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Noise and interpixel dead space studies of GaAs pixellated detectors

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Abstract

In the framework of the development of a digital radiography/autoradiography system using solid state detectors, we studied the performance of GaAs pixellated detectors regarding noise level and detection behavior of interpixel space. The detector is a 64×64 pixel array, 200 μm thick GaAs, 150 μm contact size and 20 μm interpixel space. Studies involve I–V curves, detector behavior for long-period biasing, noise as a function of temperature, and possible detection efficiency loss due to interpixel dead spaces. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Pixel detectors; GaAs

1. Introduction

The system we used is based on a solid-state pixel array detector, bump-bonded to a "photon counting chip" (PCC) developed by the Medipix Collaboration for medical applications [1]. The detector is a 64×64 pixel array, 200 μm thick semi-insulating GaAs, 150 μm contact size and 20 μm interpixel space; contact deposition (Ti/Pd/Au metal layers on both sides, non-alloyed on the ohmic side) is performed by Alenia, Italy. Each pixel is bump-bonded to a corresponding channel of the integrated electronics, based on amplifier, discriminator, and 15-bit counter. Each channel independently records the number of detected particles (over the energy threshold). After acquisition time the content of each pixel counter can be read by the control computer.

We performed measurements both on the detector itself and on the detector bump-bonded to the electronics.

2. Noise measurements vs. temperature

In a previous paper [2] we performed a study of noise level of the electronic chip (Medipix) as a function of temperature. In this paper we present measurements in which assemblies composed of detector and electronics underwent the same test in the 5–70°C range which is of interest for a variety of biological applications [2]. The method consists of determining, for each temperature, the minimum common threshold (set by an external reference bias) necessary in order to have a low noise level (defined < 2 counts/s per pixel) in a large part of

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the array (99%). Subsequently, each pixel threshold was calibrated in order to determine the actual pixel threshold (in electrons equivalent) and a mean minimum threshold was obtained. The standard deviation is related to the non-uniformity of the behavior of the pixels in the array. At the stage of chip optimization, this lack of uniformity can be reduced by adjusting, with a resolution of three bits, a local threshold present in the circuitry of each cell in the matrix array. The chipboard hosting the detector + electronics was connected to the read-out electronics by a 40-cm cable and placed in a cooled box for low-temperature measurements, and in an oven for higher temperatures. The cooling box was sealed, de-humidified, and cooled via a Peltier cell and a heat remover: temperature and humidity were constantly monitored. A large oven was used for the high-temperature measurements, the local temperature being monitored around the detector. Using a sample of 500 pixels, the mean minimum threshold and standard deviation (shown as error bars) were obtained, and are shown in Fig. 1 as a function of the temperature. As can be seen in Fig. 1, below 60°C, the mean minimum threshold apparently does not depend on temperature; in addition, the non-uniformity of the array (the standard deviation) stays around 10%. Over 60°C we see a sharp increase in the threshold needed to keep the noise level low, as well as an increase in the non-uniformity in pixel behavior. Similar behavior was observed with the electronics alone, but above 70°C [2]. It is reasonable to assume that the shrinkage in the range of "good behavior" is due to a corresponding increase in leakage current in the detector.

3. *I–V* measurements over time

The leakage current of a pixellated detector (4096 pixels, about 1.2 cm^2, 200 μm thick) was measured over time in order to study the behavior of the detector under the stress of a long biasing period. The detector was under high voltage (HV) bias for several weeks: leakage current, local temperature and humidity were monitored. The detector was continuously biased using aluminum-coated Mylar foils in contact with the Ohmic backplane (+ HV) and the Schottky pixellated plane (ground), and current was monitored using a Keithley 485 picoammeter. It was biased for about 15 days at 300 V, during which the detector current showed oscillations which were apparently due to temperature variations over daytime (Fig. 2). In a second phase (not shown in figure), the bias was increased to 350 V for 20 days: the current showed similar oscillations around a slightly higher average value. In the final phase, the detector was biased at 400 V for about 7 days, during which the detector current, after a short life of about 24 h with no variations, had a sharp increase over time (Fig. 3). This is possibly due to current injection through the non-inverting Ohmic contact and/or to the opening of conduction channels through the bulk of the detector, once the electric field reaches the Ohmic contact.

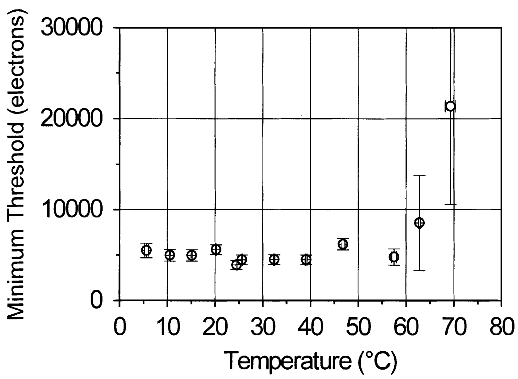

Fig. 1. Mean minimum threshold as a function of temperature.

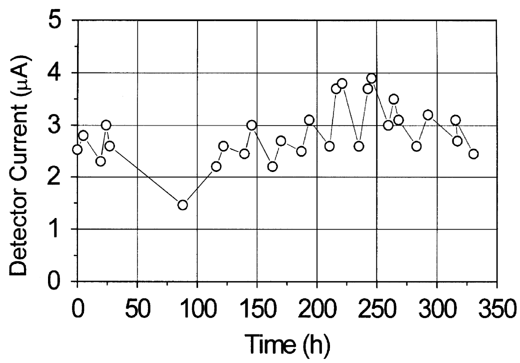

Fig. 2. Detector current vs. time of continuous biasing at 300 V (for 15 days).

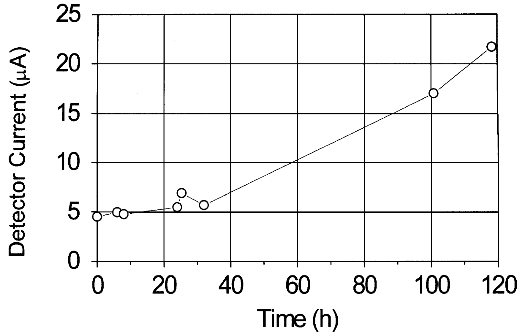

Fig. 3. Detector current vs. time of continuous biasing at 400 V (for 7 days).

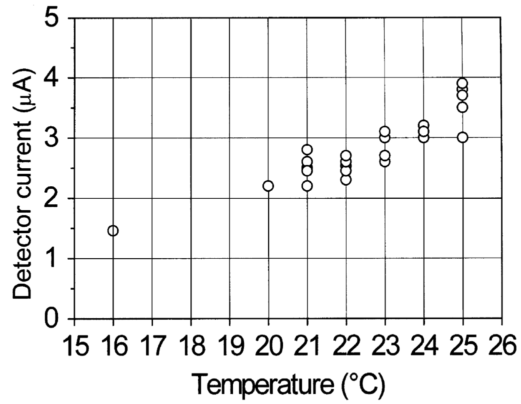

Fig. 4. Detector current vs. temperature (reverse bias voltage = 300 V).

In Fig. 4, the detector current is shown as a function of the laboratory temperature, plotting the same set of data used for Fig. 2 (measurements obtained by biasing the detector at 300 V). This confirms that the oscillations in Fig. 2 are mainly due to temperature variations in the laboratory over time.

This study originated from the observation that after biasing GaAs detectors for short acquisition times (but at high bias, in overdepletion mode), they suffered a breakdown after months of non-continuous use. This work showed that as long as we bias the detector below a given critical voltage (or field) value, detector is fully operational for a long time. On the contrary, if we over-bias it, we trigger a continuous degenerative process (either in the Ohmic contact or in the substrate) that results in an irreversible breakdown.

4. Counting efficiency vs. detector bias

The width of the depleted region is a key parameter for obtaining the best possible efficiency for the detector: a high electric field through the detector allows for total depletion, but an obvious upper limit is the breakdown voltage. The detector in our set-up is irradiated from the back (i.e. the Ohmic side) where, if the applied voltage is insufficient, an undepleted region is located. In order to evaluate the minimum voltage that can be applied to obtain the maximum detection efficiency, we studied the number of detected particles as a function of the detector bias using different β and γ sources (^{14}C, ^{35}S, ^{90}Sr, ^{210}Pb, ^{241}Am, ^{152}Eu). Point sources were sealed, positioned at a few millimeters from the detectors; these sources had different activities (which was the reason for different statistics since the acquisition time was the same). In Fig. 5, corresponding to the γ sources (in this case, all the energy is released within microns from the interaction point), we noticed that a saturation of counts is reached before 300 V. Similar behavior is shown in Fig. 6, where a ^{90}Sr β source is used. In fact, ^{90}Sr emits β particles with mean energy 196 keV, corresponding to about 120 μm range in GaAs. When the depleted region includes a suitable fraction of the track, the charge that can be collected goes over the threshold (which, in this experiment, corresponds to about 30 keV), the particle is detected, and there is no improvement in detection efficiency if the depleted region is extended. In Fig. 6 the saturation also occurs around 300 V. ^{35}S and ^{14}C emit lower energy β (mean energy 49 keV). Therefore, their tracks in the detector are much shorter (about 20 μm) and in order to collect enough charge to go over the threshold, the depleted region must advance to within a few microns from the Ohmic backplane, which is the incidence surface for the particles. In this case the saturation occurs at around 350 V (Figs. 7 and 8), which is essentially a good estimation of the voltage needed for total depletion of our 200 μm GaAs detector.

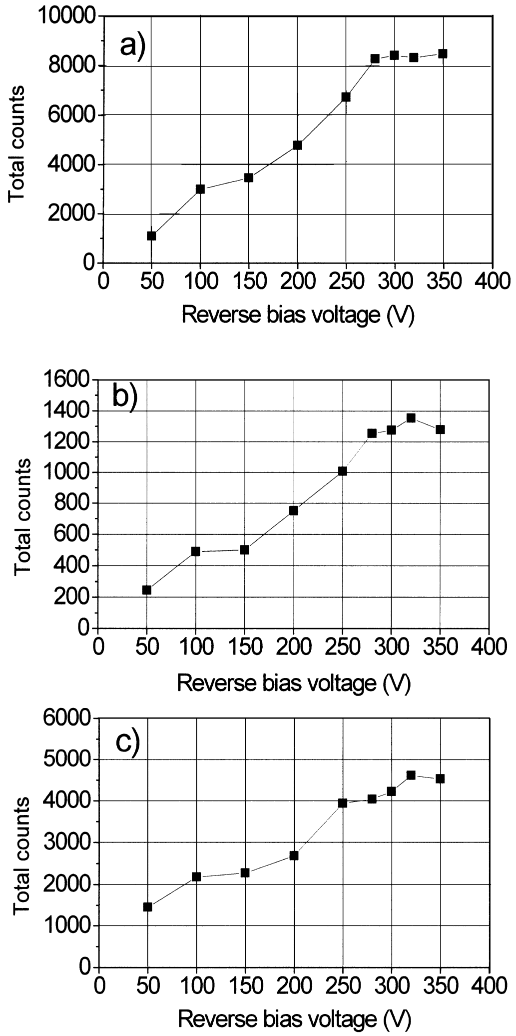

Fig. 5. Counts over the whole detector as a function of applied bias for: (a) ^{210}Pb source (γ source, energy 47 keV); (b) ^{241}Am source (γ source, energy 60 keV); (c) ^{152}Eu source (γ source, energy 122 keV).

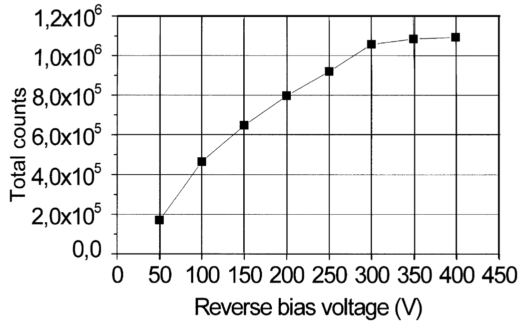

Fig. 6. Counts over the whole detector as a function of applied bias for ^{90}Sr source (β source, mean energy 196 keV).

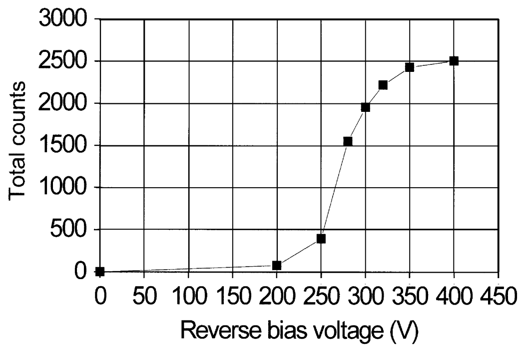

Fig. 7. Counts over the whole detector as a function of applied bias for a ^{14}C source (β source, mean energy 49 keV).

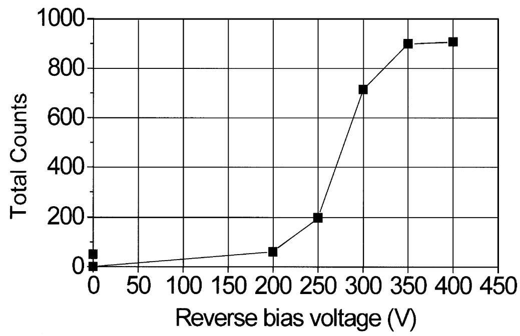

Fig. 8. Counts over the whole detector as a function of applied bias for a ^{35}S source (β source, mean energy 49 keV).

5. Dead space between pixel contacts

The Schottky side of the detector is an array of 150 μm × 150 μm contacts, with a space of 20 μm between contacts. Using a ^{241}Am γ source (60 keV) and a 30 μm collimator, we scanned the area between two adjacent pixel contacts looking for possible losses of detected photons. The collimator was positioned at about 200 μm from the detector surface, and was moved using a 10 ± 1 μm step. Counts in two adjacent pixels (#1 and #2) were recorded while the source was moved from the area over pixel #1 across the interpixel space and then over pixel #2. As can be seen in Fig. 9, while some

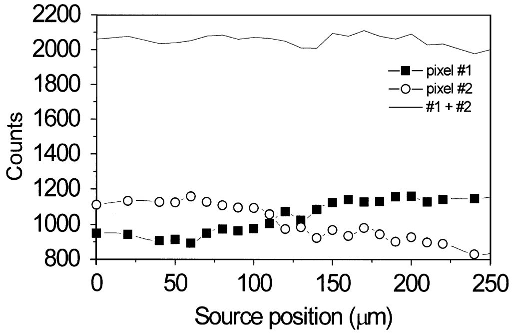

Fig. 9. Adjacent pixels counts vs. source position.

variations due to low statistics and noise could be observed along the whole scan, no evident loss in total counts was noticed while the source was passing over the interpixel area. It is, therefore, assumed (as expected) that the electric field lines below each pixel bend and reach the interpixel area which is, therefore, made sensitive.

6. Conclusions

The extensive work performed on some samples of semi-insulating GaAs detectors and associated electronics allowed us to observe good behavior (from the point of view of noise) of the assemblies in the temperature range of 5–70°C, to establish that the detectors could be operated with no damage for a long period of time as long as the applied bias is below 400 V, and that, for several commonly used laboratory sources, 350 V bias is sufficient to obtain maximum efficiency. Finally, it was confirmed by our measurements that no loss of efficiency is to be expected from interpixel spaces in the geometry of our detector.

Acknowledgements

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