubes were tested to NASA's Generalized Prototype Qualification level (14.1 G_{rms}). No significant change in the operation of any of the tubes was found.

Conclusion

The Hamamatsu R5900-00-M64 multianode photomultiplier tube is a versatile readout device which has many characteristics that make it suitable for use with scintillating fibers. We have shown that the MAPMT is able to withstand the rigorous environment of space through thermal/vacuum and vibration testing. The MAPMT shows considerable promise for use in a wide variety of applications both on the ground and in space.

Acknowledgements

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References

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