Radiation Hardness of the Avalanche Photodiode onboard Pico-satellite Cute-1.7

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The avalanche photodiodes (APDs) have attracted considerable attention since good features of both the photomultiplier tubes (PMT) and the photodiodes (PD) are shared by APDs. Thanks to its signal amplification with a typical gain of 10−100, APD can be used as an excellent soft X-ray detector at room temperature or at lightly cooled environment. We obtained the best energy resolution of 379 eV (FWHM) for 5.9 keV X-rays, measured at −20 deg. Moreover, it has been reported that an APD with a few mm^2 detection area has fast timing properties better or comparable to that of a fast PMT. In the previous studies, we have confirmed that APD can record more than 30 % of input X-ray signals (8 keV) even at the high input rate of $\sim 10^8$ cts/s [3].

Similar to the PIN photodiode and the Si Surface Detectors (SSDs), APDs can also work as a high-performance particle detector. We therefore plan to use it as a "Radiation Belt Monitor (RBM)" onboard the pico-satellite Cute-1.7, which will be launched by Japanese M-V rocket in the winter of 2005 ([4]; see also the report for R63). The prime purpose of Cute-1.7 mission is a preliminary test of using APDs in the space environment, since the APD will be one of the key sensors for the future X-ray astronomy satellites NeXT and the XEUS. In Cute-1.7 mission, we can also study the distribution of low-energy ($E < 10$ keV) electrons and protons geomagnetically trapped around the Earth. Such a low-energy, high-counting ($>10^6$ cts/s) particles are difficult to detect by the SSD or the PIN photodiode, which are often used as a RBM in the previous geophysical/astronomy satellites.

Unfortunately there were only a few papers about the radiation hardness of APD devices. Anzivino et al. 1999 reported a catastrophic failure mode for large area APDCT irradiated with high energy particles. Similarly, Laird et al. 2004 reported a significant damage of APD which results in a reduction of the breakdown bias and siginificant increase of the dark current, which raised a serious question about using APDs in space environment. However, both APDs tested in these experiments have quite different device structures, as compared with the APDs we are developing for Cute-1.7. We therefore examined APD behavior under the constant illumination of 53.2 MeV proton beam. Note that, such situation is actually expected in satellite orbit, since the geomagnetically trapped protons are accumulated and hit the satellites at a rate of 3×10^3 cts/cm^2/s in the South Atlantic Anomaly. Furthermore, most significant paricles in orbit would be protons with energy 50−100 MeV.

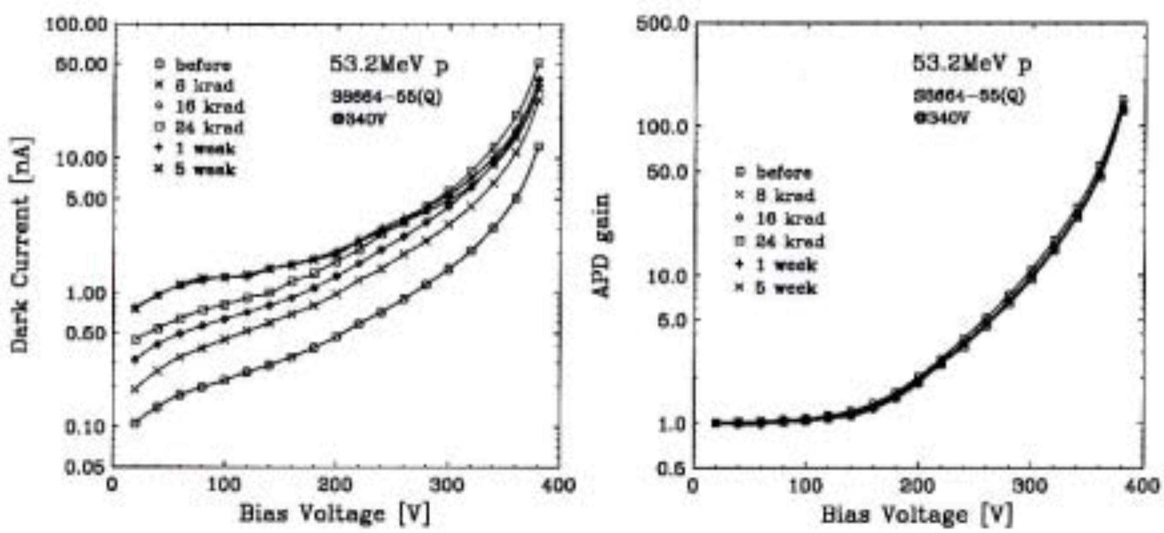

Figure 1: Changes in the APD dark current (left) and the gain characteristic (right) after the irradiation of 53.2 MeV protons.

Integrating over the lifetime of Cute-1.7 in orbit (~1 yr Max), total dose would be 4×10^9 protons/cm^2, or in other words 17 krad. We therefore investigated the changes in the device characteristics for two different types of APDs that have not been tested so far. We monitored the changes of dark current and gain characteristics after the total dose of 8 krad, 16 krad, and 24 krad. We also monitored the "burn-out" of the APD device after

1 week and 5 week from the proton beam test. Fig. 1 (left) shows the variation of the dark current, whereas the Fig. 1 (right) shows the APD gain as a function of bias voltage [2]. Also Fig. 2 shows the changes of 5.9 keV X-ray spectrum obtained with the APD after 24 krad irradiation.

Interestingly, the dark current increased by an order of magnitude after 20 krad illumination of the proton beam, but the gain characteristic has never been changed. An increase of dark current is always expected for Si devices, such as PIN photodiode and SSD, and not peculiar to the APD device. The gain characteristic of the APD after the irradiation is excellent, and seems to be quite different from other types of APDs in literature [1,5]. We therefore conclude that our improved APD devices can be used as a particle detector onboard Cute-1.7.

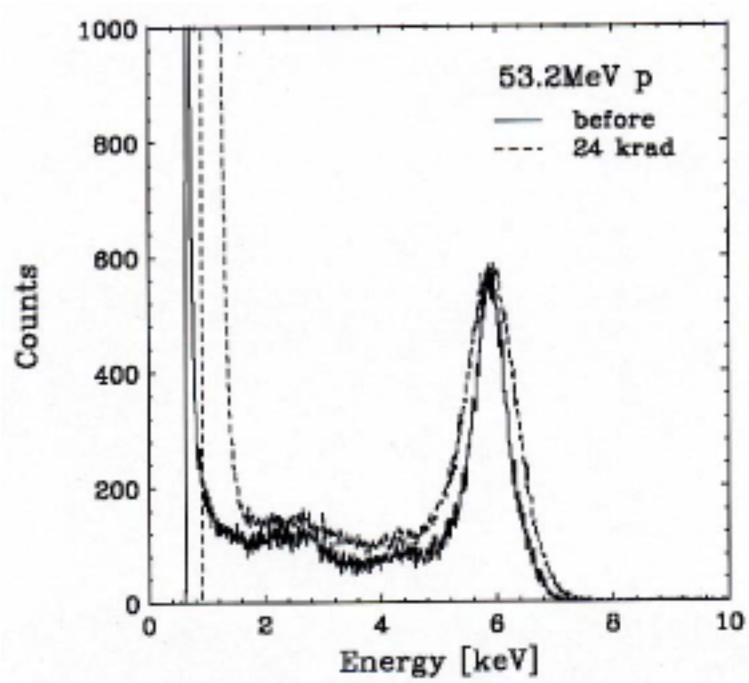

Figure 2: A 5.9 keV (^{55}Fe) spectrum obtained with the APD device before/after the irradiation of 53.2 MeV protons.

References

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