GUARD-RING AND CHARGE COLLECTION EFFICIENCY OF GaAs DETECTOR

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Summary The study presents the results of an experimental investigation focused on the influence of guard-ring on detector charge collection. The tested detector is based on semi-insulating (SI) GaAs substrate with a base thickness of 250 μm, where the depletion region is created by a PN-junction. The experiments were executed in vacuum using the ^{241}Am source emitting 5.48 MeV alpha particles. Obtained results show noticeable increase of charges collected with higher collection efficiency in spectrum, when guard-ring was read out together with detector electrode.

1. INTRODUCTION

A film as a detection medium in visible and X-ray imaging has dominated for more than a century. Nowadays, microelectronics opens new ways for the conception of modern imaging detectors. Small dimensional detectors arranged in a matrix or a line can successfully substitute conventional film imagination and bring numerous advantages. Such digital imaging offers higher sensitivity and consequently decreases the radiation ballast of patients examined by an X-ray apparatus. Moreover, the work with electronic information is more comfortable and less time-consuming. Pulse-processing front-end electronics suppresses low frequency noise. Setting the threshold allows to discriminate noise from signal and also photon energies. Multiple threshold implementation opens completely new perspectives for X-ray imaging applications, since the density profile monitoring is enabled.

Recently, the most studied detectors in digital imaging field are detectors based on the compound semiconductors. They include advantage of single photon counting and of direct photon detection. Ionizing particles, which passed through the studied object, are directly detected by detector matrix connected to the separate CMOS (Complementary metal-oxide semiconductor) readout chip providing obtained information to personal computer.

Development of high quality radiation detector belongs to the most important steps in preparing the digital imaging system. Detector material has to fulfill succeeding properties. It has to have a high enough atomic number to yield sufficient photon absorption. The material should have a low dielectric constant, to ensure low capacitance and therefore system noise. From electronic point of view, the band-gap energy should be high enough to prevent thermal generation of carriers at room temperature (RT) and the energy per electron-hole pair creation as small as possible, to ensure good energy resolution. Additionally, the resistivity should be high to allow larger biases to be applied, resulting in faster drift velocities and deeper depletion depths. GaAs compound belongs to semiconductor compounds, which comply well with these criteria. Radiation detector can be prepared either as a PN-junction or as a Schottky contact on semiconductor. Both arrangements form so-called depletion region, which creates an active detector volume for registration of ionizing particles and photons. Recently, GaAs detectors for digital imaging are mostly prepared using the Schottky contact [1 - 4] but first GaAs detectors with PN-junction have been tested with positive results [5]. In digital radiography, where detection part consists of a semiconductor wafer segmented into small sensor cells by pixel, pad (two-dimensional) or strip (one-dimensional) electrodes, the electric field spreading of each electrode is important. The cross-talk of two neighbouring electrodes is responsible for distortion of detected signal and deteriorates the resolution of whole sensor. The electric field spreading is now often regulated by a biased guard-ring (a thin metallic strip surrounding the whole electrode). Detector tests with alpha particle irradiation will show as the charge collection efficiency of detector changes, when the guard-ring is read out together with detector pixel electrode as a second ring-shaped electrode.

2. EXPERIMENT

Tested sample was prepared from high purity and high resistive N-type SI (semi-insulating) GaAs substrate. The substrate has resistivity higher than 10^7 Ωcm, the Hall mobility higher than 6000 $cm^2V^{-1}s^{-1}$ and the thickness of 250 μm. PIN structure was created using MOCVD (Metal Organic Chemical Vapour Deposition) depositing of P+ (C, 300 nm) epitaxial layer from the top and an N+ (Si, 400 nm) from the bottom side of the substrate. The top contact on P+ layer was formed by TiAu (10+200 nm) metallization and the bottom metal contact was prepared by evaporation of AuGeNi (200+100+100 nm) on N+

layer [5]. Finally, the metallization etching was executed to form designed contact pattern with guard-ring (Fig. 1) followed by the substrate etching (using the metallization as an etching mask) to form MESA structure. The overall lateral dimensions of the detector are 5×5 mm^2.

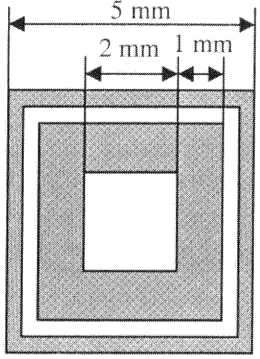

Fig. 1 Top view of GaAs detector metallization: pixel and guard-ring

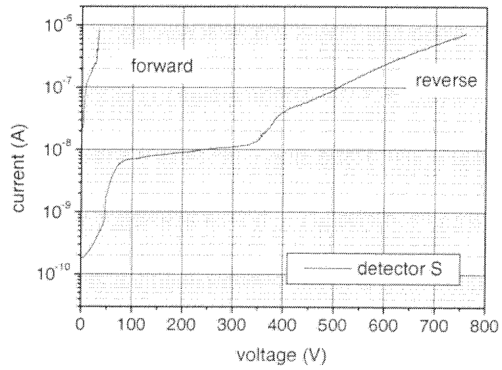

Fig. 2 The current-voltage characteristics of GaAs detector under forward and reverse biasing

Current-voltage characteristic of the detector (Fig. 2) was measured by an automatic I-V system (D/S Lab Ltd.). As is seen from the Fig. 2 the current saturation occurs under reverse bias voltage in the range of 100 – 300 V. This is considered to be a working region of the detector. The break-down process starts over bias voltage of about 350 V. The observed value of current density in the saturation region is satisfyingly low, of about 2 nA/mm^2.

Pulse-height spectra have been performed using standard spectroscopy electronics, which includes charge sensitive preamplifier PEVOT NUE 108 followed by a linear amplifier with a Gaussian shaping time of 0.5 μs, whose output was connected to the multichannel analyzer CICERO 8k. The spectra were measured using ^{241}Am (5.48 MeV) alpha-source of an activity of 8.779 kBq at various bias voltages applied (100 - 350 V) at RT. The detector and source were placed in a vacuum of < 20 Pa. The distance of the source from the sample was kept at 5 cm to minimize the detection of particles angle emitted from the source.

3. RESULTS AND DISCUSSION

Charge collection efficiency (CCE) is a parameter characterizing detector ability to collect the charge generated by impinged particle. It is defined as ratio of charge collected by detector (Qcol) and the charge calculated theoretically (Qcal), which should have been collected. The theoretical value can be calculated dividing the energy of ionizing particle by energy per electron-hole pair creation. The CCE is related to the position of an observed peak in detected spectrum. The higher channel number means higher CCE. The advantage of detector tests with alpha particles rests in their well-defined penetration range in chosen material. Alpha particles with the energy of 5.48 MeV will be absorbed in a depth of about 20 μm of GaAs according to simulation program SRIM 2003 [6].

The spectra measured with disconnected guard-ring (Fig. 3) show that the CCE is decreasing with higher reverse bias voltage applied. This tendency can be explained by low homogeneity of detector material, where regions with lower CCE dominate after spreading the active detector area with increasing voltage. Described decrease in CCE is observable up to 250 V, where the CCE saturation occurs, which means the end of the spreading of detector active area (detail in Fig. 4).

When the guard-ring was connected to the reverse bias and read out together with detector pixel electrode, measured alpha spectra (Fig. 5) have showed the increase of counts in higher channels (300 - 500) in comparison with separate electrode readout. This effect is caused by collection from area under guard-ring, which is very thin and the produced electric field at the edge of ring electrode is very sharp causing very good charge collection, so-called 'edge-effect' [7]. In the case of ring, the edge contribution is much higher than in the case of a pixel. Comparing with Fig. 3, the counts registered in higher channels can also be noticed but in much lower numerousness. It is observable that the increase of applied reverse bias voltage has caused the growth of guard-ring counts in ever-higher channels up to saturation at 250 – 350 V. This assumes that the charge collection was supported by increasing electric field intensity up to applied voltage of 250 V, where the full depletion occurs [8] and the field does not spread any more.

The assumption of the ring contribution to signals detected in higher channels is confirmed by measured spectra, where only a guard-ring was read out (Fig. 6). Here the peak measured by pixel electrode is missing and contrariwise only the contribution from guard-ring appears.

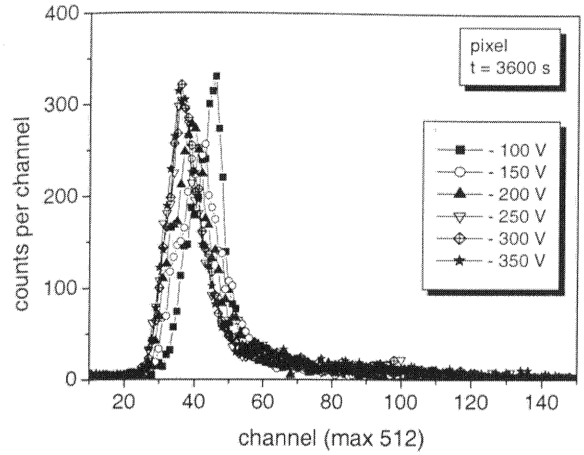

Fig. 3 ^{241}*Am spectra obtained with detector pixel electrode at different reverse bias voltages applied*

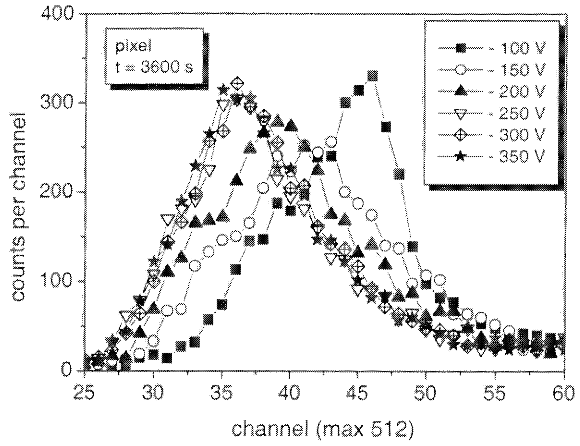

Fig. 4 Zoom in Fig. 4 spectra

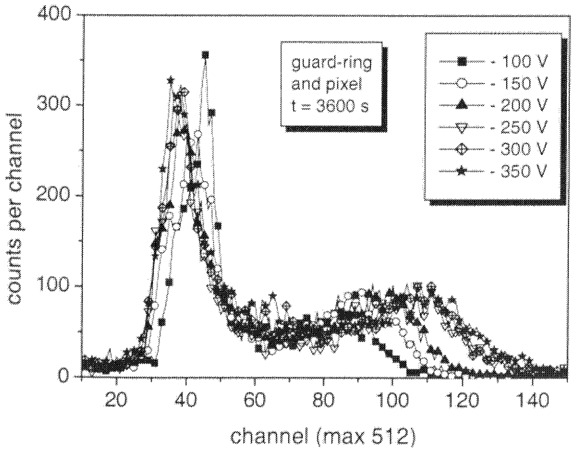

Fig. 5 ^{241}*Am spectra measured with guard-ring and detector pixel connected to the readout electronics*

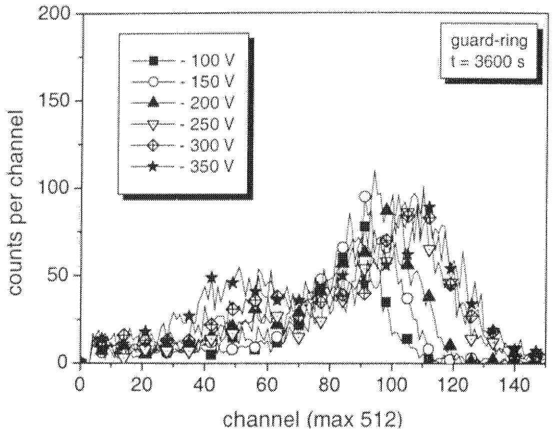

Fig. 6 ^{241}*Am spectra measured with guard-ring connected to the readout electronics*

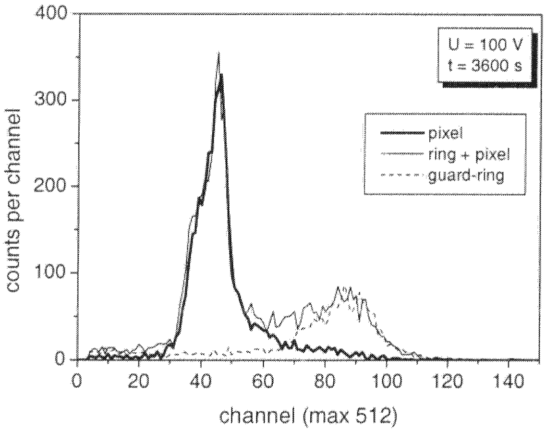

Fig. 7 ^{241}*Am spectra measured with connected pixel, guard-ring or both to the readout electronics*

Spectra depicted in Fig. 7 confirm that pixel electrode produces counts registered mainly in lower channels and guard-ring in higher. Moreover, the sum of spectrum from guard-ring and spectrum from pixel is equal to count distribution in spectrum from their joint readout. This tendency was observed within all the reverse bias voltages applied. The assumption that counts in observable in higher channels after guard-ring connection are caused by a breakdown pulses or trap charge release can be refuted by following experiments. The increase of counts was fluent in time (Fig. 8). The pulses due to break-down usually do not increase gradually, but randomly. Moreover, no signal was registered by the detector without alpha source, except noise consecutively reduced by setting of the Low level Discriminator.

The last experiment shows, that guard-ring pulses does not exceed the 100 % CCE. To determine the channel of 100 % CCE the reference silicon detector was used. The silicon detector reaches the 100 % CCE already at 30 V and the peak was recorded in channel 308 (Fig. 9). Considering the different energies necessary to produce electron-hole pair for Si and GaAs, the 100 % CCE for GaAs was determined to be at the channel 266, which is much higher than the guard-ring peak position.

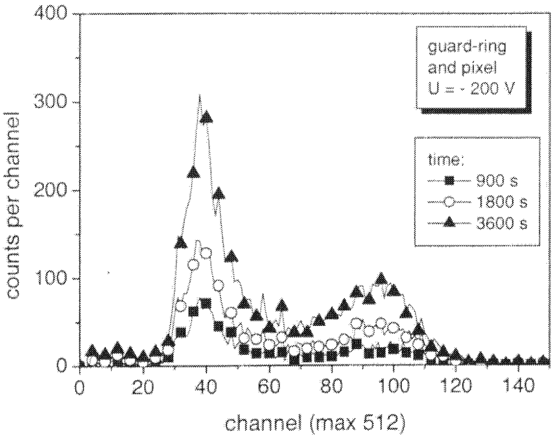

Fig. 8 ^{241}Am spectra measured with connected pixel and guard-ring to the readout electronics recorded in time

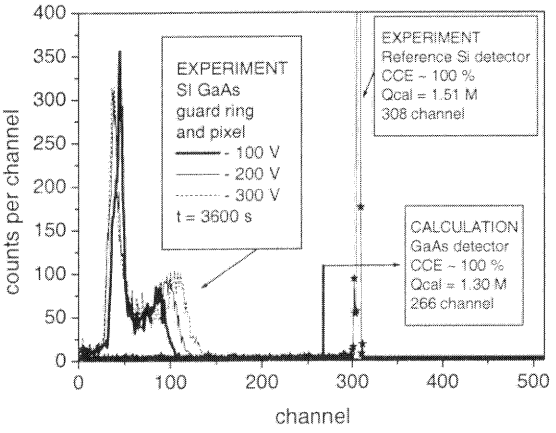

Fig. 9 ^{241}Am spectra obtained with tested sample compared to reference silicon detector

4. CONCLUSION

We have presented the results of an experimental investigation of SI GaAs detector focused on the influence of guard-ring, when read out with detector electrode, on detector charge collection. Connecting the guard-ring, which is in fact a ring-shaped electrode, to the readout electronics and its biasing causes remarkable increase of number of detected counts with higher amplitude. This effect can be explained by higher edge contribution in the case of guard-ring in comparison with pixel electrode. The electrode edges cause higher intensity of electric field collecting created electron-hole pairs and thus producing higher electric signal for readout electronics. The possible confusion of signal for breakdown pulses or trap charge release was refuted by monitoring the spectra measuring in time, determining the 100 % CCE boundary in GaAs and reiteration of the experiment without alpha source.

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