Influence of base material thickness on spectrometry of semiconductor detectors based on semi-insulating GaAs

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Abstract—**The bulk semi-insulating GaAs material was used for preparation of pad radiation detectors with circular contacts of 1 mm diameter. The spectrometric properties of a semiconductor detector depend on the quality of the base material and on the deposited metallization. Another factor affecting the detector spectrometry is the applied bias controlling the electric collection field. With increasing bias, the charge collection efficiency of particular detector grows. However, this spectrometric property should be changing with detector thickness, which affects the intensity of electric collection field at constant bias applied through the detector sandwich structure. In this paper we have studied the electrical and spectrometric properties of semi-insulating GaAs detectors as a function of their thickness. The measured saturation reverse current was in the range of 3 – 30 nA, increasing with decreasing detector thickness at a substrate resistivity of about of 10^7 Ωcm. The maximal obtainable charge collection efficiency evaluated from ^{241}Am gamma spectra grew with decreasing detector thickness from 50% for a 450 μm thick detector to 80% for a 230 μm thick detector.**

Keywords —**GaAs detector, bulk semi-insulating, detector thickness, charge collection efficiency.**

I. INTRODUCTION

Semiconductor detectors of ionizing radiation are a rapidly developing field with expanding applications. The most common semiconductor material is silicon, however, there are other alternatives used for detector preparation like semi-insulating (SI) GaAs [1-9]. The SI GaAs is a material with a high resistivity of about 10^8 Ωcm and a high charge carrier mobility of up to 8000 and 400 $cm^2V^{-1}s^{-1}$ for electrons and holes, respectively, at room temperature (RT) leading to a high detector reaction rate. Its wide bandgap of 1.42 eV enables detector operation at RT. In comparison to silicon, the GaAs exhibits much better radiation hardness [10-16] and has higher detection efficiency for photons thanks to its higher electron density. However, in comparison to silicon detectors, its spectrometry quality is a limiting factor. The spectrometry properties are affected by the base material quality and also by the detector structure. In the case of single pad SI GaAs detectors with a circular electrode the collecting field of the charge generated by the radiation is affected by detector thickness and applied bias influencing the spectrometric properties of the detector. Typical thickness of SI GaAs wafer for detector preparation ranges from 500 μm down to 230 μm, obtainable by wafer polishing.

In this paper we have prepared the SI GaAs detectors of various thicknesses 230, 350 and 450 μm and evaluated their important electrical and spectrometric properties with respect to the detector thickness. The charge collection efficiency (CCE) during the spectrometry of alpha particles and gamma rays from ^{241}Am is presented as well as current-voltage characteristics measured for prepared detectors.

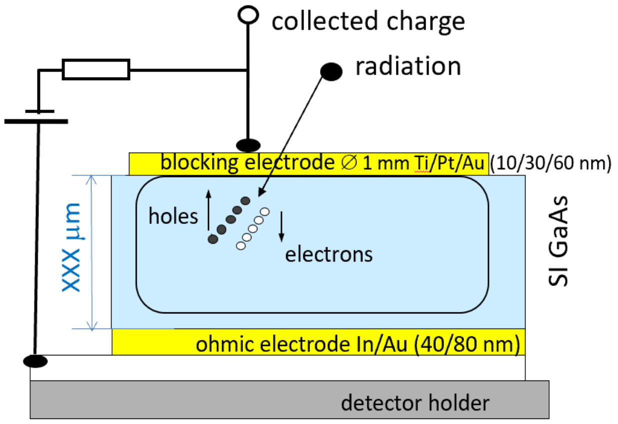

Fig. 1. The cross-section view of prepared SI GaAs radiation detector. The different thicknesses are marked as "XXX".

II. DETECTOR STRUCTURE

The detectors were fabricated at the Institute of Electrical Engineering of SAS in Bratislava from bulk undoped SI GaAs substrates double-side polished to three various thicknesses: 230, 350 and 450 μm. Top blocking electrode was realized as circular Schottky contact of a 1 mm diameter made of Ti/Pt/Au (10/30/60 nm) multilayer evaporated through a metal contact mask. The bottom ohmic electrode was covering whole substrate area and was prepared as In/Au (40/80 nm) double layer by evaporating in a high vacuum chamber. The cross-section view of the detector structure is depicted in Fig. 1.

III. EXPERIMENT AND DISCUSSION

A. Current-voltage measurements

Foremost, the current-voltage characteristics of the fabricated SI GaAs detectors were measured at RT to determine the correct operation of the detectors. The reverse current depicted in Fig. 2 affects the value of the noise signal during radiation detection. Its saturation value was in the range of 3 to 30 nA depending on the detector thickness. The lowest saturation current was measured for the thickest (450 μm) detector and as the detector thickness decreases, the saturation reverse current increases, which is understandable as the resistivity of all compared SI GaAs substrates was similar of 10^7 Ωcm.

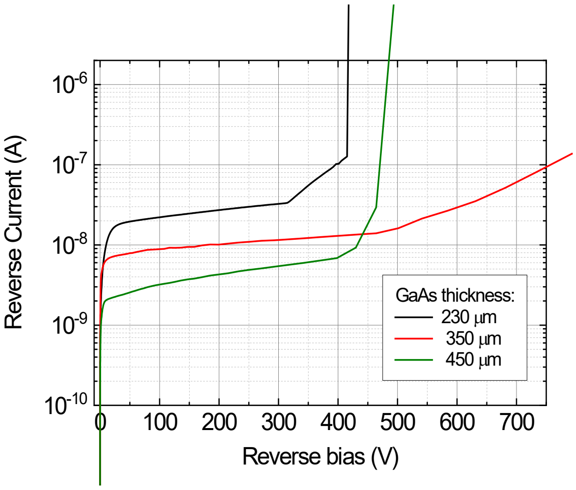

Fig. 2. The typical reverse current–voltage characteristic of GaAs detectors for various detector thicknesses.

B. Alpha spectrometry

The detectors were fabricated for spectrometry of alpha particles and gamma rays and examined by combined ^{241}Am alpha and gamma source. Measured alpha spectra of ^{241}Am are shown in Figs. 3. – 5. for various biases applied. The shift of the peak to higher channels with increasing bias can be observed for all three detector thicknesses. However, this phenomenon is the most intensive with the thinnest detector, which reaches the highest channels corresponding to the highest CCE and reaching also the best peak height. As the thickness of detector grows, the peak becomes smaller and wider indicating inhomogeneities in charge collection.

The CCE as a function of reverse bias for all three types of detectors is depicted in Fig. 6. The increase of CCE with applied bias was reached due to higher charge drift velocity obtained by increasing intensity of electric collection field. The CCE during alpha detection is affected dominantly by electron collection, as alpha particles interact close to the Schottky electrode. The 5.485 MeV alpha particles from ^{241}Am had to penetrate 6 mm of air and the metallization of top Schottky contact before reaching the active detector volume in our experiment. According to results of simulation in SRIM [17], the particles penetration depth is 17 μm in GaAs [16]. The electrons as charged carriers in GaAs exhibit very high mobility of 8000 cm^{2}V^{-1}s^{-1} and the effect of detector thickness on CCE is minimal. On the other hand, the 350 and 450 μm thick detector substrates have measured electron Hall mobility @ 300K: 6200 cm^2/Vs and the 230 μm thick ones: 7119 cm^2/Vs, which led to lower CCE of thicker detectors.

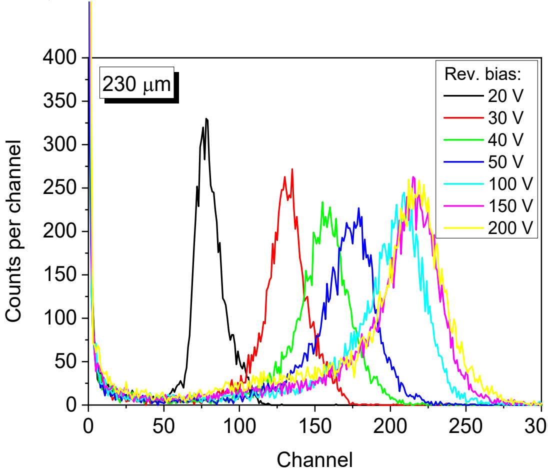

Fig. 3. The alpha spectra of 5.5 MeV alpha particles from ^{241}Am measured by a 230 μm thick SI GaAs detector at various reverse biases.

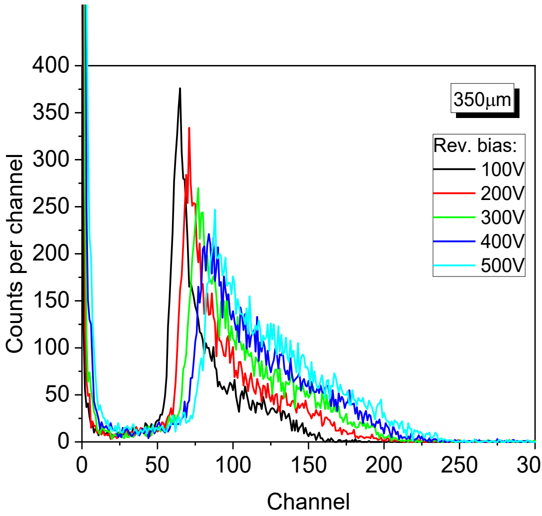

Fig. 4. The alpha spectra of 5.5 MeV alpha particles from ^{241}Am measured by a 350 μm thick SI GaAs detector at various reverse biases.

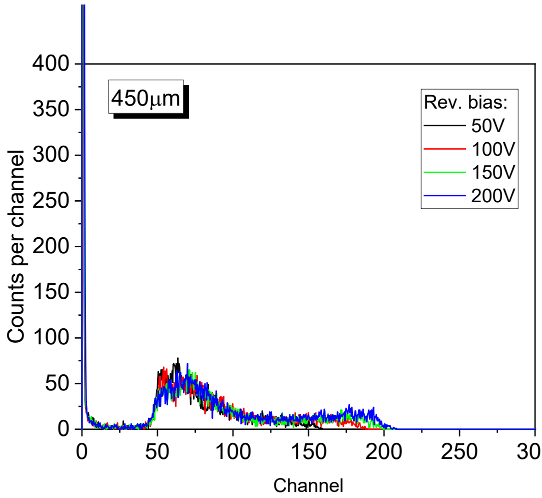

Fig. 5. The alpha spectra of 5.5 MeV alpha particles from ^{241}Am measured by a 450 μm thick SI GaAs detector at various reverse biases.

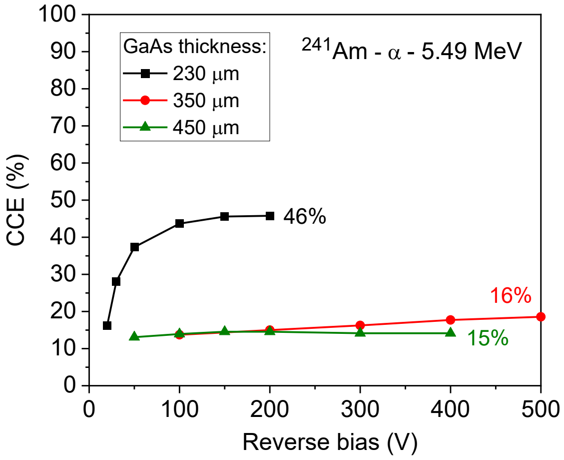

Fig. 6. The CCE for alpha spectrometry as a function of reverse bias for three different detector thicknesses.

C. Gamma spectrometry

The gamma spectra of ^{241}Am were measured with thin aluminum foil to stop the alpha particles and with higher preamplifier gain to detect the 60 keV gamma rays. The gamma spectra measured at various reverse biases by detectors with different thicknesses are shown in Figs. 7.-9. Similarly to alpha spectra, higher bias leads to higher CCE shifting the photopeak to higher channels. The thinnest detector reaches the peaks in the highest channels. On the contrary to the alpha spectrometry, the gamma rays penetrate along whole detector thickness and are absorbed through whole detector volume. Thus, both types of charged carriers are participating at charge collection, also the holes with lower mobility than electrons. This might affect the maximal obtainable CCE during gamma spectrometry, which decreases with increasing detector thickness. Limited charge carriers' lifetime will prevent holes from transporting too large detector thickness reducing reachable CCE.

In Fig. 10, we can observe the CCE as a function of the applied reverse bias for all three types of detectors with different thickness. The thinnest (230 μm) detector has reached saturated CCE of 80.4% at 300 V, whereas the middle (350 μm) detector CCE goes up only to 60.4% and the thickest (450 μm) detector did not exceed 51% CCE even at much higher bias applied (450 V). A similar tendency was observed with Cr-doped n-type GaAs detectors in [18], where 60 keV ^{241}Am peak floated to higher channels at 500 V with 715 μm thick detector than peak measured by 830 μm thick detector at 600 V and this one has had slightly higher CCE than 1200 μm thick detector at 800 V. Mentioned CCEs were in the range from 70% up to 80%.

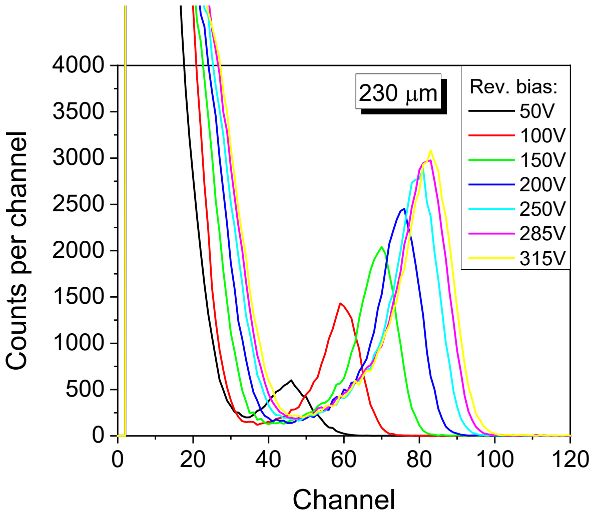

Fig. 7. The gamma spectra of 60 keV gamma rays from ^{241}Am measured by a 230 μm thick SI GaAs detector at various reverse biases.

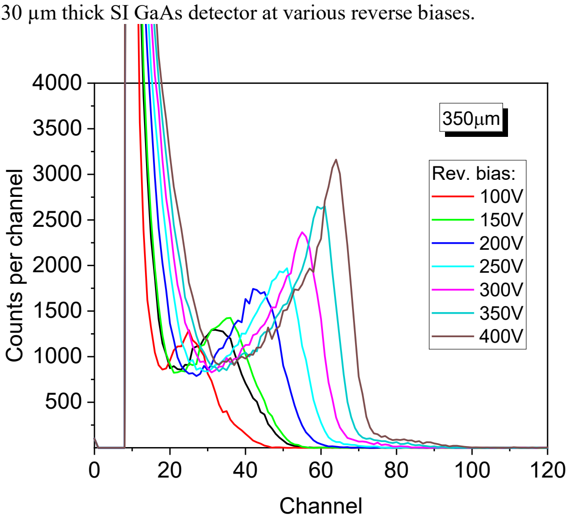

Fig. 8. The gamma spectra of 60 keV gamma rays from ^{241}Am measured by a 350 μm thick SI GaAs detector at various reverse biases.

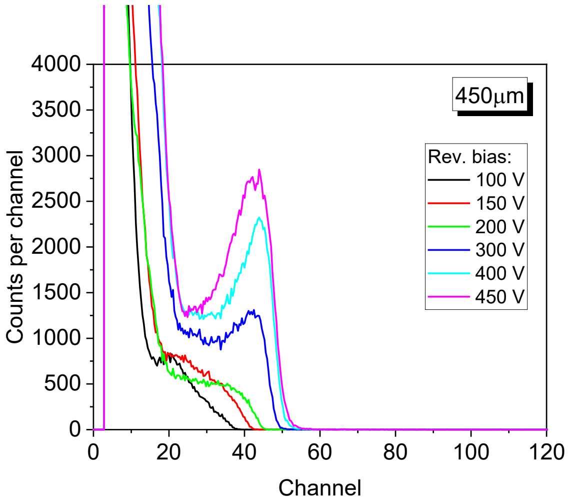

Fig. 9. The gamma spectra of 60 keV gamma rays from ^{241}Am measured by a 450 μm thick SI GaAs detector at various reverse biases.

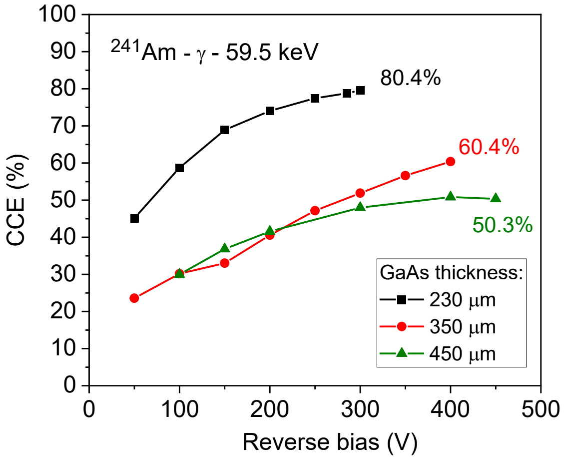

Fig. 10. The CCE for gamma spectrometry as a function of reverse bias for three different detector thicknesses.

IV. CONCLUSIONS

We have fabricated SI GaAs pad detectors for spectrometry of alpha particles and gamma rays of various thicknesses but with the same electrode-size of 1 mm in diameter. Obtained saturation reverse current was in the range of 3 – 30 nA, increasing with decreasing detector thickness from 450 down to 230 µm.

The spectrometric properties of fabricated SI GaAs detectors were evaluated from the gamma and alpha spectra of ^{241}Am with respect to detector thickness. An improvement in the charge collection efficiency with increasing reverse bias was observed in both experiments, in alpha and also gamma spectrometry. However, during alpha spectrometry the CCE as a function of reverse bias depended dominantly on electron Hall mobility, which was significantly higher for 230 µm thick detectors leading to lower CCE of thicker detectors. In the case of gamma spectrometry, where charge collection does not depend dominantly on electron transport in GaAs, the hole lifetime affected the results and thicker detectors suffered lower maximal obtainable CCE.

ACKNOWLEDGMENT

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