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CHARACTERISATION OF GaAs DETECTORS FROM TOMSK

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ABSTRACT

Detectors with p-π-ν-p structure and 320 μm thickness have been studied using ^{90}Sr and ^{57}Co radioactive sources. The charge collection efficiency was found to be between 41 and 47% and was constant with increasing bias voltage above 200V. The I-V dependence is close to linear. At a reverse bias of 200 V the current density does not exceed 100 nA/mm^2.

1. Introduction

The GaAs detectors produced in the Siberian Institute for Physics and Technology (SITP), Tomsk, Russia have been found to have a reasonable charge collection efficiency and a very good radiation stability[1]. A distinctive feature of these detectors is the use of Fe and Cr dopant to convert LEC GaAs to nearly intrinsic material. The doping profile allows to have in part of the GaAs bulk a slight p-type conductivity (that is usually denoted as π-type material), while the other part has a slight n-type conductivity (ν-type material). One of the drawbacks of earlier detector designs[2,3] was that the $\pi - \nu$ region extended for only about a half of the physical 300 μm detector thickness. Recently a new version of the detectors was developed at SITP. In the new detectors the high ohmic $\pi - \nu$ region occupies almost all of the 340 μm of detector thickness while low ohmic p layers on the sides of the detector have only about 10 μm thickness each i.e. the sensitive detector thickness is about 95% of its physical thickness.

Three samples of these new SITP detectors were available for tests at Lancaster University early this year. In this paper we present the results of a study of the detector response to 2 MeV electrons and 122 keV gamma rays.

2. Experimental set up

The block diagram of the experimental set up is shown in Fig.1. The detector was connected to a fast BIPOLEST preamplifier[4] followed by a shaper producing a signal of nearly gaussian shape with about 20 ns peaking time. This signal was then amplified by a factor of about 20 with the help of a LeCroy 612 AM amplifier in NIM standard. To produce a self trigger and to allow a measurement of the counting rate in the detector one of the output signals from this amplifier was sent to a discriminator via an attenuator allowing adjustment of the trigger threshold. The second signal from the amplifier was sent to a digital oscilloscope (Tektronix TDS 350) which served as the main signal analysing instrument.

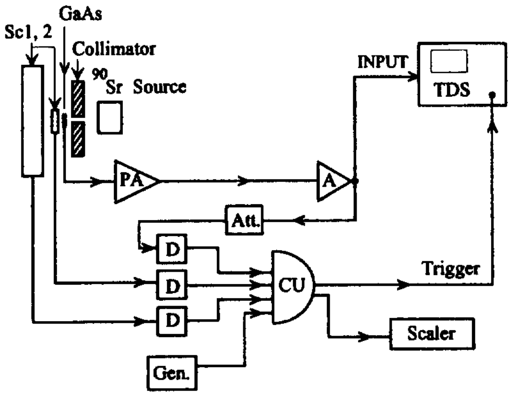

Fig.1 Experimental set up. Notation: Scl,2 - scintillator counters, PA - BIPOLTEST preamplifier, A - LeCroy amplifier, D- discriminators, CU- coincidence unit, Att- attenuator, Gen-pulse generator, TDS - digital oscillpscope.

The signal arriving at the TDS was then integrated within the gate of 70 ns. To increase the signal-to-noise ratio the bandwidth of the scope was reduced to 20 MHz. The resulting pulse shape for a signal from relativistic beta particle is shown in Fig.2. The numerical data from the scope were stored in a computer via a GPIB interface.

Three types of scope trigger were used in the measurements:
a) from the detector itself;
b) from a coincidence of the 2 scintillator counters installed behind the GaAs detector;
c) from a pulse generator.

Trigger a) was used for detection of 122 keV gamma rays from a ^{57}Co source; trigger b) allowed to select electrons from ^{90}Sr beta decays with high enough energy to be minimum ionising; trigger c) was used for the measurement of the pedestal position and the noise of the channel. The latter was found to be about 2200 electrons.

The dimensions of the detectors under study were 3x2x0.32 mm^3. For the measurements with beta particles the detectors were irradiated through a teflon collimator with 3.5 mm thickness and having a 1.6 mm diameter hole. The first scintillator counter (Scl) installed immediately after the detector has dimensions 5x5x5 mm^3 while the second one (Sc2) is of 25x25x10 mm^3 size. To produce a coincidence between Scl and Sc2 a beta particle has to cross the GaAs detector, the first scintillator counter and deposit some energy in the second one. It corresponds to an electron kinetic energy of more than 1.9 MeV. (The thickness of the scintillator wrappings was also taken into account in the calculation of this minimum energy.) The maximum energy of the ^{90}Sr beta particles is 2.3 MeV. Thus the coincidence trigger selected in the GaAs detector projectiles with γ-factors between 4.8 and 5.5 i.e. minimum ionising particles (MIPs).

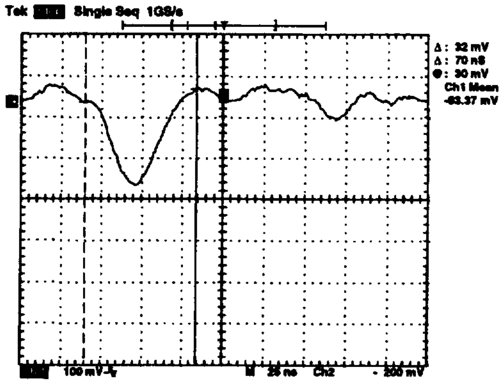

Fig. 2a. Typical single pulse shape for minimum ionising particles.

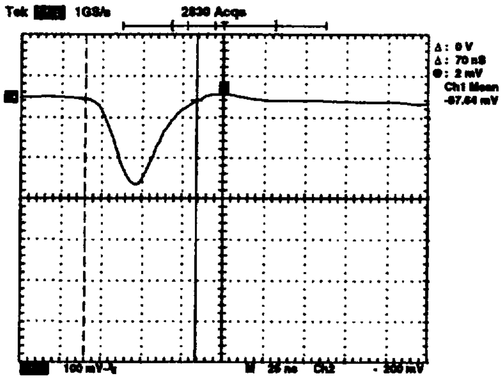

Fig. 2b. The same for the average of 256 pulses.

The theoretical expectation for the most probable energy depositions was calculated for electrons with $\gamma = 5.0$ and a sensitive detector thickness 0.32 mm. It was found to be 172.4 keV. (About 5% of this value is due to the effective increase of the incident electron path in the detector because of multiple scattering). In this calculation the energy needed for electron-hole pair production in GaAs was assumed to be 4.2 eV.

An absolute calibration of the electronics was performed by injection of a known charge via a small calibration capacitance to the preamplifier input. It was then verified by a measurement of the 122 keV photopeak position in a signal spectrum from a reference 300 μm Si detector. Both calibrations coincided within 5% accuracy.

The typical counting rates in the experiment were as following.
a)From the 400 kBq ^{57}Co source at about 3 mm distance from the detector: about 150 Hz in the detector with a self trigger threshold near 12 000 electrons.
c) From the ^{90}Sr source: 80 kHz in the GaAs detector, 10 kHz in Scl, 5 kHz in Sc2, 100 Hz in SclxSc2 coincidences. In the latter nearly 2Hz were due to accidental coincidences and about 15 Hz were triggers that produced no signal in the GaAs detectors (most likely due to an interaction of a bremsstrahlung photon in one of the scintillator counters with the resulting electron reaching the other counter). The use

of low Z materials for the beta particle collimators reduced considerably the number of bremsstahlung photons produced by stopping electrons, and allowed to achieve a reasonable trigger efficiency in spite of the large difference in area between the GaAs detector and the smallest scintillator counter.

c)From the pulse generator: 20 Hz.

The maximum acceptance rate of the digital oscilloscope with the necessary waveform analysis was about 2Hz. So in all cases it was the intrinsic speed of the TDS 350 that defined the rate of data accumulation.

3. Experimental results

The standard set of measurements consisted of a sequence of runs with triggers of type a) or b) interleaved with runs using type c) triggers to allow monitoring of the noise and pedestal position. No change of noise with bias voltage was observed for any of the three detectors under study. A typical time needed for a measurement at one value of bias voltage was about half an hour. The dark current in all three detectors was found to be reasonably stable during the measurement time apart from a small drift associated with a change of the ambient temperature. A positive bias voltage was applied to the p-electrode adjacent to the ν-layer i.e. a reverse bias at the $\pi - \nu$ junction. However, similar results with pulses of opposite polarity, were obtained with the opposite bias (ie forward). The dependence of the leakage current vs.bias voltage is shown in Fig.3. It is almost linear, which is typical for so-called relaxation type material[5]. The ambient temperature during these measurements was about 25 C changing by less than 0.5 C during the time needed for a full set of measurements for one detector.

A typical spectrum obtained with the ^{90}Sr source using trigger (b) is shown in Fig.4. One can see in this spectrum a small peak around bin 5 resulting from the false triggers which shows the pedestal position. The main part of the spectrum consists of beta particle energy deposition in the GaAs detector. It was fitted by a Landau curve using the following three parameters free: a)Δmp-most probable energy deposition, b) σ- r.m.s. of a Gaussian distribution with which the Landau spectrum was smeared, c) Enorm-the normalisation factor for the Landau distribution equal to the total number of events in the Landau spectrum. The parameter ξ defining the width of the Landau distribution should be correlated to the value of Δmp. To take into account the loss of charge during collection it was assumed that ξ changes proportionally to Δmp. A value of ξ_0 = 12.68 keV calculated together with the theoretical expectation for Δmp was used as the normalisation point. So in the fit it was:

$$\xi = 12.68keV(\Delta mp/172.4keV)$$

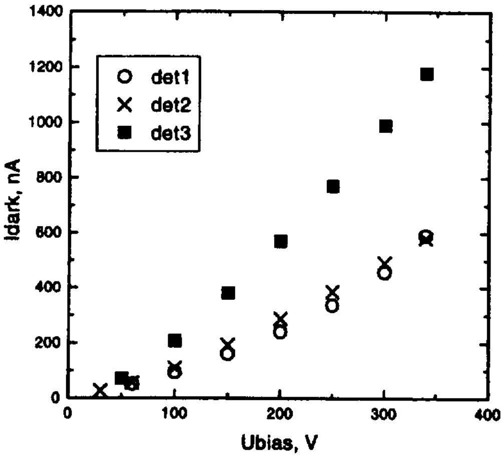

Fig. 3 Dark current for all detectors measured at 25C.

Only a part of the experimentally measured data was used for the Landau fit, though the resulting curve is presented in the full range of the data. In the example shown in Fig.4 the fitted bins were from 11 to 27. The lower limit was applied to cut off the noise. The upper limit is necessary to suppress the difference between the energy lost by an incident particle (described by the Landau distribution) and that actually deposited in the detector. The latter is usually smaller than the energy loss due to the escape of energetic δ-electrons from the detector. The quality of the fit was usually quite good.

The dependence of Δmp vs. bias voltage Ubias is presented in Fig.5. One can see that for all 3 detectors the value of Δmp reaches a saturation above 200 V. The saturation level corresponds to 41-47% of the 172 keV expected for the electrons traversing the full 320 mm thickness of the GaAs detector.

The value of σ- was found to be independent of bias voltage. Its value after quadratic subtraction of the electronic noise contribution was found to be about 16% of Δmp. It is due to atomic binding effects[6], path length fluctuations because of incident electron multiple scattering and to other smearing effects such as possible fluctuations of charge collection efficiency. The number of events found in the fit Enorm also did not depend on bias voltage which illustrates that the quality of the trigger and analysis procedure were good.

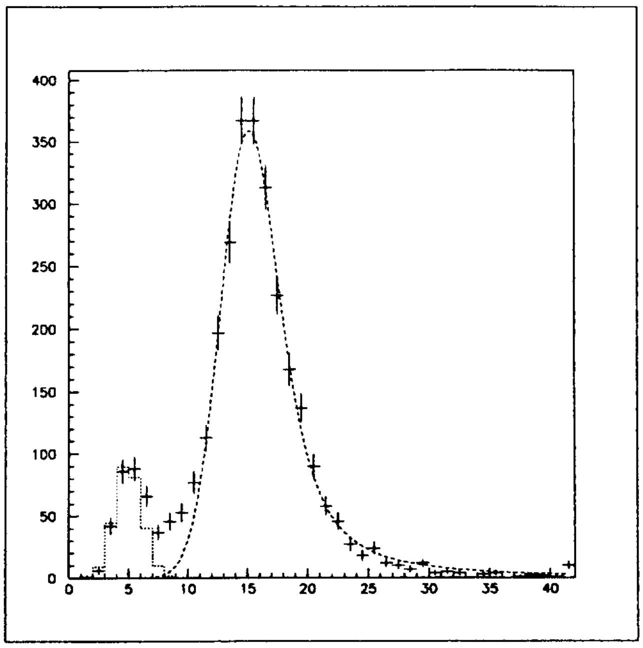

Fig.4 Minimum ionising particle spectrum measured by detector No.2 at 250 Volts bias. The Landau fit is shown by the dashed curve (see text for the fit procedure details). The dotted curve is the pedestal spectrum measured separately and normalised to the wrong trigger peak area.The events in bins 7-10 are most likely due to the particles crossing the detector at the edge.

The response of these detectors to 122 keV photons from the ^{57}Co source allows one to understand whether the signal deficit observed in the MIP data as described above is due to incomplete charge collection efficiency (CCE) or to the sensitive region of the detector being smaller than the assumed 320 μm. The range of 122 keV photoelectrons in GaAs is about 40 μm. So if one assumes that CCE=1 and the MIP signal deficit is due to the active detector thickness being about 40% of 320 μm, this reduced thickness is still sufficient to keep the photoelectron energy deposition well contained in detector sensitive volume. Under such an assumption the photopeak position will be at the full photon energy of 122 keV that is **higher** than the value of Δmp measured for MIPs (see Fig.5). On the other hand if the sensitive detector thickness is the full 320 μm and an average CCE for gamma induced ionisation is the same as for MIPs (it is a reasonable assumption since the points of γ conversions are distributed uniformly along the detector) i.e. about 45%, then the photopeak position will be lower than Δmp for MIPs by factor 122keV/172keV.

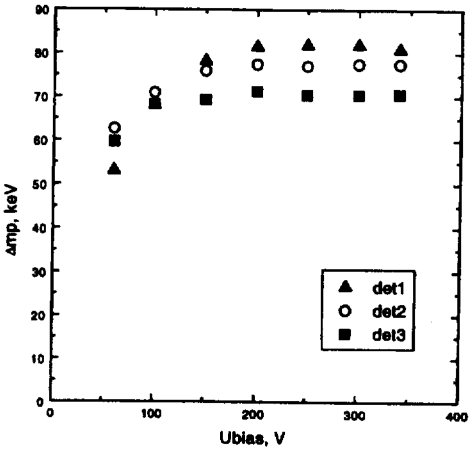

Fig. 5 Dependence of Δmp vs. Ubias for all detectors

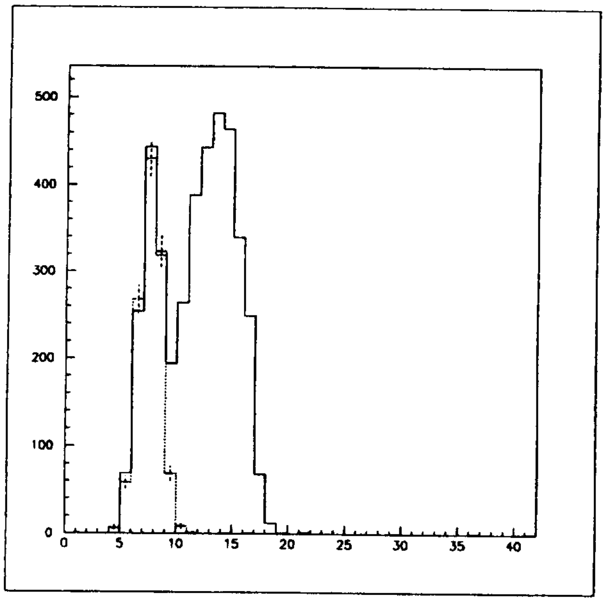

Fig.6 A 122 keV photon spectrum measured by detector No.2 at 300 bias voltage. The left peak is due to the noise tail. The separately measured noise spectrum normalised by noise peak area is shown by the dashed curve. The signal peak left side is due to the threshold cut.

A typical ^{57}Co signal spectrum is shown in Fig.6. The photopeak position is very close to the self-trigger threshold and is noticeably lower than MIP peak position (compare with Fig.4). Since the left side of the signal peak in ^{57}Co spectrum is cut by the trigger threshold it is impossible to determine the correct value of CCE in γ induced events. However, one can conclude that there is no contradiction with the assumption that CCE is the same for gammas and MIPs, while the assumption of CCE=1 is completely ruled out.

One should expect that in the bias region where the value of Δmp does not depend on Ubias the signal from ^{57}Co will also stay stable. This was found to be the case as one can see from Fig.7 where the normalised values of Δmp and the ^{57}Co counting rate are presented vs. bias voltage. Though the shown data refers to only one of the detectors it is similar for all of them. The more sharp drop in γ counting rate compared to that in Δmp means that the decrease in the latter can't be explained solely by the decrease in the thickness of detector sensitive region because in this case both curves should have the same behaviour. Therefore one can conclude that a decrease in CCE is one of the reasons (possibly the dominant one) for the decrease of Δmp outside the plateau region.

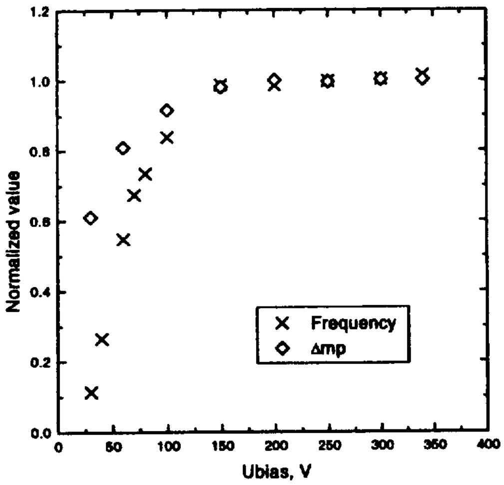

Fig.7. Dependence of ^{57}Co counting rate and Δmp for MIP normalised to their values in the plateau region vs. bias voltage for detector No.2

4. Conclusions

In three $p-\pi-\nu-p$ GaAs detectors the observed MIP signals were well fitted by a standard Landau distribution. In all detectors the value of the most probable energy deposition stays constant above 200 V of bias voltage. The charge collection efficiency calculated under the assumption of 320 μm sensitive thickness of the detector was found to be between 41 and 47 %. The absolute value of the observed signal is close to that from a Si detector with 250 μm thickness.

The signals observed from 122 keV photons agree with the assumption of the same charge collection efficiency in these events as in the case of MIPs. The assumption of the signal deficit in MIP events being due to a small sensitive thickness of the detector with CCE=100% is completely ruled out by the photon signals.

The dark current of the detectors grows almost linearly with bias voltage which is characteristic of relaxation type materials. At 200 V the current density for 25C temperature does not exceed 100 nA/mm^2.

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