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Development of a 128 channel silicon drift detector for spectroscopic purposes

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Abstract

A linear silicon drift detector with an active area of $1.28 \times 2.56\ \text{cm}^2$ has been designed. On each short side of the detector a row of 64 anodes is placed. The detector is intended for X-ray fluorescence purposes. Position resolution is obtained only from the anode number and not from drift time. Energy resolution is important and lateral charge diffusion to neighboring anodes cannot be tolerated.

In this work minimization of the lateral charge diffusion by a sawtooth shape of the cathode biasing strips is studied. The main advantage of this method is that additional processing steps are not required.

We measured ^{55}Fe spectra using a small detector in which the influence of lateral diffusion was still present. For the 128 anode detector of the right size we report charge collection over the maximum drift distance of 1.28 cm. Unfortunately this specific detector did not allow the extraction of diffusion data.

1. Introduction

Generally, single-anode (circular) silicon drift detectors (SDDs) are used for spectroscopy, and multi-anode (linear) SDDs for 1D and 2D position measurement. The former are mainly used because of their low detector capacitance in the order of tens of fF. The latter are used in moderate luminosity fields because of the reduced readout electronics when compared to pixel or strip detectors. For 2D position resolution the count rate is limited by the drift time in the order of μs. We intend to use every single anode of a multi anode SDD for low energy X-ray spectroscopy. In Fig. 1 a schematic layout of the detector is shown. The SDD contains two rows of 64 anodes on the short sides of the detector with a pitch of 200 μm. The total detection area is $1.28 \times 2.56\ \text{cm}^2$. The maximum drift length for the charge is 1.28 mm. Intended applications for this detector are diffraction with an 8 keV source and fluorescence with variable energy down to the K-α line of boron (180 eV). The latter application requires an optimized entrance window [1] and integrated electronics [2] to deal with the signal-to-noise problem but these topics are beyond the scope of this work.

In this work the attention is focused on another phenomenon common to linear SDDs, the diffusion and electrostatic repulsion of charge during drift. For tracking the diffusion can be used to obtain more precise position information, however at the expense of an increase in the observed occupancy. The extraction of the improved position resolution also requires extra electronics or computer power. It is therefore not always a welcome phenomenon. For spectroscopy with single anodes the charge loss to neighboring strips severely deteriorates the energy resolution of the SDD and should be prevented. The standard deviation for the free diffusion of an electron cloud within silicon can be calculated using

$$\sigma_e = \sqrt{(2 \times D_e \times \tau)}, \tag{1}$$

where D_e is the electron diffusion constant ($35\ \text{cm}^2/\text{s}$ at room temperature) and τ the drift time in the detector.

The problem of lateral diffusion is solved with success by Castoldi [3], but implies additional processing steps, involving an epitaxial layer and a deep p-type implantation. Castoldi [3] found experimentally that the

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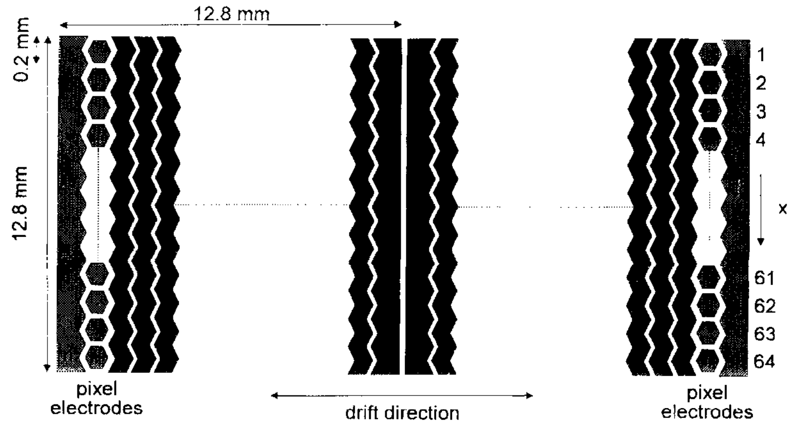

Fig. 1. Schematic layout of the 128 anode drift detector. The sawtooth shape of the biasing strips can diminish lateral diffusion in order to allow spectroscopic measurements.

confinement works adequate if the potential gutter is deeper than 3 times the sum of the thermal voltage and the electrostatic repulsion between the electrons. For X-ray energies up to 10 keV this means that a potential gutter of 100 mV is sufficient to confine the charge.

We try to confirm the idea proposed by Hijzen [4,5] which leaves the original processing scheme intact and induces a potential gutter in the bulk by only a modification of the shape of the biasing strips, which are now transformed into sawtooth shaped lines. A schematic representation is shown in Fig. 2. The sawtooth shape will modify the electrical field in the detector in such a way that per anode a potential gutter pointing towards the anode will confine the electrons when drifting. The depth of the potential gutter is influenced by the different shape factors of the sawtooth: α, p_x and p_y.

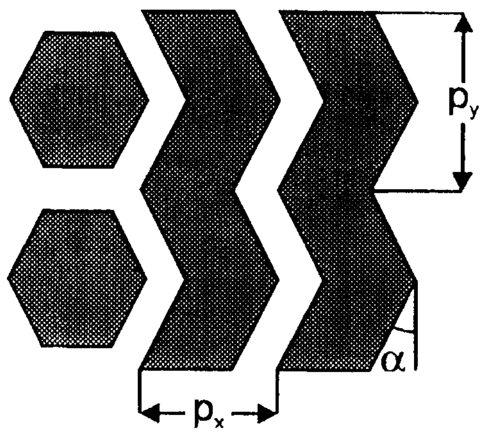

Fig. 2. Schematic layout of the sawtooth shaped biasing strips. The six-angular shapes are the anodes. The parameters α, p_x and p_y determine the shape.

2. Measurement setup

The measurements presented here were performed with two types of drift detectors. A small SDD with an anode pitch of 250 μm and a maximum drift length of 3 mm. The sawtooth shape factors are $\alpha = 21.8^\circ$, $p_x = 250$ μm, $p_y = 250$ μm. The other type of drift detector has the dimensions mentioned in the introduction and will be referred to as large. The sawtooth shape factors of this design are $\alpha = 24.2^\circ$, $p_x = 150$ μm, $p_y = 200$ μm.

Measurements on the charge collection area were performed with an X–Y position controllable pulsed laser (50 ps pulses at 10 kHz rate). Using neutral-density filters the injected charge was varied. The laser can be positioned with an accuracy of one micron and the spot has an aerial spread of $\sigma = 65$ μm on the detector surface.

The ^{55}Fe spectra were recorded with a Bertuccio type preamplifier [6] and Ortec 672 spectroscopic amplifier. All measurements were done at unstabilized room temperature. The detectors used had no integrated electronics on the SDD and the total capacitance at the input of the preamplifier is estimated to be in the order of 10 pF. The energy resolution therefore remains above 1 keV (FWHM).

3. Results and discussion

In Fig. 3 the charge collection efficiency of the small SDD is shown for two distances from the anode. The injected charge is approximately 750 electrons per pulse and the drift field 230 V/cm. The leakage current of this type is 1 nA/cm^2. The shift in the measurements is caused by a misalignment of the X–Y orientation between the laser and the SDD and resulted in a rotation of about 2°. The charge collection efficiency has a spread caused by the laser spot itself and by diffusion. Above the anode the spread is caused by the light spot only. By assuming a gaussian shape of the laser spot and a perfect block shaped collection area, the standard deviation of the laser spot can be extracted from the measurement directly atop of the anode. The measured standard deviation is $\sigma = 65$ μm and has been confirmed by other experiments. At 3 mm from the anode we still assume a perfect block shaped collection area, but the gaussian profile is now the quadratic sum of the laser spot and diffusion. For a drift distance of 3 mm a $\sigma = 103$ μm is calculated from Fig. 3. Given the drift time in the detector of 1 μs the free diffusion is calculated using Eq. (1) as 80 μm. Taking the quadratic sum of the standard deviation of the laser spot and the diffusion, the observed standard deviation reproduces within 5%.

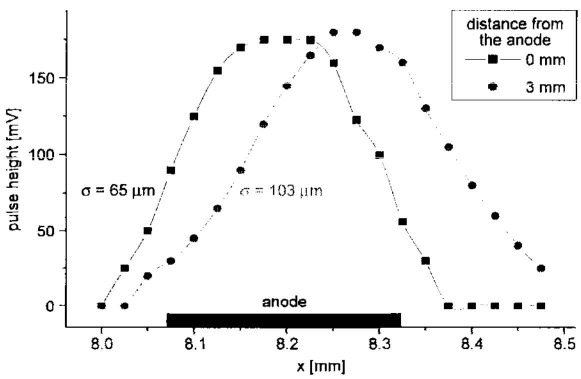

Fig. 3. Charge collection in the small SDD for two distances from the anode. The given standard deviation is that of the assumed gaussian profile of the laser spot including diffusion. The shift of the charge collection area is caused by a rotation of about 2° between the laser and the SDD.

This means that the sawtooth shape is unable to confine the charge. Simulations that were performed showed that with an anode pitch p_y of 200 μm and an angle α of 45° the potential gutter induced by the sawtooth shape is in the order of 100 mV so that for the given smaller angles the gutter is not deep enough to confine the electrons. Further simulations are required to optimize the design of the sawtooth shapes. Diffusion is also reduced by higher drift fields: the drift time reduces and for sawtooth shaped biasing strips the potential gutter deepens also.

Using the small SDD we were able to record energy spectra from a ^{55}Fe source as is shown in Fig. 4. Spectra are shown for one, three, and five anodes tied together. The spectra are adjusted in the Y-direction to equal the maximum number of counts in the peak. Each spectrum contains at least 10 000 counts. It can be seen that the low-energy tail at the 5.9 keV peak decreases when the number of anodes is increased from one to three. The reduction of the tail also improves the energy resolution from 1.5 to 1.4 keV FWHM. A further increase in the number of anodes does not lower the low-energy tail but this could be hidden by the increased leakage current contribution. The increased leakage current also results in an enlarged energy resolution of 1.8 keV FWHM. In

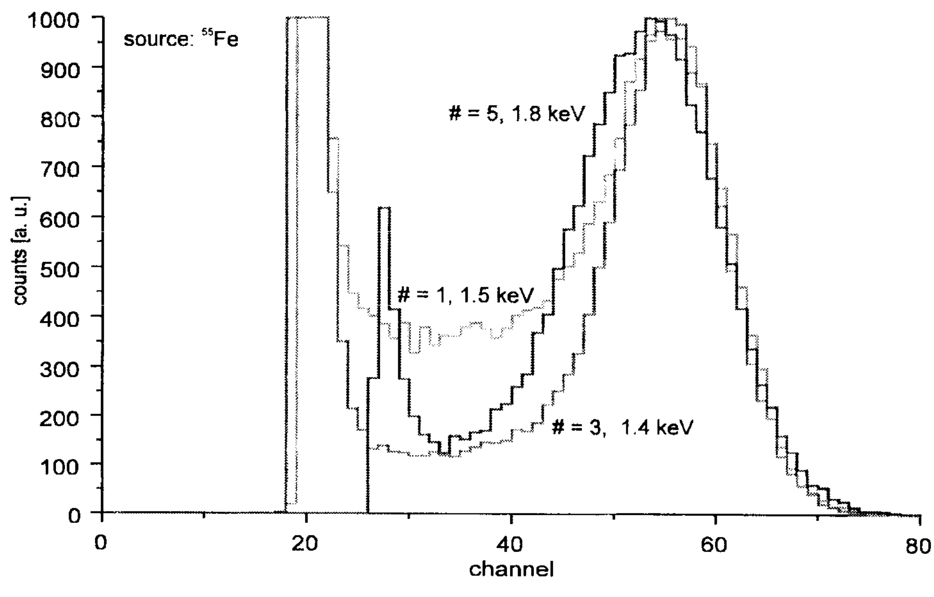

Fig. 4. Energy spectra from a ^{55}Fe source measured with the small SDD for one, three or five anodes. The FWHM is also indicated in keV.

the case of one anode the low-energy tail is mainly the result of diffusion. The peak-area to valley-area ratio should be much larger if only split events could occur. Assuming an initial charge sphere with a diameter of 3 μm this ratio should be $\geq$ 250 μm/6 μm. For the three anode case the ratio improves drastically, but also in this case it remains above 750 μm/6 μm.

The large SDD was available only recently and currently only the charge collection efficiency was measured. Collection over the full 1.28 cm is observed for five anodes tied together. However due to the leakage current above 10 nA/cm^2 and the required increased laser pulse power energy spectra and diffusion properties could not be measured.

4. Conclusions

In this work silicon drift detectors have been tested with sawtooth shape of the biasing strips. This shape should prevent the lateral diffusion of the charge cloud in the detector. For a small type of drift detector ^{55}Fe spectra were recorded. The 5.9 keV peak shows a low-energy tail due to diffusion. Confirmation about diffusion was obtained with a pulsed laser. With the sawtooth shapes and biasing voltage of the tested detector we were unable to confine the charge during the drift. The induced potential gutter could not be made deep enough. Larger angles α and a higher drift field are required. Better adapted SDDs are being processed.

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