EVALUATION OF SI GaAs DETECTORS AFTER RADIATION DEGRADATION VIA ALPHA SPECTROMETRY

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1. Introduction

Recent progress in radiation treatment of various materials together with high energy physics experiments, hadron therapy, and space applications carry radiation harsh environment, which the used devices have to be adjusted for. High-energy electrons play also an important role among the other types of ionizing radiation. Electronics in the spacecraft is exposed to electrons with energies of a few MeV and fluences up to 10^{10} $cm^{-2}day^{-1}sr^{-1}$ [1]. The future electron-positron collider planned in Europe [2] will be exposed to electron-positron pairs from bremsstrahlung of a dose of about 1 MGy per year. Industrial linear electron accelerators for radiation treatment bring still more applications in various areas of our lives. There are very few studies dealing with radiation resistance of GaAs detectors against high-energy electrons [3-5]. We have studied the influence of 5 MeV electrons on electrical and spectrometric properties of our GaAs detectors up to a cumulative dose of 120 kGy so far [4, 5].

An interesting phenomenon was observed in our study [5], that the number of counts in photopeak registered by detector when measuring gamma-rays increases with cumulative dose induced by high energy electrons. It could have been caused by radiation induced defects in GaAs, which prevent from homogeneous spreading of electric collecting field in detector substrate towards backside contact. If the field spreads with dose to sides behind the detector contact edges, the active detector area is larger and will collect more counts. This assumption can be proved by alpha spectra measurements, as alpha particles are absorbed in the surface layer of detector substrate and the extension of the detector active volume to the depth of substrate with applied voltage will not influence the results. The spreading of electric field to the sides should be observed as an increase of detected counts in alpha spectrum with rising dose at particular applied reverse voltages.

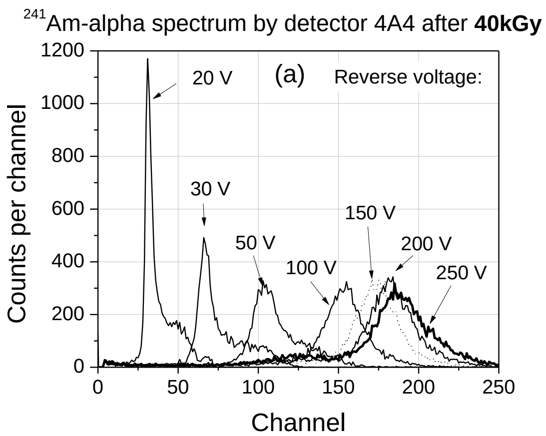
2. Experimental Details

Examined detectors were prepared from a bulk VGF (Vertical Gradient Freeze) semi-insulating (SI) GaAs substrate made in CMK Žarnovica Ltd. (Slovakia). The wafer was double-side polished to a thickness of 230 μm. The Schottky electrode of the detector, a 120 nm thick Ti/Pt/Au metallization of circular shape with 1 mm diameter, was evaporated onto the top side using photolithographic masking. A whole area Ni/AuGe/Au quasi-ohmic metal electrode was formed on the back side of the substrate. The substrate segment with four detectors was glued onto a separate PCB (Printed Circuit Board) support with detectors wire bonded. SI GaAs detectors were irradiated from the detector Schottky contact side by a pulsed beam (3.5 μs pulse duration) of 5 MeV electrons at room temperature using a linear accelerator UELR 5-1S. Detectors fixed on the PCB holder were placed on a 1 cm thick Al board during the irradiation. The distance between the Al board surface and the foil of the accelerator exit window was 95 cm. The beam scanning width was set to 40 cm and the beam scanning frequency to 0.25 Hz during irradiation. The beam repetition rate was set to 10 Hz, reaching the beam current of 8 μA, obtaining the dose rate at sample of 20 kGy/h. The surface doses of detectors were measured using B3 radiochromic films, evaluated by Spectrophotometer GENESYS20 and verified with RISO polystyrene calorimeters.

The detectors were irradiated in thirteen steps to a total dose of 136 kGy by 5 MeV electrons. The alfa spectra measurements were performed with an ^{241}Am alpha source after irradiation to doses of 24, 40, 56, 71, 86, 101, 116 and 136 kGy. The distance between the source and the detector was about 5 mm of air, which caused particles' energy loss less than 100 keV, which is beyond the detector resolution. The active volume in the case of SI GaAs detector enlarges with the reverse voltage applied to the Schottky contact. The thickness of active detector volume is about 38 μm at reverse voltage of 20 V, which is more than the projected range of 5.5 MeV alpha particles in GaAs (18.4 μm), and it increases linearly to full depletion (230 μm) at 300 V [6]. It means that during all performed experiments, the active detector thickness was larger than the particle range in GaAs material.

First, the alpha spectra were measured for various reverse bias voltages applied on detector in the range from 20 V up to breakdown voltage (Fig. 1a). One can observe that the peak is shifted to higher channels with increasing voltage, which refers to higher collection efficiency of the charge produced by alpha particles in detector active volume as the intensity of electric field rises. One can notice also the change in the shape of the peak, which is high and asymmetric at low voltages and fluently decreases in its height and becomes wider and more Gauss-shaped at higher voltages. This was caused by inhomogeneity of electric collecting field, creating zones with different charge collection efficiencies, but improving with increasing reverse voltage.

The aim of this research was to reveal the behaviour of GaAs detectors, particularly of their electric collecting field, after radiation degradation with high energy electrons. In Fig. 1b it is shown how the measured alpha spectra change with cumulative dose of electrons. With increasing dose the peak is moving to lower channels, which indicates the charge collection efficiency degradation. However, the height of the peak is increasing, which heralds higher detection efficiency, which is analysed in the next chapter in detail.



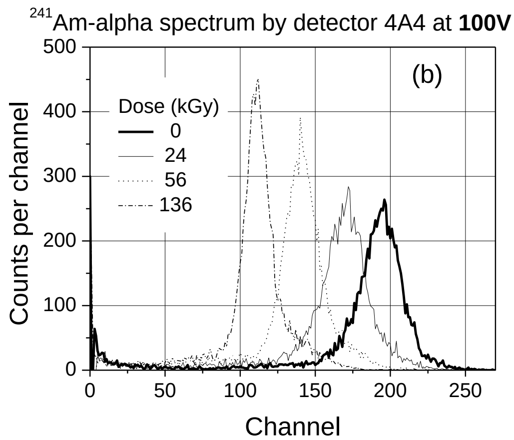


Fig.1: *Alpha spectra of ^{241}Am measured by SI GaAs detectors at different reverse bias voltages applied for dose of 40 kGy (a) and for various cumulative doses of electrons at a reverse voltage of 100 V (b).*

3. Results and Discussion

The alpha spectra measured before degrading irradiation of SI GaAs detectors by electrons and after irradiation to 8 different doses were evaluated in terms of integral number of counts in peak. In Fig. 2, there is the dependency of registered counts in peak on the cumulative dose. One can observe its increase with increasing dose up to 71 kGy at all applied reverse voltages followed by saturation and decrease at 136 kGy. It means that the active detector area spreads to the sides, behind the edge of detector Schottky contact, and detector collects more particles, which occurs not only with increasing applied reverse voltage, as it was already observed in [7, 8] and is obvious in Fig. 2, but also by radiation degradation (with applied dose). It has to be noticed that at low reverse voltage (50 V) the number of counts in peak before irradiation rises by 72 % after irradiation to a dose of 101 kGy. On the other hand, at higher reverse voltage (e. g. 200 V) this growth is only by 36 %.

The diameter of Schottky contact metallization is of 1 mm which represents the active detector area. However, the real active area of detector is slightly larger and depends on the applied reverse voltage. The dimension of which is the radius of real active detector area larger than the radius of Schottky contact metallization is defined as field extension in μm. In Fig. 3 there is the field extension evaluated from integral number of counts in peak as a function of reverse voltage. The linear increase of field extension with voltage can be observed. From point of view of applied dose one can observe that the initial field extension is larger for higher doses but its further enlargement with reverse voltage is more moderate. For example, the electric field was extended by 20 μm at 50 V and the extension was increasing linearly with voltage up to 144 μm at 200 V before irradiation. On the other hand, the field extension was almost 116 μm at 50 V after irradiation to 101 kGy and increased to only 144 μm at 200 V. Nevertheless, the maximum field extension of about 185 μm at 250 V will never be exceeded by any radiation degradation.

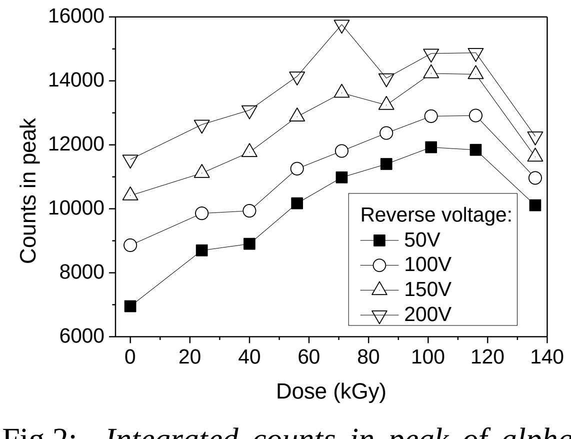


Fig.2: *Integrated counts in peak of alpha spectra measured by SI GaAs detector as a function of applied cumulative dose for different reverse voltages applied (50 to 200 V).*

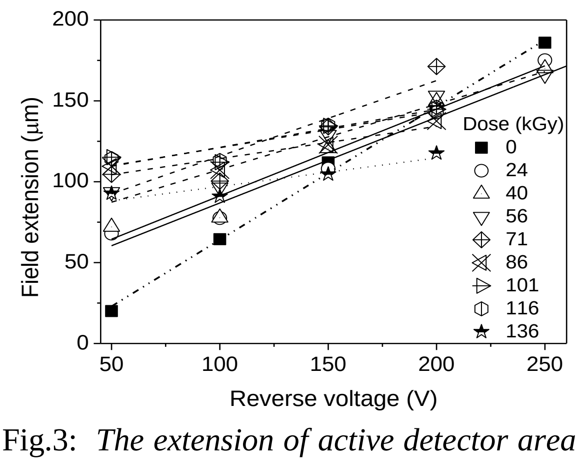


Fig.3: *The extension of active detector area behind the Schottky contact edge as a function of applied reverse voltage displayed for various degradation doses of electrons.*

Fig. 4 represents the rate of field extension with voltage at particular dose. The field extension rate (μm/V) was evaluated from Fig. 3 as the slope of straight line fitted through experimental data. One can observe that the field extension rate is highest for non-irradiated detector (0.82 μm/V) and after irradiation it decreases with rising dose.

The effect of field extension with reverse voltage was already observed with GaAs detectors in [7, 8]. In reference [7] lower field extension rate of 0.315 μm/V was evaluated in the case of VGF SI GaAs detectors with higher substrate thickness of 350 μm and lower material quality. In reference [8] the field extension of 0.48 μm/V was estimated in the case of LEC (Liquid Encapsulated Czochralski) SI GaAs detector of lower quality and of a thickness of 300 μm. Mentioned field extension rates were studied for non-irradiated samples and they are depicted in Fig. 4 for comparison with our experimental data.

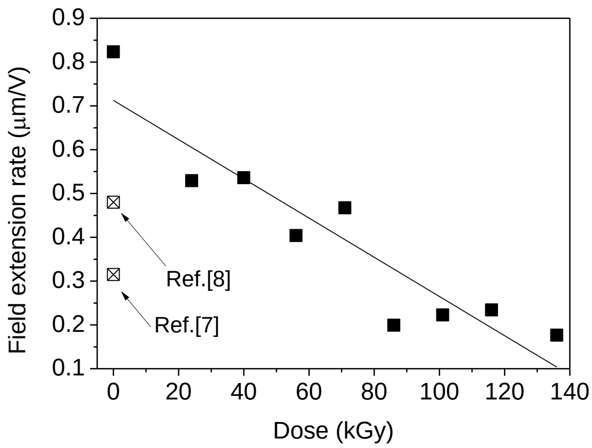


Fig.4: *The field extension rate as a function of applied cumulative dose.*

4. Conclusion

We have employed the alpha spectrometry to reveal the behaviour of SI GaAs detectors after radiation degradation by 5 MeV electrons. We have aimed at the electric field distribution in detector substrate. The results proved that the electric field spreads behind the Schottky contact edges not only with increasing applied reverse voltage but also with rising cumulative dose of radiation degradation. It helped to explain the increase of the detection efficiency of gamma rays, which was in fact caused by enlargement of the active detector area (by lateral field spreading behind physical contact size), caused by radiation degradation.

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