BEAM TESTS OF GaAs STRIP DETECTORS

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Abstract

We report on test beam measurements of GaAs detectors. The detectors differ in pitch (44, 200, 375 and 1000 μm) and thickness ($d = 500$ and 200 μm). Results on the charge collection, the signal to noise ratio and the charge division were obtained with a 5 GeV/c pion beam at the CERN-PS. Position dependent measurements of cross talk between strips and the charge collection efficiency (CCE) were performed at the 1.5 MeV He^+ beam of the Freiburg Van de Graaff facility.

1 Introduction

In the last years there has been growing interest in GaAs as a material for radiation detectors [1-6]. GaAs seems to be a suitable material for the next generation of experiments in high energy physics (e. g. LHC), since it is much radiation harder than silicon. It is also commercially available due to its application in electronic industry. There has been progress in designing GaAs read-out electronics and there is hope to integrate GaAs electronics and detectors in the future. It is the aim of this paper to present results from operating our GaAs detectors under test beam conditions. For the read-out conventional silicon electronics was used. Important features of the GaAs detectors like the signal to noise ratio, the charge collection efficiency (CCE) and the cross talk will be measured using our test set-up. The design of the detectors will be briefly covered in section 2. Results obtained on the signal to noise ratio and the charge division with the 5 GeV/c pion beam of the CERN-PS will be described in section 3. The cross talk between detector strips and the CCE will be discussed in section 4. Finally, conclusions will be given in section 5.

2 Processing of the detectors

For all measurements presented in this paper, we used 2 inch diameter semi-insulating GaAs wafers of thickness $d = 500 \mu\text{m}$ and $d = 200 \mu\text{m}$, respectively. Both sides of the wafers are polished. The GaAs is grown by applying the liquid-encapsulated Czochralski (LEC) technique [7]. In order to operate as Schottky diodes, the wafers were first vacuum deposited and subsequently patterned using the lift-off technique.

The design of the detectors is shown in Fig. 1. The frontside of the detectors consist of strips which are Schottky contacts made of Ti, Pt and Au layers. The whole frontside is passivated with silicon nitride to prevent oxidation. The backside of the $500 \mu\text{m}$ thick detectors are ohmic contacts made of Ni, Ge and Au layers, the backside of the $200 \mu\text{m}$ thick detectors are Schottky contacts. The detectors also have different gap widths and pitches (Tab. 1):

typ	pitch [μm]	gap width [μm]	d [μm]	backside
A	44	22	200	Schottky
B	44	22	500	ohmic
C	200	100	500	ohmic
D	375	50	500	ohmic
E	1000	100	500	ohmic

Table 1: The different detector types used for the test beam measurements.

The material for the $200 \mu\text{m}$ thick microstrip detectors has been supplied by MCP¹⁾, the material for the other detectors by Wacker²⁾. The detectors were processed at the IAF³⁾ and the IPM⁴⁾. A more detailed description of the detectors can be found in reference [8].

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3 Test beam studies

The detectors were tested using 5 GeV/c pions from the Proton Synchrotron (PS) at CERN. For the measurements two strip detectors of 375 μm pitch and one microstrip detector of 44 μm pitch ($d = 200 \mu\text{m}$) were mounted behind each other. Scintillators were installed in front of the first and behind the last detector. They were used for starting the read-out cycle of the 375 μm detectors.

The 44 μm detector was aligned carefully behind one of the strips of the 375 μm detector. The number of signals from pions read out with the 44 μm detector was maximized by requiring a coincidence of the signals from the scintillator and from the 375 μm detector to start the read-out cycle.

Amplifiers supplied by Fujitsu⁵⁾ were used for the 375 μm detectors. The risetime of the output signal after this amplification was measured to be 6 ns. The pulses were 30 ns long. The 44 μm detector was read out using conventional charge sensitive preamplifiers connected to Ortec⁶⁾ 478 fast timing filter amplifiers with 50 ns shaping time. The shaped pulses of both detector types were then recorded using a 16 channel Tektronix 644A oscilloscope interfaced to a PC via IEEE bus.

The bias voltages V_B applied to the detectors were 375 V for the 375 μm detector and 135 V for the 44 μm detector. Due to hole injection from the backside Schottky contact into the detector, a break-through of the 200 μm thick detectors took place for $V_B > 135$ V. This problem could in principle be solved by replacing the backside Schottky contact with a n^+n -contact [9].

First we tested the uniformity of the response of the strips by measuring the average total collected charge $\langle Q_{coll} \rangle$ per strip of both detector types (Fig. 2a and Fig. 2b). Only 8 adjacent strips were connected to the read-out system for the different detector types. In both cases the strips show good uniformity within 15 % for $\langle Q_{coll} \rangle$, typical values are $\langle Q_{coll} \rangle = 10000$ electrons for the 375 μm detector and $\langle Q_{coll} \rangle = 16000$ electrons for the 44 μm detector. The higher collected charge $\langle Q_{coll} \rangle$ for the thinner detector can be explained by Ramo's theorem [10] via

$$Q_{coll} \propto \frac{x_D}{d}. \quad (1)$$

The collected charge Q_{coll} increases with the drift length x_D of the generated charge and decreases with the thickness d of the detector.

In Fig. 3a and Fig. 3b we show the signal to noise ratio, $\langle Q_{coll} \rangle / \langle Q_N \rangle$, for adjacent strips which is determined from the average collected charge of the signal peaks, $\langle Q_{coll} \rangle$, and noise peaks, $\langle Q_N \rangle$, of the pulseheight spectra. The signal to noise ratio is about 10 for the 375 μm detector with a small fluctuation from strip to strip. It is about 12 for the 44 μm detector, fluctuating between about 10 at the edges and 16 at the center of the detector.

A modified pulseheight spectrum of the 44 μm microstrip detector is presented in Fig. 4 in units of the electron charge. It is obtained by selecting the strip with the highest charge and adding the charge of an adjacent strips, if the charge of the adjacent strip is larger than 4 times the r.m.s of its noise. Therefore the mean of the pulseheight spectrum is about 5 % larger than in Fig. 2a. The signal peak is clearly separated from the noise.

For comparison a pulseheight spectrum of clusters ($Q_{cluster}$) is shown in Fig. 5. These clusters were reconstructed if the signal of each one of two adjacent strips is larger than 4 times the r.m.s of the noise, i. e. the pion is assumed to have hit the detector between

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⁶⁾ Ortec Nucl. Electronics, 100 Midland Road, Oak Ridge, U.S.A.

the two strips. The two charges were added to form a cluster. The $Q_{cluster}$ distribution has the shape of a Landau distribution as expected for minimum ionizing particles (mips) and the shape is similar to the signal spectrum of a single strip in Fig. 4. However, it is slightly shifted towards higher charges. The response of GaAs microstrip detectors can therefore be assumed to be uniform over the surface of the whole detector including the region between the strips.

Charge division between the strips is also studied using the parameter η , which is a fundamental parameter for characterizing strip detectors [11-13], defined as

$$\eta = \frac{Q_{coll}(A)}{Q_{coll}(A) + Q_{coll}(B)}, \quad (2)$$

where $Q_{coll}(A)$ and $Q_{coll}(B)$ are the charges induced at any two strips labeled A and B . The sum $Q_{coll}(A) + Q_{coll}(B)$ has to be larger than 4 times the r.m.s of the summed noise of the two strips.

The η distribution for the 44 μm detectors is presented in Fig. 6a for adjacent strips and in Fig. 6b for non adjacent strips. The two peaks at 0 and 1 in Fig. 6a are due to hits on a strip or close to a strip. In this case the charge is collected mainly by this strip. The entries in the region $0.2 < \eta < 0.8$ between the peaks are generated by pions hitting the detector between the strips. Because of charge division, signals are seen on both strips. As expected the η distribution for non adjacent strips in Fig. 6b contains less events in the intermediate region $0.2 < \eta < 0.8$. This demonstrates that charge division works for the 44 μm microstrip detector with $d = 200 \mu\text{m}$. Using charge division in suitable reconstruction algorithms, a spatial resolution better than the value $12.7 \mu\text{m} = 44 \mu\text{m} / \sqrt{12}$ of a uniform hit distribution could be accomplished.

4 Van de Graaff measurements

At the Van de Graaff facility of the University of Freiburg we made position dependent measurements of the cross talk between strips and the charge collection efficiency (CCE) of the detectors using He^+ ions of 1.5 MeV energy. To avoid radiation damages to the detector, the intensity of the He^+ ion beam was reduced by scattering the ions from a 1 μm thick Ni target located 10 cm in front of the detectors.

The beam was then collimated using a pinhole of 20 μm diameter. The distance between the pinhole and the detectors was about 50 μm . The pinhole was moved across the detector and fixed with an accuracy of a few μm .

The CCE is defined as the ratio between the measured charge Q_{coll} induced at the contacts and the charge Q_0 generated by the ionizing particle,

$$\text{CCE}[\%] = 100 \times \frac{Q_{coll}}{Q_0}. \quad (3)$$

The He^+ ions are usually stopped in the detector. The charge Q_0 generated by the He^+ ions is about one order of magnitude larger than the charge Q_0 generated by the test beam pions. Q_0 is calculated from the ratio of the energy deposit ($E_{\text{He}^+} = 1.5 \text{ MeV}$) and the effective energy required to create an electron-hole pair (4.27 eV for GaAs). The CCE should be 100 % for an ideal detector.

In Fig. 7 the CCE is shown as a function of the relative position of the edge of a strip with respect to the beam position as defined by the pinhole. For detectors with a pitch of 1000 μm and 375 μm , the CCE is much larger at the edges of the strips than

at the center. The CCE for detectors with smaller pitch, 200 μm and 44 μm , is nearly constant across the strip width. The maximum CCE increases with smaller pitch size.

The high CCE of GaAs strip detectors can possibly be explained by field inhomogeneities due to higher leakage currents at the edges of strips [14]. A higher leakage current leads to a deeper depletion zone. Due to Ramo's theorem [10] this effect increases the CCE in this region.

The coupling strength between two strips is defined as the ratio of the charge measured at the target strip and the charge measured at the neighbour strip. In Fig. 8 the coupling strength is again shown as a function of the relative position of the edge of the strip. It is negative for all our detectors, this means that an ion incidenting on a strip generates a charge signal of opposite sign at the adjacent strips.

The correlation between charge signals (here given in number of ADC channels) of adjacent strips is shown in Fig. 10 for uncollimated α particles from an ^{241}Am source. This behaviour can be explained by the weighting concept [15, 16]. The current j induced in a selected strip by a charge q moving inside the detector can be calculated via

$$j = q \vec{v} \cdot \vec{E}_w, \quad (4)$$

where $\vec{v}$ is the velocity of the charge q generated by the α particle through ionisation of atomic electrons. $\vec{v}$ is determined by the real electric field, not $\vec{E}_w$, of the detector. The induced current j is defined for a given strip and the integration of the current j yields the total charge collected by the strip. $\vec{E}_w$ is the weighting field which is calculated by setting the potential Φ_w of this strip to 1 (Fig. 11). The potential Φ_w of all other strips and of the ohmic contact is set to 0.

If an α particle (or He^+ ion) of several MeV hits strip A , the complete energy is deposited in the first few μm of the detector and a signal of positive polarity is induced in the strip. Line (a) in Fig. 11 corresponds to the path of the induced charge. If the ion hits the neighbouring strip, the charge induces a bipolar signal on strip A (line (b)). It can be shown that in a perfect detector without recombinations (trapping) a bipolar signal is always induced. Therefore the positive and negative charge components compensate each other. This is different in a GaAs detector hit by ions which generate the charge in the first few μm and where additional trapping occurs. The components of the positive and negative signal are not equal which leads to a coupling strength of negative polarity.

This effect is expected to be much weaker for mips, because charge is generated in the whole detector. In Fig. 9 the same correlation between adjacent strips is shown for an uncollimated pion beam. For mips negative coupling is not observed. However, this could also be due to the smaller signals and limitations caused by the energy resolution of the system.

5 Conclusion

Several types of GaAs detectors have been tested with a 5 GeV/c pion beam at the CERN-PS and with a 1.5 MeV He^+ beam at the Freiburg Van de Graaff facility. The detectors differ in pitch between 44 and 1000 μm .

It was shown with the pion test beam that the signal to noise ratio is better than 10 for the two detectors tested (44 and 375 μm pitch). Signal and noise peak are well separated. The strip to strip uniformity in charge collection lies within 15 %. The mean charge collected by one strip is about 16000 electrons for a 44 μm microstrip detector of 200 μm thickness. The charge division between the strips was measured which can be used to improve the spatial resolution of the detector.

The signals from He^+ ions incidenting at the edges of a broad strip are much larger than for ions incidenting at the middle of a strip. For detectors with a small pitch the charge collection efficiency (CCE) is constant accross the strip width. The ions generate a negative coupling between the strips. This effect can be explained by the concept of a weighting field. For mips (pions) this effect was not observed.

Our measurements confirm that our GaAs detectors can operate successfully under test beam conditions.

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Figure 1: Layout of our detectors. All numbers are in units of μm .

Figure 2: Average total collected charge $\langle Q_{coll} \rangle$ in number of electron charges of (a) a type D ($d = 500 \mu\text{m}$) and (b) a type A ($d = 200 \mu\text{m}$) GaAs strip detector. $\langle Q_{coll} \rangle$ is shown for adjacent strips.

Figure 3: Signal to noise ratio, $\langle Q_{coll} \rangle / \langle Q_N \rangle$, for a 500 μm thick type D (a) and a 200 μm thick type A (b) GaAs strip detector for adjacent strips.

Figure 4: Pulseheight spectrum of a 44 μm pitch GaAs microstrip detector obtained with 5 GeV/c pions at 135 V bias. The noise peak has been cut for the display.

Figure 5: Cluster spectrum of adjacent strips of a 44 μm pitch GaAs microstrip detector obtained with 5 GeV/c pions at 135 V bias.

Figure 6: η distribution of a 44 μm pitch GaAs microstrip detector for adjacent strips (a) and non adjacent strips (b).

Figure 7: Variation of the CCE across the strips. The CCE is shown as a function of the relative position of the edge of the strips with respect to the beam. The bold lines indicate the position of the strips.

Figure 8: Coupling strength between the strips as a function of the relative position of the edge of the strips with respect to the beam. It is negative for all detectors. The bold lines indicate the position of the strips.

Figure 9: Correlation between signals of two adjacent strips measured with 5 GeV/c pions.

Figure 10: Correlation between signals of two adjacent strips measured with uncollimated α particles.

Figure 11: Schematic drawing of the weighting field E_w for a strip detector. A charge moving along line A induces an unipolar, a charge moving along line B a bipolar signal in the strip with $\Phi_w = 1$.