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Investigation of the Radiation Damage of GaAs Detectors by Neutrons and Photons¹

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Abstract

Surface barrier particle detectors, processed in Aachen using SI GaAs from several manufactures, have been irradiated with neutrons (peak energy $\sim 1\text{MeV}$) up to fluences of 4.0×10^{14} n/cm² and with photons from a ⁶⁰Co source with a dose of 100 Mrad. All detectors work well after the irradiation. Detectors biased with 200V during the neutron irradiation show no significant difference from those not biased. After irradiation with 4.0×10^{14} n/cm² the leakage currents at 200V are a factor of four greater than those before irradiation. At the highest radiation level the signal for minimum ionizing particles corresponds to 7200 electrons (at 200V bias voltage) independent of peaking times between 40 ns and 2.2 μs . The signals for α -particles (2.2 μs peaking time, 200V bias voltage) are about 20% of those before irradiation. The exposure to the 100 Mrad photon dose caused little change of the detector performance. The leakage currents were even reduced by about 10%.

1 Introduction

The radiation resistance of GaAs detectors is a key issue regarding their use as inner tracking detectors at the future high energy collider LHC (Large Hadron Collider) at high luminosity [1].

To further investigate the effect of irradiation on the detectors [2] we fabricated surface barrier diodes made of SI-GaAs

with two Schottky contacts (NiCr/Au) [3] [4]. Two wafers from the AXT company [5] and one wafer of Freiburger (FEW) material [6] were processed. The parameters for the three wafers are shown in Table 1³.

Wafer 19 (AXT) was cut into four pieces. Three of them were sent in April 1994 to the Rutherford Appleton Laboratory to be irradiated at the ISIS neutron facility [7] with fluences of 6.2×10^{13} n/cm², 2.2×10^{14} n/cm² and 4.0×10^{14}

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³ In Table 1, # denotes the number of diodes.

Table 1

Parameters of the three irradiated wafers.

Parameter	wafer 19		wafer 41		wafer 4	
Material	GaAs (AXT)		GaAs (FEW)		GaAs (AXT)	
Thickness	300 μm		250 μm		350 μm	
Diameter	50.8 mm		50.8 mm		50.8 mm	
Area (Diode)	ϕ 3 mm		$5 \times 5 \text{ mm}^2$		$5 \times 5 \text{ mm}^2$	
# of Diodes	110		16		16	
Contacts	NiCr/Au		NiCr/Au		NiCr/Au	
Irradiation fluences	flux	#	flux	#	Dose	#
	$6.2 \times 10^{13} \text{ n/cm}^2$	20	$4.0 \times 10^{14} \text{ n/cm}^2$	4	100 Mrad	4
	$2.2 \times 10^{14} \text{ n/cm}^2$	23				
	$4.0 \times 10^{14} \text{ n/cm}^2$	20				

n/cm^2 respectively⁴. The neutron spectrum was peaking at 1 MeV. For control purposes the fourth piece was not irradiated.

Wafers 4 and 41 were also cut into four pieces with four detectors on each part. One piece of wafer 4 was irradiated with 100 Mrad γ -particles from a ^{60}Co source at the Fraunhofer Institut für Naturwissenschaftliche - Technische Trendanalysen [8] (in Feb. 1993). Four diodes of wafer 41 were irradiated at ISIS with $4.0 \times 10^{14} \text{ n/cm}^2$ (in Dec. 1994).

2 I-V Characteristics

Figure 1 shows the mean values of the leakage current density for the diodes of wafers 19 and 41 at room temperature as a function of the reverse bias voltage, be-

fore and after irradiation with neutrons.

Fig. 1. I-V characteristics of the detectors at room temperature before and after neutron irradiation.

⁴ The estimated uncertainty in fluence is $\pm 25\%$.

Fig. 2. I-V characteristics of the detectors biased with 200V during the neutron irradiation and those not biased (22 °C).

The I-V curves before irradiation show the typical behaviour of diodes: after initially increasing with reverse bias voltage, the leakage current density saturates at a value $\leq 1.8 \mu\text{A}/\text{cm}^2$. Although these diodes were operated without individual guard rings, recent investigations have shown that for diodes with this configuration the leakage current contributions from boundary or surface currents are small. After irradiation we observe an increase of the leakage currents with the neutron fluence. For the AXT material this increase amounts to approximately a factor of four at 200V after exposure to $4.0 \times 10^{14} \text{ n}/\text{cm}^2$. The corresponding value of the damage constant α is $1.17 \times 10^{-19} \text{ A}/\text{cm}$. For the Freiburger material the increase of the leakage current amounts approximately to a factor of 2.6 at 185 V.

Above 200V for wafer 19 (150V for wafer 41) the leakage currents increase more

rapidly with the reverse bias voltage, showing an approximately linear dependence. For higher fluences of the exposure this effect is more pronounced and its onset is correlated with the saturation of the charge signals for minimum ionizing particles (MIPs) (see next section).

During the exposure five diodes per piece of wafer 19 were biased with 200V. The I-V characteristics of the biased and non-biased detectors after irradiation are shown in figure 2. No significant differences are observed.

Fig. 3. I-V curves of the detectors before and after 100 Mrad photon irradiation.

Figure 3 shows the I-V curves of the diodes of wafer 4 before and after irradiation with photons (100 Mrad), demonstrating a similar detector behaviour before and after the exposure. After irradiation the leakage currents are reduced by about 10%.

Fig. 4. Spectrum for ^{90}Sr electrons after $4.0 \times 10^{14} \text{ n/cm}^2$ with a peaking time of 100 ns.

3 Response to Minimum Ionizing Particles

To investigate the effects of the irradiation on charge collection we measured the detector response to MIPs (electrons from a ^{90}Sr source) [9] at different reverse bias voltages between 100 and 350V. All detectors were found to function well after the exposure. Figure 4 shows the pulse height spectrum for electrons from a ^{90}Sr source after $4.0 \times 10^{14} \text{ n/cm}^2$ taken at 200V with 100 ns peaking time, showing a signal/noise ratio of 10:1.

The mean values of the pulse heights of the MIP signals for several diodes obtained for a peaking time of $2.2 \mu\text{s}$ before and after exposure to the different fluences are plotted in figures 5 and 6. Before irradiation the charge signals show the typical approximately linear dependence on reverse bias voltage for both wafer types. For all fluence levels, the detec-

tors show a similar signal dependence on reverse bias voltage: following an approximately linear rise for small voltages, the signal pulse height flattens off or even decreases with increasing bias. The voltage value at which the flattening off occurs decreases with increasing fluence and coincides with the change of slope in the I-V curves (see figure 1). At 200V signal pulse heights of 7200 electrons are obtained for wafer 19 after irradiation with $4.0 \times 10^{14} \text{ n/cm}^2$. A comparison of figures 5 and 6 shows, that the detectors made of Freiburger material behave similarly as those made of AXT.

We have also measured the pulse height values of the AXT material (wafer 19) for ^{90}Sr electrons with peaking times of 100 ns and 40 ns. The results for a peaking time of 40 ns as a function of the reverse

Fig. 5. Mean value of signals for ^{90}Sr electrons (peaking time $2.2 \mu\text{s}$) as a function of reverse bias voltage before and after neutron irradiation with different fluences for wafer 19.

Fig. 6. Mean value of signals for ^{90}Sr electrons, measured with a peaking time of $2.2\ \mu\text{s}$, versus reverse bias voltage before and after neutron irradiation for wafer 41.

Fig. 7. Signals for ^{90}Sr electrons, measured with a peaking time of $40\ \text{ns}$, versus reverse bias voltage before and after neutron irradiation for wafer 19.

bias voltage (before and after irradiation) are shown in figure 7. The general behaviour is similar as for a peaking time of $2.2\ \mu\text{s}$ (figure 5). The signal is rising with bias voltage before irradiation, while it saturates or even decreases after the exposure. A closer comparison of the data at a bias voltage of 200V for all three peaking times as a function of the neutron fluence is given in figure 8. We observe that the signals for all three peaking times are similar after irradiation, while for the non-irradiated probes the signals at $100\ \text{ns}$ and $40\ \text{ns}$ peaking time are 30% smaller than the signals obtained with a peaking time of $2.2\ \mu\text{s}$. We also see that for a bias voltage of 200V the signal is largest (13800 electrons) after an irradiation of $6.2 \times 10^{13}\ \text{n/cm}^2$ decreasing to 7200 electrons for the highest fluence of $4.0 \times 10^{14}\ \text{n/cm}^2$. The signal height variation with peaking time

is a consequence of the time structure of the charge pulse as can be seen from figure 9. The shape of the pulse of the non-irradiated probe is obviously dominated by a contribution with a large time constant, which is rapidly dying out after irradiation⁵.

The MIP signals obtained with detectors of wafer 4 before and after irradiation with photons (100Mrad) are shown in figure 10. Following the photon irradiation the signal pulse height is reduced to 80% of the pre-irradiation value at 200V . The behaviour of the signals as a function of reverse bias voltage remains largely unchanged, thus showing that the damage caused

⁵ A systematic investigation for peaking times ranging from $40\ \text{ns}$ to $2.2\ \mu\text{s}$ and bias voltages between 100V and 300V will be given in a subsequent publication.

Fig. 8. Signals for ^{90}Sr electrons, measured with different peaking times, as a function of the neutron fluence for wafer 19.

by even a large dose of photons (100Mrad) is small.

4 Signals for α -particles

For detectors of wafer 19, Figure 11 shows the average charge collected, before and after exposure to neutrons, for α -particles (from an ^{241}Am source) incident perpendicularly on the reversely biased Schottky contact. For all fluences, the charge signal shows the typical saturation behaviour for α -particles. With increasing fluence, the onset of saturation moves to lower voltage values, from 150V after $6.2 \times 10^{13} \text{ n/cm}^2$ to 50V after $4.0 \times 10^{14} \text{ n/cm}^2$. For a given bias voltage the mean value of the signal decreases with increasing irradiation fluence: at 200V it is reduced to about 20% of its pre-irradiation value following the exposure to $4.0 \times 10^{14} \text{ n/cm}^2$.

Fig. 9. Time structure of charge pulse for ^{90}Sr electrons before and after exposure to neutrons for wafer 19 at 200V.

Figure 12 shows the effect on the α -particle signal for diodes of wafer 4 after a photon dose of 100 Mrad. At 200V the signal is reduced to 88% of its value before the exposure.

5 Conclusion

More than 60 GaAs detectors processed in Aachen were irradiated with neutron fluences of $6.2 \times 10^{13} \text{ n/cm}^2$, $2.2 \times 10^{14} \text{ n/cm}^2$ and $4.0 \times 10^{14} \text{ n/cm}^2$ (the peak neutron energy is $\sim 1\text{MeV}$). Four detectors were irradiated with photons from a ^{60}Co source with a dose of 100 Mrad. All detectors work well at room temperature even after the highest fluence of $4.0 \times 10^{14} \text{ n/cm}^2$. In the latter case a ratio $S/N=10$ was obtained for ^{90}Sr electrons (MIPs) with 100 ns peaking time.

No significant difference can be obser-

Fig. 10. Mean value of signals for ^{90}Sr electrons, measured with a peaking time of $2.2 \mu\text{s}$, versus reverse bias voltage before and after 100 Mrad photon irradiation (wafer 4).

ved between the detectors biased with 200V during the exposure and those not biased. After irradiation with $4.0 \times 10^{14} \text{ n/cm}^2$ the current increases by a factor of four at 200V, while the current density remains smaller than $5 \mu\text{A/cm}^2$.

Independent of peaking times between 40 ns and $2.2 \mu\text{s}$ we observe at a bias voltage of 200V for ^{90}Sr electrons (MIPs) a maximum signal of 13800 electrons after an irradiation with $6.2 \times 10^{13} \text{ n/cm}^2$, which decreases to 7200 electrons for an exposure to the highest fluence of $4.0 \times 10^{14} \text{ n/cm}^2$. Compared to the non-irradiated probes we find for 200V bias voltage at the highest fluence a degradation of 30% at a peaking time of $2.2 \mu\text{s}$ and practically no loss of signal for peaking times of 40 ns and 100 ns. The signal for α -particles is reduced to about 20% of the pre-irradiation values at 200V reverse bias voltage for a peaking time of $2.2 \mu\text{s}$ at the highest fluence.

Fig. 11. Mean value of signals for ^{241}Am α -particles, measured with a peaking time of $2.2 \mu\text{s}$, as a function of reverse bias voltage before and after neutron irradiation (wafer 19, AXT).

Irradiation with photons (100 Mrad) does little damage to the performance of the detectors. Following the exposure, the charge signal for MIPs is reduced to 80% and for α -particles to 88% of the pre-irradiation value at 200V, while the leakage current actually decreases by roughly 10%.

We repeated the measurements on the irradiated detectors half a year after the exposure and could not observe any evidence either for annealing or for antiannealing effects.

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Fig. 12. Mean value of signals for ^{241}Am α -particles, measured with a peaking time of $2.2 \mu\text{s}$, versus reverse bias voltage before and after 100 Mrad photon irradiation.

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