New Ideas for Two Dimensional Position Sensitive Silicon Drift Detectors

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Abstract

In this paper we present two new ideas for drift detectors with two dimensional position resolution. The first idea is based on the regular drift detector, but has a slightly different design in order to deal with diffusion problems. The second idea embodies a completely new type of drift detector that uses drift time measurements for both dimensions. The design consists of concentric quadrilateral closed strips with a small collecting anode in the centre. At first electrons travel perpendicular to the strips until they reach a diagonal. Then they proceed along this diagonal until they are collected at the centre. Position resolution in two dimensions can be obtained when both the time the electrons need to reach the diagonal and the time they need to reach the centre are measured. The latter is obtained from the collecting anode, the former from a diagonal strip present at the back side of the detector. Compared to common 2D drift detectors this detector offers the advantage of a small amount of read out electronics. It also has the advantage of having just one small collecting anode with a very low capacitance, resulting in low noise and therefore in a good energy resolution.

I. INTRODUCTION

Silicon drift detectors are becoming more frequently used devices for two dimensional position sensitive radiation detection (e.g. [1]). A typical layout of such a device is shown in Fig. 1. It consists of regular drift detector geometry\textsuperscript{2,3}, but the anode is divided into pixels. Position resolution in the drift direction (x) is obtained from the drift time information. In the other direction (y) the number of the collecting anode pixel supplies position information. The spatial resolution is mainly determined by lateral diffusion of the electrons and the pitch of the anodes. When, due to diffusion, electrons are collected at more than one anode, the position can be determined by interpolation of the signals from the different anodes. Thus a position resolution smaller than the anode pitch can be achieved. For small numbers of electrons, lateral diffusion is a problem, since then the relatively large statistical spread makes accurate interpolation difficult. In such a case it would be desirable to suppress the diffusion in order to collect all the electrons at one anode.

To diminish the effect of diffusion in the direction transverse to the drift direction, attempts have been made to use so called channel stops [4]. These are regions with p\textsuperscript{+} implantation (for n-type silicon) perpendicular to the strips of the detector. This gives rise to a small potential barrier near the surface which results in suppression of the diffusion. The potentials applied to such a device must be chosen in such a way that the potential minimum lies close to the surface because the potential barriers are only present in the vicinity of the surface. This makes biasing of the device very critical since there is a significant chance that the electrons are trapped near the surface.

In section II we present an alternative method to diminish the effect of diffusion. This method consists of a change of the common rectangular shape of the p\textsuperscript{+}-strips into a saw tooth shape. This creates a small electric field in the direction parallel to the surface and perpendicular to the drift direction of the electrons. This field confines the electrons within one period of the saw tooth. Depending on the dimensions of the saw tooth it is possible to confine the electrons throughout the whole thickness of the detector.

Another problem for regular two dimensional drift detectors is that, for large detector areas, the amount of read out electronics becomes too large. A solution would be to use a drift detector that can provide drift time information for both dimensions. In section III we discuss a new type of drift detector that can be used for this purpose. Section IV contains conclusions and discussion.

Fig. 1. Common drift detector with two dimensional position resolution.
II. SAW TOOTH DRIFT DETECTOR FOR DIMINISHING LATERAL DIFFUSION

In order to suppress lateral diffusion, a new drift detector design with saw tooth shaped strips has been developed. A schematic picture of such a design is shown in Fig. 2. When a drift field is applied in the y-direction, a small electric field in the x-direction is created, due to the shape of the strips. Simulations show that in this respect the period of the saw tooth in the x-direction is the most important: The gutter extends to a depth corresponding to approximately one half of the saw tooth period. This is important in cases where one requires a position resolution smaller than the thickness of the detector. Then the biasing of the detector must be chosen in such a way that the potential minimum is situated closer to the surface.

III. REAL 2 DIMENSIONAL DRIFT DETECTOR

A. Principle of Operation

The second type of drift detector discussed in this paper will from here on be referred to as the R2D3 (Real 2 Dimensional Drift Detector). The principle of operation will be explained with the help of Fig. 4. The detector consists of an n-type substrate with several concentric quadrilateral closed p+ strips and one n+ anode in the centre on the front side. The negative potential applied to the p+ strips is increasing from the centre to the edge of the detector. The back side of the detector consists of eight planes and four diagonal strips that are all kept at the same potential. When impinging radiation creates electron-hole pairs the holes drift to a strip at the front surface or to a back plane. The signal induced on the back plane can be used for self triggering. The electrons will travel in a direction perpendicular to the strips until they reach a diagonal. From that point on they will continue drifting along the diagonal towards the anode.

The potential in a plane parallel to the surface is shown in Fig. 5, together with a typical electron track. Position information in two dimensions can be obtained when the time the electrons are generated, the time they reach the diagonal and the time they arrive at the centre are known. The first can be provided by an external trigger, or, when this is not possible, by one of the back planes of the detector. The time the electrons reach the diagonal is obtained from the signal...
induced on the diagonal strip, and the time they arrive at the centre is obtained from the collecting anode.

Fig. 5. Potential distribution of one quadrant of the R2D3 for a constant z value. Also indicated is a typical electron track.

B. Fabrication

Three R2D3's were included in a batch fabricated in DIMES (Delft Institute of Microelectronics and Submicrontechnology) using n-type (111) silicon with a resistivity of 4-10 kΩ cm and a thickness of 400 μm. The process used was comparable with the planar process developed by Kemmer [5,6]. The total size of each of the detectors was approximately 1 cm², with an active area of 0.5 cm². A picture of an R2D3 is shown in Fig. 6. The strips are not completely covered with aluminium, because this allows a visible light laser to be used for testing the detector. The strip pitch was 250 μm and the strip width 200 μm. The leakage current of the detectors was in the order of 100 nA/cm² for two of the detectors and 13 nA/cm² for the third. The latter was used to collect the data presented in this paper.

Fig. 6. Picture of the R2D3, (a) front side and (b) back side.
C. Measurements

Because the back side of the detector consists of a continuous p+ implantation, increasing the drift field will result in a shift of the potential minimum towards the surface. Therefore, the drift field cannot be chosen too high, since then the electrons will recombine near the surface before they have reached the anode. Theoretically, the maximum applicable drift field is twice the depletion voltage over the active detection area and is therefore related to the resistivity of the bulk material. It appeared that the R2D3 functioned best at a drift field of around 70 V/cm. For operation at higher drift fields, the use of silicon with lower resistivity would be desirable.

To test the detectors we made use of a pulsed laser with a wavelength of 675 nm and a pulse width of 50 ps. Because of this short wavelength, the strips of the detector could not be completely covered with aluminium. Therefore only small bond pads were present on the strips as can be seen in Fig. 6. As explained above we need three time signals (start, intermediate and stop) to obtain 2 dimensional position resolution. The start signal is provided by the trigger of the laser, the intermediate by the diagonal strip on the back side, and the stop signal by the collecting anode. This is visualised in Fig. 7.

Thus the actually measured time differences are Δt₁ and Δt₂. These times can be transformed into two "orthogonal times" for the x and y axis, tₓ and tᵧ respectively. When we do this we have to take into account that the electric field in the diagonal is smaller than the field outside the diagonal by a certain factor. Here we assume that this factor is equal to cosa, where a is the angle between the diagonal and the y axis. Then the relations between tₓ, tᵧ, Δt₁ and Δt₂ for y ≥ x become:

\[ tₓ = \frac{Δt₂}{\sin a \cos a}, \quad tᵧ = Δt₁ + \frac{Δt₂}{\cos^2 a}. \]  (1)

For y ≤ x, tₓ and tᵧ in Eq. (1) have to be exchanged. To demonstrate the two dimensional position resolution, we measured the drift times in one quadrant of the detector on grid points with a period of 250 μm in each direction, equal to the strip pitch (Fig. 8).

![Fig. 8. Schematic picture of the detector area used to measure the drift times. The X markers indicate the points for which the drift times were measured.](image)

Fig. 9 gives the simulated result of such a measurement. The deviation from a perfect square is caused by the fact that the electric field the electrons experience on the diagonal is apparently smaller than 1/cosa times the field in the linear region. The deviation of the points on the diagonal can be explained when we look at the path the electrons follow: Electrons travel towards the diagonal in a straight line, but will be bent from this line towards the centre before they actually reach the diagonal. This implies that the electrons reach the diagonal somewhat later than they would have if they had remained on the straight line. Important to mention is that in this simulation the effect of diffusion of the electrons was not taken into account. This could be of great influence since underneath the strips close to the surface the field becomes almost zero. With diffusion the electrons could pass these regions much faster.
Fig. 9. Drift time in the x direction $t_x$ vs. drift time in the y direction $t_y$ obtained from simulations. The solid lines connect points with constant x- or y-value.

Fig. 10. Drift time in the x direction $t_x$ vs. drift time in the y direction $t_y$ obtained from measurements on the R2D3.

IV. CONCLUSIONS AND DISCUSSION

In this paper, two new ideas were presented for two dimensional drift detectors. The saw tooth design is useful for diminishing lateral diffusion in cases where a small number of electrons have to be detected with reasonable position resolution, and the relatively large amount of read out electronics is no problem. The second design (R2D3) demonstrates for the first time a drift detector with two dimensional drift time read out. The position resolution obtained with a pulsed laser beam appears to be quite satisfactory for a first attempt. The intrinsic capabilities of the detector are such that it can have an energy resolution comparable to circular drift detectors [7,8], because of the small size of the anode. Since future applications of the R2D3 could very well lie in the field of X-ray detection, further investigation of the detector's behaviour for this type of radiation should take place. It is important to perform future measurements in a temperature controlled environment, in order to eliminate the effect of mobility fluctuations. Also, should this detector be produced with lower resistivity silicon, in order to allow larger drift fields.

V. REFERENCES