Development of wide-band X-ray gamma-ray imagers using reach-through APD arrays

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Abstract

It is quite important to obtain wide band spectra of high energy astrophysical phenomena at the same time in order to probe emission processes or structures. Especially observations of transient objects, such as gamma-ray bursts of active galactic nuclei, expect detectors with wide energy band coverage for the sake of an efficient spectroscopy within limited time windows. An avalanche photo diode (APD) is a compact photon sensor with an internal gain of ~100. We have developed an X-ray/gamma-ray detector using a reach-through APD ($5 \times 5\,\mathrm{mm}^2$) optically coupled with a conventional CsI(Tl) scintillator, which covers typically from 1 keV to 1 MeV. Further, we developed a 1-dimensional array of the 8/16 APDs (net $16 \times 20)\,\mathrm{mm}^2$) for the purpose of an imaging photon detector combined with coded masks, to be applied in future missions. We present the current status and performances of our hybrid detector.

Key words: instrumentation: detectors, photometers, spectrographs

1. Introduction

An avalanche photo diode (APD) is a semiconductor device having not only characteristics of photo diodes, which are high quantum efficiency (~80%) and fast response ($<$ 1 nsec), but also an internal gain of ~100. Recently in-orbit operation of an APD is successfully demonstrated by a pico-satellite *Cute 1.7+APD II* (Kataoka et al. 2009), and APDs will be applied to *ASTRO-H*. A reach-through type APD has a thick depletion layer (~100 μm), larger part of which works as a photon-absorbing and electron-drifting layer. The rest of the depletion layer located at its thin edge causes an avalanche amplification. Therefore every signal is completely amplified when photons are absorbed anywhere in the depletion layer. On the other hand, dark currents are a little higher than reverse type APDs because the reach-through APD multiplies even lots of thermal electrons. Therefore an optimal shaping time may differ to establish the best signal-to-noise ratio. Detailed study of reach-through APD is described in Yatsu et al.(2006).

2. Wide band spectrometer with an APD

We optically coupled a Hamamatsu APD (SPL5767, 5×5 mm^2) to a CsI(Tl) scintillator (4×4 mm^2) and illuminate gamma rays from the APD side. Soft X-rays are detected directly by the APD while hard X-rays are absorbed by CsI(Tl). In the latter case the APD works as a readout of scintillation photons. These two components are distinguished by the difference of the signal rise times. The signal from the APD is led to a charge sensitive amplifier and then divided into two lines. The one is connected to a fast shaping amplifier ($\tau = 50$ nsec) and the other to a slow amplifier ($\tau = 2$ μsec). When a photon is absorbed by the APD, the fast amplifier responds with a larger signal than the slow amplifier. On the contrary, the photon detection by the scintillator results in smaller and larger signals from the fast and slow amplifiers, respectively. As a result we successfully obtained a spectrum of ^{137}Cs in the 3 orders of energy. Obtained energy resolutions (FWHM) at 32 keV and 662 keV are 6.6±0.4 % and 7.6±0.1 %, respectively (Tanaka et al. 2007).

3. APD array

Using the technique described in the previous section, we have been developing imaging detectors with coded masks. As a first step we developed 1-dimensional arrays of the APD with Hamamatsu (Fig. 1 left), which are manufactured by dividing 16×20 mm^2 APD into 8 or 16 slits with common cathodes. In this section a stand-alone test of the APD arrays is mentioned. We measured ^{55}Fe spectra for each pixel at the room temperature and

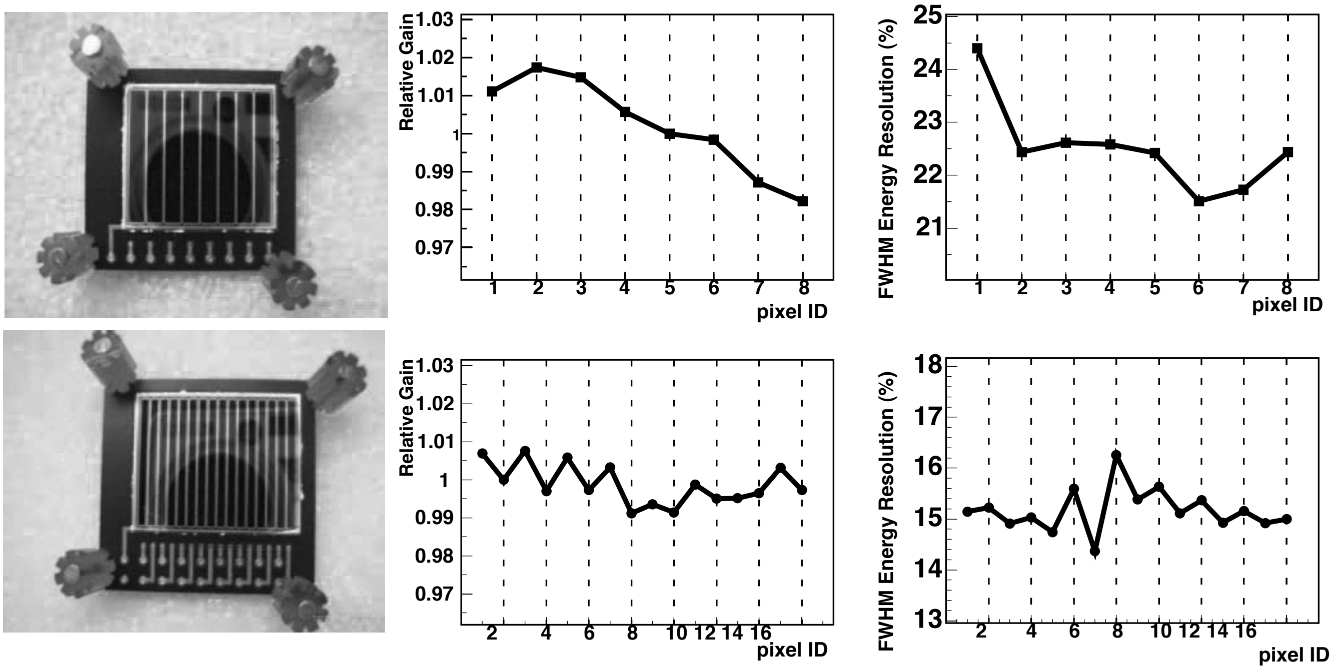

Fig. 1. **(Left)** APD arrays with 2.2 and 1.1 mm width for the 8-ch and the 16-ch array, respectively. **(Middle)** Relative gain along with the APD channel. **(Right)** Energy resolutions of 5.9 keV line for each channel. The top and bottom panels in each column correspond to 8-ch and 16-ch array, respectively.

a typical energy threshold is $\sim$2 keV. Fig. 1 (Middle and Right) shows relative gains and energy resolutions at 5.9 keV for each pixel determined by the Gaussian fitting, in which the fluctuations across the pixels are within $\sim$2 % and $\sim$1 %, respectively. It is already known using a test pulse that the capacitive noise is larger (typical capacitance of 25 and 19 pC for 8-ch and 16-ch array, respectively), mainly due to the noise characteristics of the charge sensitive amplifier used. Here the better energy resolution obtained by 16-ch array can be understood by the smaller capacitance than 8-ch array. In addition the measurement was at the room temperature and while we plan to use it at -20 degree. Thus we think we can expect better resolution with some optimization.

4. APD array with scintillator

We produced CsI(Tl) scintillator to fit to the APD pixel sizes, which are $2.2 \times 10.0 \times 16.0$ mm^3 and $1.2 \times 10.0 \times 16.0$ mm^3 for the 8- and 16-ch arrays, respectively. We wrapped the larger one with commercially available Enhanced Specular Reflector (ESR) and optically combined it to the 8-ch array. And then the stacked detector was exposed to a ^{137}Cs gamma-ray source at the room temperature. We demonstrated the two components are clearly separated and we extracted events corresponding to the photons detected by the APD and the scintillator. The energy resolution at 32/36 keV and 662 keV are 8.0 % and 8.4 %, respectively. The current measurement has a little energy gap between the APD and CsI(Tl) spectra at $\sim$50 keV. In order to solve this problems it is necessary to measure at a lower temperature e.g., -20°C.

5. Conclusions & Future work

The 8- and 16-ch APD arrays works well together with the CsI(Tl) array and they showed very uniform performance among each pixels. More measurements are required especially at the temperature of -20°C for the purpose of higher energy resolutions and wide band spectroscopy without the gap.

We have more things to check such as absorbed position dependence of the gain uniformity in a single APD pixel and scintillation light leakage from neighbouring CsI(Tl) pixels. We also develop a specific LSI for the readout of the 16-ch APD array, having lower gain and lower capacitance gradient than conventional VATAs, and its performance will be tested. A design study of coded masks using geant4 are now underway.

References

Kataoka, J., et al. 2009, JGR, submitted
Yatsu, Y., et al. 2006, NIM A, 564, 134
Tanaka, S., et al. 2007, NIM A, 582, 562