Electron Confinement in Multi-Anode Saw Tooth Silicon Drift Detectors With an Anode Pitch of 250 μm[1]

J. Šonský[2], H. Valk[2], J. Huizenga[2], R.W. Hollander[2], *Member, IEEE*, C.W.E. van Eijk[2], *Member, IEEE*, P.M. Sarro[3]
[2]Radiation Technology Group, Interfaculty Reactor Institute, Delft University of Technology,
Mekelweg 15, 2629 JB Delft, The Netherlands
[3]Delft Institute of Microelectronics and Submicron Technology, Delft University of Technology,
Mekelweg 4, 2628 CD Delft, The Netherlands

Abstract

Recently it has been experimentally shown that saw tooth shaped p^+ strips allows confinement of drifting electrons in the lateral direction. This is achieved by means of potential gutters induced by an appropriate saw tooth design of p^+ cathodes. The saw tooth period p_x (= anode pitch) is the parameter mainly determining the maximal capacity of confined charge. Up-to-now the confinement effect was experimentally observed with a saw tooth detector with p_x = 500 μm. The final detector is intended to have an anode pitch of 250 μm. The simulation of a saw tooth configuration with p_x = 250 μm, p_y = 200 μm, and α = 60° showed that potential gutters with a depth of 80 mV will be produced assuming a drift field of 250 V/cm. We will give experimental evidence of these shallow charge confining potential gutters.

I. INTRODUCTION

The performance of multi-anode linear silicon drift detectors (MLSDDs) is influenced by the time evolution of the signal electron cloud drifting towards an array of anode pixels [1]. The electron cloud broadens due to thermal diffusion and mutual electrostatic repulsion. This broadening effect is more pronounced especially for the case of long drift time, *i.e.* large detectors with long total drift distance and/or detectors working with a relatively low drift field, and a large amount of signal charge. The purpose of our work is to develop a 250 μm pitch MLSDD with a very good energy resolution for the detection of low energy X-rays. In a traditional MLSDD with straight p^+ strips the charge cloud broadening results in a position dependent loss of charge to adjacent anodes and consequently worsening of the energy resolution.

In the saw tooth configuration (see Fig. 1) an electric field component transversal to the drift direction is introduced [2]. This component creates gutters with smaller negative potential confining and guiding the electrons straightly towards one anode pixel. Hence, we will call this new drift detector multi-anode saw tooth silicon drift detector (MSSDD). The depth of potential gutters is determined by the saw tooth period p_x (= anode pitch), pitch p_y, angle α, and applied drift field. Recently [4] we have presented the experimental results on the diminished lateral spread of electron clouds in a MSSDD with an anode pitch of 500 μm. The calculated depth of potential gutters (ΔV_{max}) varied from 0.45 V for α = 30° to 1.1 V for α = 60°. The ΔV_{max} was also measured by means of the maximal number of electrons confined in one potential gutter. The measured values and the calculated ones match well. In the case of an anode p_x = 250 μm, the influence of the saw tooth configuration on the potential distribution in the middle of a 500 μm thick wafer is much smaller than for p_x = 500 μm. Effects, like local variation of bulk doping concentration or temperature which influence the depth of potential gutters, will be relatively more pronounced.

II. DETECTOR DESIGN AND ELECTRON CONFINEMENT

The layout of designed and fabricated MSSDDs is shown in Fig. 1. The detector is bi-directional with anodes at the outsides. The total active area of the detector is 2.5x1.3 cm^2. To study the effect of the saw tooth angle α we have splitted the active area of the detector into 4 sections with the following α: 0° (rectangular strips), 30°, 45°, and 60°. The other saw tooth parameters are period p_x = 250 μm and pitch p_y = 200 μm. The strips are designed on both front and back sides. The anodes are insulated with a p^+ implantation to avoid the leakage of charge to adjacent anodes caused by the small inter-anode conductance. The active area of the detector is surrounded with a guard anode to collect the externally generated electrons. For the fabrication we have used 2-10 kΩ cm n-type Czochralski wafers of 500 μm thickness.

Prior to the design, the potential distribution inside the detector has been simulated using the SEMISIM package [2]. The calculation showed that confinement of a few thousand electrons can be achieved with an anode pitch of 250 μm. The potential difference (ΔV_{max}) between the saw tooth and the rectangular strip configuration as a function of α is plotted in Fig. 2. The other saw tooth parameters used in the simulations are: p_x = 250 μm, p_y = 200 μm, and the drift field is 250 V/cm. The plotted potential difference ΔV is taken at the depth where the drifting potential is minimal (z = 250 μm). For successfull confinement of N electrons inside a sphere of radius R, the following condition is necessary [3]

$$(\phi_T + \frac{e}{4\pi\varepsilon}\frac{3}{5}\frac{N}{R}) \leq \frac{1}{3}\Delta V_{max} \qquad (1)$$

---

[1] This research has been supported by the Netherlands Technology Foundation (STW).

0018-9499/99$10.00

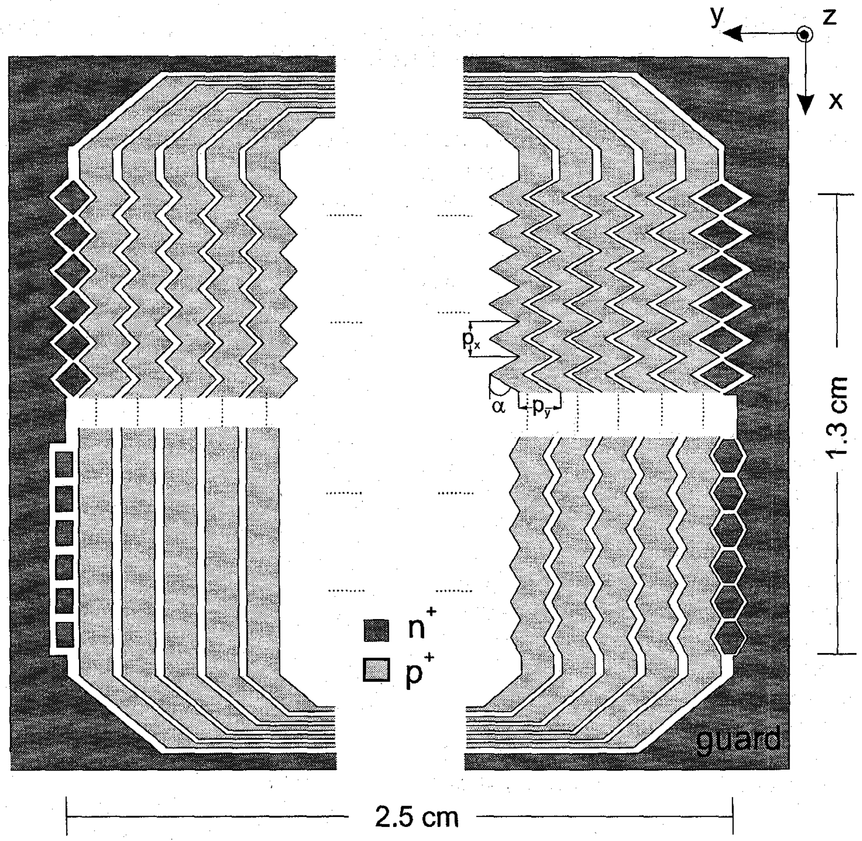


Fig. 1 Schematic of fabricated MSSDD with four sections showing different saw tooth angle $\alpha = 0°$ (rectangular strips), 30°, 45°, and 60°. The definitions of saw tooth period p_x, pitch p_y, and angle α are also indicated.

where ϕ_T is a thermal voltage (ϕ_T = 0.025 V at room temperature), e the elementary charge, and ε the dielectric constant. From formula (1) with R = 125 μm and ΔV_{max} as indicated in Fig. 2 we can calculate that 2.7×10^3 electrons will be confined for $\alpha = 60°$. For smaller α, ΔV_{max} is too small and the formula (1) can not be used, nevertheless the potential gutters are still deep enough to compensate the thermal voltage ϕ_T. Thus in principle, the thermal diffusion should be suppressed even for $\alpha = 30°$.

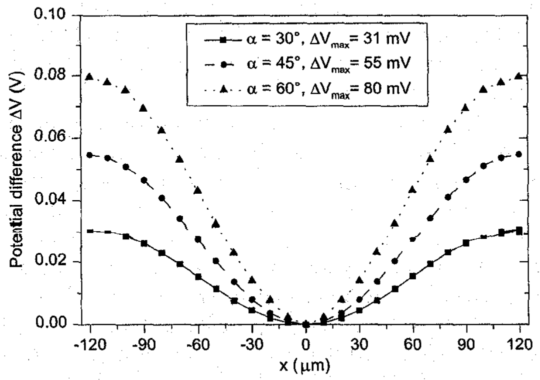
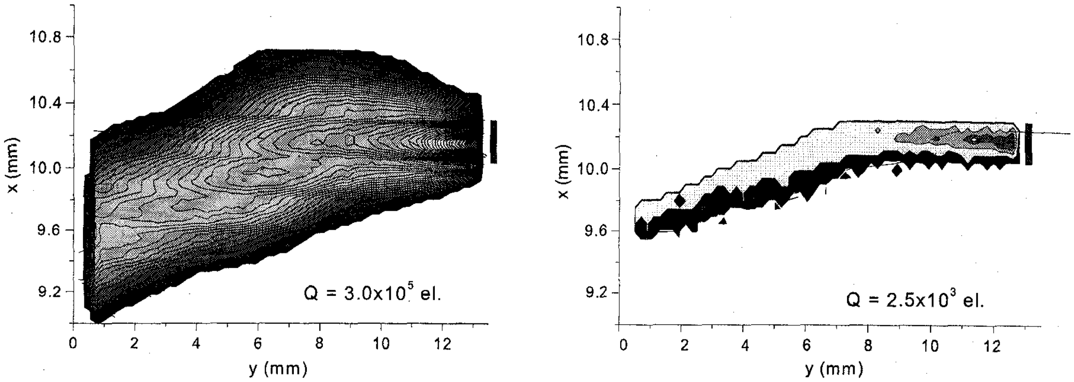


Fig. 2 The influence of the saw tooth angle α on the potential in the gutter. The maximal gutter depth (ΔV_{max}) is indicated for each angle α. The other parameters are p_x = 250 μm, p_y = 200 μm, and the drift field is 250 V/cm.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The time development of the signal charge cloud can be monitored by measurement of the collection of the charge injected at different distances from the anode. To obtain information about the uniformity of the charge collection over the whole width of one potential gutter (equal to anode pitch) the measurement has to be carried out for different x-positions of charge injection as well. We have used a focused pulsed laser beam (675 nm) to generate the signal electrons. The laser spot has a gaussian distribution with standard deviation σ = 40 μm. We have varied by means of pin-holes and gray filters the amount of charge generated per pulse in the detector from 2.5×10^3 to 3.0×10^5 electrons. The detector was operated under the drift field of ~200 V/cm and the drifting potential minimum was slightly shifted out of the centre of the wafer. We have measured a maximal electron drift time of 5.2 μs for a drift distance of 1.25 cm.

Because the simulation showed that the confinement of even a small amount of electrons in a MSSDD with α smaller then 60° is questionable, we will focuse our attention on the MSSDD with $\alpha = 60°$. Fig. 3(a)-(b) shows the normalized charge collection over the active area of one connected anode



(a) (b)

Fig. 3 Normalized charge collection over the whole active area of one connected anode for α = 60° for the following charge levels: (a) Q = 3.0x10^5 and (b) Q = 2.5x10^3. The anodes are located at the right side. The thicker line on the right side represents the anode pitch.

(α = 60°) for two different charge levels. For Q = 3.0x10^5 electrons, the signal charge is too high to be confined within one potential gutter and the electrons spread over up to 5 gutters. As we decreased the injected charge level, the electron cloud gets narrower. Finally for Q = 2.5x10^3 electrons, there is only a little overflow from the central gutter to the first adjacent gutters and at least 85 % of injected electrons is collected at the central anode along the whole drift length.

To highlight the influence of the saw teeth on electron broadening, we have plotted in Fig. 4 a normalized charge collection along the whole drift length at one anode provided that the charge injection occurs at the centre of the gutter. Comparing the charge collection for Q = 2.5x10^3 with the simulation for the free-diffusion case (the electrostatic repulsion is left out), the improvement in charge collection reached with saw teeth (α = 60°) is clearly visible. For a high charge level case of 3.0x10^5 electrons, we see a relatively constant collection along the drift length and steep rise of collected charge close to the anode. This means that the electron cloud is shortly after generation broadened by initial electrostatic repulsion. This broadening remains unchanged during the drift toward anode pixel.

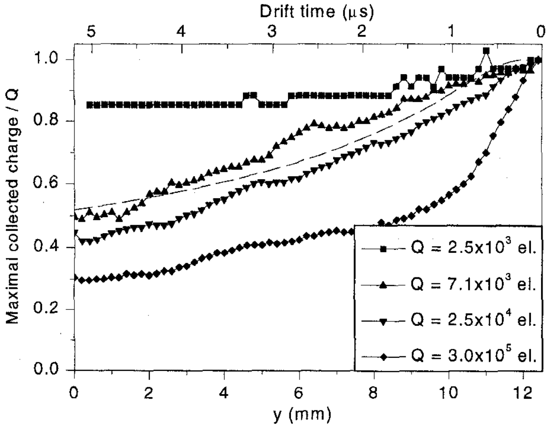


Fig. 4 Normalized charge collection at one anode for different charge levels provided that the charge injection occurs at the centre of the gutter. The dashed line shows the calculated charge collection in the case of thermal diffusion (without electrostatic repulsion). The bottom axis indicates the drift distance, *i.e.* (12.5 mm - y), and the top axis corresponding drift time.

From Fig. 3(a)-(b), one can deduce that the electron trajectories are deviated from expected straight lines. This is due to a electric field perturbation caused by bulk doping non-uniformities [5]. The doping non-uniformity was measured to be as as high as 15 % for our wafers. This plays a crucial role in the formation of confining potential gutters. The local doping variation will lead to the variation of the depth of potential gutters. Thus the confining barriers can locally vanish and these spots will cause a leak of signal charge to adjacent gutters. In fig. 3(a) we can see that the doping non-uniformity creates a "gutter" going across the potential gutters induced by the saw teeth. These two types of gutters have in our case at least the same depth and any information obtained from measurements will be distorted.

IV. CONCLUSION

We have presented the electron confinement in a MSSDD with an anode pitch of 250 μm. We have experimentally found that ~2500 electrons can be confined for α = 60°. Assuming that the applied drift field was smaller than the field used in simulations, we can conclude that theoretically predicted charge confining capacity roughly matches the measured one. Further improving of confinement should be achieved by optimalization of the drift field. To avoid problems with bulk doping non-uniformity, Neutron Transmutation Doped wafers should be preferentially used instead of Czochralski ones.

V. REFERENCES

[1] E. Gatti, A. Longoni, P. Rehak, and M. Sampietro, "Dynamics of electrons in drift detectors," *Nucl. Instrum. Methods, vol. A 253, 1987* pp. 393-399.

[2] E.A. Hijzen, E.M. Schooneveld, C.W.E. van Eijk, and R.W. Hollander, "New silicon drift detector design for diminishing lateral diffusion," *Nucl. Instrum. Methods, vol. A335, 1993* pp. 271-275.

[3] A. Castoldi, P. Rehak, and L. Strüder, " Electron confinement

in Drift Detectors by Means of 'Channel-Stop' Implants: Characterization at High Signal Charges," *IEEE Trans. Nucl. Sci., vol. 43, 1996* pp. 3201-3206.

[4] J. Šonský, H. Valk, C.P. Allier, R.W. Hollander, C.W.E. van Eijk, and P.M. Sarro, " Diminished Electron Cloud Broadening in a Silicon Drift Detector by Saw Tooth p^+ Strips," accepted for publication in *IEEE Trans. Nucl. Sci.*.

[5] A. Castoldi, S. Chinnici, E. Gatti, A. Longoni, M. Sampietro, A. Vacchi, and P. Rehak, "A method for doping fluctuations measurement in high resistivity silicon" *J. Appl. Phys, vol. 71(7), 1992* pp. 3593-3599.