Nuclear Instruments and Methods in Physics Research A 664 (2012) 282–288

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Variability of the minimum detectable energy of an APD as an electron detector

S. Kasahara [a,*], T. Takashima [a], M. Hirahara [b]

[a] Institute of Space and Astronautical Science, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa 252-5210, Japan
[b] Solar-Terrestrial Environment Laboratory, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan

ARTICLE INFO

Article history:
Received 23 August 2011
Received in revised form
9 November 2011
Accepted 9 November 2011
Available online 18 November 2011

Keywords:
Avalanche photodiode
Electron measurements
Space physics
Planetary magnetospheres

ABSTRACT

The purpose of this study is to evaluate the variability of the minimum detectable energy of the avalanche photodiode which would be applied for measurements of medium-energy ($\sim 10-100$ keV) electrons in future magnetospheric exploration. The minimum detectable energy is affected by temperature variations as well as radiation. Our experiments and theoretical considerations show that the minimum detectable energy is significantly deteriorated at room temperature after proton irradiation of >10 krad mainly due to an increase in the dark current, whereas such a degradation is less prominent when the device is cooled down to $<5\,^{\circ}$C. These results provide a guideline for the thermal design of the medium-energy electron instruments especially for harsh-radiation space missions.

1. Introduction

The application of avalanche photodiodes (APDs) as electron detectors has recently been considered intensively, especially for use in space missions. Electrons have been observed around magnetized objects and it has become well known that they are accelerated at various sites such as collisionless shocks [1] and magnetic reconnection regions [2]. The typical energy of accelerated electrons around planets is a few to tens of keV, whereas their original energies are tens to hundreds of eV. Further energetic (relativistic) electrons are observed in radiation belts, which exist in the inner magnetospheres of planets. Theoretical studies have suggested that these relativistic electrons are probably generated by consuming the energy transported from medium-energy (10–100 keV) electrons via wave–particle interaction [3,4]. However, the direct evidence for such energy transport has not been obtained thus far. In order to promote a greater understanding of these electron accelerations, medium-energy electron measurements with state-of-the-art instruments are essential.

With near-future magnetospheric missions in mind, Kasahara et al. [5] designed an electron sensor composed of a cusp-type electrostatic analyzer (ESA) [6] and APDs for the measurements of medium-energy electrons in space. The ESA determines the energy of an incoming electron, and also rejects ions and photons. APDs are used instead of classical electron detectors such as microchannel plates (MCPs) and channel electron multipliers (CEMs), since the quantum efficiencies of MCPs and CEMs fall off in the energy range above a few keV [7] and it has been difficult to accurately predict the efficiency curve for the medium-energy range. Furthermore, signal charge multiplication by APDs, which enhances the signal to noise ratio, is the significant advantage over classical solid-state detectors. The feasibility of APDs as electron detectors has recently been confirmed in space [8,9].

In addition, the ability of APDs to measure particle (and photon) energy is especially useful for background reduction during observations in a harsh radiation environment, since spurious signals are eliminated by a consistency check of the energy, which is determined by the ESA and APDs independently [5].

Among a few types of APDs [10], reverse-type and reach-through type have recently been applied for electron measurements [8,11,9,12], and the latter has the advantage on the highest detectable energy. The thicker depletion layer of the reach-through type is more appropriate for the energy determination above ~ 50 keV (whereas a thin depletion layer results in the serious ambiguity in the energy determination, since higher-energy electrons cannot stop in a depletion region and thus only a fraction of the incident energies are deposited).

The minimum detectable energy (MDE) is also limited by the APD. In order for an electron to be detected, the signal charge generated by the incident electron must be larger than the internal electric noise level of the APD. Therefore, the electric noise as well as the charge multiplication factor ("gain") is the key restrictions on the MDE. In addition, the energy loss of incident electrons at the dead layer is an important element [12].

In general, the gain decreases and the electric noise level increases with increasing temperature, and therefore the MDE is

* Correspondence to: Institute of Space and Astronautical Science, Sagamihara, Kanagawa 252-5210, Japan. Tel.: +81 50 3362 2566; fax: +81 42 759 8456.
E-mail address: kshr@stp.isas.jaxa.jp (S. Kasahara).

0168-9002/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2011.11.033

lower (better) at low temperature. In addition, irradiation of the detector also generally results in noise level increase, which deteriorates the ability to detect lower-energy electrons. It is essential to evaluate these effects since they provide significant constraints on the instrument design, and in particular, for the thermal design. In this paper, we quantify the MDE of our APD in electron measurements based on laboratory experiments and theoretical considerations.

2. Experiments

2.1. Specification of the device

We have developed a reach-through type APD with Hamamatsu Photonics (s10936-9767(×), Fig. 1) especially for a near-future radiation belt mission [13,14]. The area of this APD (5 mm × 5 mm) is designed to fit the exit slit of our ESA, on which the APDs are installed. This size is medium compared to those of previous APDs developed for electron detection [12,15,16,11,17]. The thickness of the depletion layer (∼40−50 μm including an avalanche region from few to tens μm) has been determined to stop >80 keV electrons, according to the requirement on our instrument. The moderate thickness compared to recent reach-through APDs [11,17] has been selected since a thicker detector would capture more background X-rays [5].

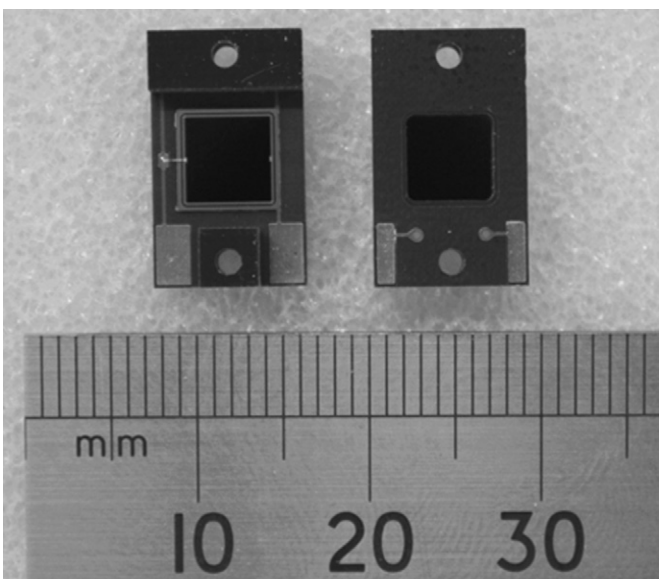

Fig. 1. APD of type S10936-9767(X), manufactured by Hamamatsu photonics K.K. The left one shows the back side (*n*-side), whereas the right one shows the incident side.

We operate this APD with a bias voltage of ∼120−180 V, which leads to an effective internal gain of ∼10−20 for electrons at room temperature. At the front end (i.e., in front of the depletion layer), there is a dead layer in which the electric field is so weak that the charge collection efficiency is very low. Its thickness has been estimated in our experiment to be 0.2−0.3 μm.

2.2. Experimental setup

Fig. 2 shows the experimental setup. The electrons were emitted from a heated filament and then pre-accelerated before being bent by a pair of cylindrical plates between which an electric field was applied. This curved structure is used with a magnet for mass discrimination in the case of ion beam experiments; in the case of electron beam experiments like the present study, we remove the magnet and apply the electric field so that introduced electrons can transmit through the curved tunnel. Electrons are further accelerated electrostatically to gain their total energy, which is the sum of the pre-acceleration and main acceleration. In our experiments, the typical pre-acceleration energy was 5–7 keV and the maximum total energy was 110 keV. The typical count rate was $\sim 10^3$ counts/s.

We used a high-voltage power supply CP6661P, a preamplifier CP580K (manufactured by CLEAR PULSE), and a shaping amplifier ORTEC571 (manufactured by ORTEC). The shaping time was set to be 0.5 μs. The bias resistor in the CP580K of 1 GΩ was replaced by a resistor of 100 MΩ, in order to avoid the significant drop of the bias voltage due to the dark current (nevertheless the potential drop is not negligible after the proton irradiation, as mentioned later). The peak values of the pulse-shaped signals were collected by a 12-bit multichannel analyzer (MCA8000A, manufactured by AMPTEK) and the data were stored on a PC. The temperature during the experiments was monitored by an AD590 that was installed right beside the APD (not shown in the figure). The temperature of the APD was controlled by Peltier devices. We compare the performance of electron detection under "cold" (5 °C), "moderate" (room temperature, ∼20 °C), and

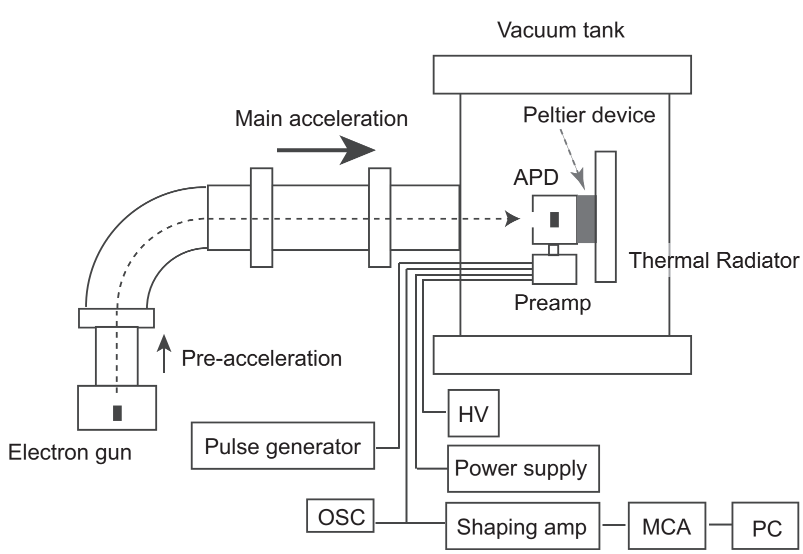

Fig. 2. Experimental setup for electron measurements.