Study on solid-state detectors for measurements of 1-100 keV electrons

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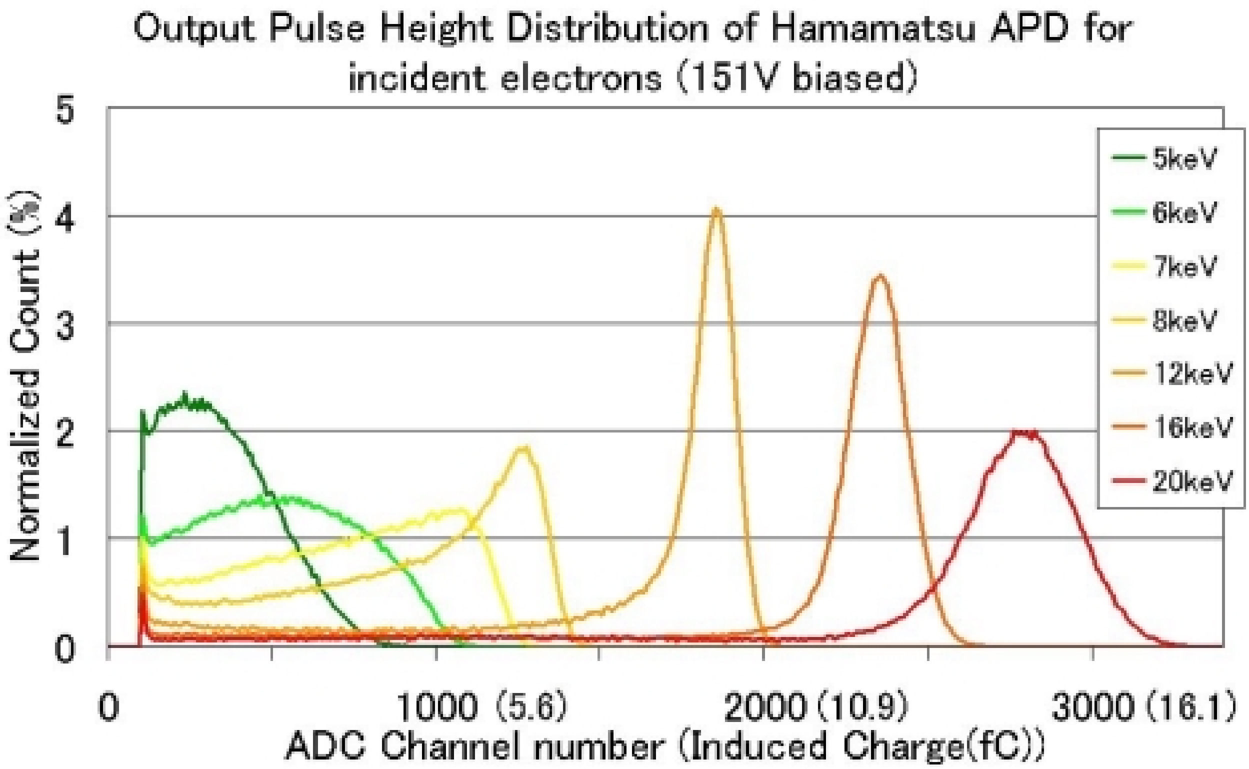
Information on energy spectra of 1-100 keV electrons is expected to provide an important clue to understand heating and acceleration processes of magnetospheric plasmas. However, the distribution functions in the transition energy range of thermal to non-thermal energies are not well known due to problems in the measurement techniques.

Micro Channel Plates (MCPs) and Channeltron Electron Multipliers (CEMs) have been used for detection of low-energy particles with energies lower than several tens of keV. The gradually decreasing detection efficiency toward higher energies than several keV causes the magnification of statistical errors and insufficient time resolution at this energy range. In addition, MCPs or CEMs are also sensitive to penetrating energetic particles and photons or secondary electrons, which cause background noise.

Solid-state detectors (SSDs) have been used to measure energies of cosmic rays (energetic particles and photons) individually. In the detection of particles with energies lower than several tens of keV, however, the energy losses in the dead layer near the surface is significant, and the small number of created electron-hole pairs makes it very difficult to measure the particles under the existence of noise source, such as leakage currents and thermal noise.

The above technical problems have kept us away from the achievement of reliable measurements of 1-100 keV electrons in space. This study aims at bridging the gap with the development of a new measurement technique to detect these electrons with high reliability by using a solid-state APD (Avalanche PhotoDiode) detector instead of the conventional SSDs and MCPs. The APD is a kind of p-n junction semiconductor with an internal gain due to the avalanche amplification of electrons and holes in the strong electric field within its depletion region, which is usually applied for photoelectronic devices.

In order to study the APD performance, we have set up an electron gun, which can generate 1-20keV electron beams impinging onto the APD (Type Z7966-20, Hamamatsu Photonics Co. Ltd.), in a vacuum chamber. The experimental result shows that the pulse height distribution from the APD signal exhibits a significant peak for the electrons with energies above 8keV (up to 20keV; the maximum energy in the present experiment). First of all, positions of peaks shows good linearity and incident electron energy can be highly resolved. Although the pulse height distribution shows an energy resolution better than 1.5keV in FWHM, the energy resolution depends on the incident electron energy. For low-energy electrons (lower than 10keV), it has a characteristic tail on the low energy side, while for incident electrons at higher energies (near 20keV) the energy resolution gets a little worse and the position of the peak appears at a bit lower channel than should be expected. Qualitatively, low energy tail features can be caused by the dead-layer on the surface of the device and its inhomogeneity. Nonlinearity and worse resolution of high-energy peaks may have caused by space charge effect of created e-h pairs. For the quantitative understanding, we have developed a Monte Carlo particle simulation of charge transport and collection inside the APD. We also have done a comparative experiment between APD and CEM (Burle industry Co. Ltd.) in terms of detection efficiency. Promisingly, this APD shows better efficiency compared to CEM at higher energy range than 5keV and nearly three times higher efficiency at 20keV. Similarly to the former case, we have used Monte Carlo Method to estimate efficiency on the assumption that the cause of miscounts is mainly back-scattered electrons.



Output Pulse Height Distribution of Hamamatsu APD for incident electrons (151V biased)
Normalized Count (%)
0
1
2
3
4
5
5keV
6keV
7keV
8keV
12keV
16keV
20keV
0
1000 (5.6)
2000 (10.9)
3000 (16.1)
ADC Channel number (Induced Charge(fC))