Mimosa 25 chip overview

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1 Introduction

Mimosa 25 chip has oppend the new field for research on radiation tolerance of CMOS sensors based on partially depleted substrate. Radiation tolerance of CMOS Monolithic Active Pixel Sensors was proved up to the yearly fluence of 10^{13} neutron equivalent. This fluence seems to be the limit for currently used technology and the substrate with $\sim$14μm thick epitaxial layer. Charge generated by impinging particles is limited by thickens of the epitaxial layer where movement of electron or holes occurs due to their thermal diffusion. Minimum Ionising Particle (MIP) generates in average 80e$^-$ while it is crossing 1μm of silicon. Thus in 14μm EPI layer 1 MIP will generate around 1120e$^-$. Unfortunately due to the charge spread between pixels only 20-25% of generated electrons are transferred to the sensing diode. Assuming typical value of noise to be around 12e$^-$, signal to noise ratio is located below 25. Due to the bulk damage after irradiation only a fraction of signal is available and SNR drops substantially. In order to keep signal to noise ration on acceptable level two approach can be taken: first to reduce the noise and second to increase signal generated by impinging particle available on the sensing diode. Mimosa 25 chip was produced in order to explore the properties of partially depleted substrate available in commercial technology offered by XFAB. Technology with minimum transistor channel length of 0.6μm was chosen since it was the only one where substrate with resistivity of 1 k$\Omega \cdot$ cm was available. Such resistivity of substrate is equivalent to dopping of silicon material with around $10^{13} \cdot$ P-type dopands per cm^{-3}. Diode created on such substrate is expected to have depleted volume under, thus efficiency of charge collection of single diode is expected to increase by factor of 2 (TCAD simulations) in comparison to sensors manufactured in the past. Assuming that noise level will stay unchanged in comparison to previously used technologies, signal to noise ratio should stay on acceptable level even after substantial irradiation. Exact properties of substrate are the

Table 1: Mimosa 25 versions

Mimosa 25 versions		
Version	Pitch	Pixels
Mimosa 25 A	20 μm 30 μm	192 128
Mimosa 25 B	20 μm 40 μm	192 96

subject of studies. Also properties after irradiation with neutrons are unknown. It can be assumed that in depleted volume electrons generated by impinging particle can move faster and the probability to be captured by active states introduced by irradiation is reduced. Nevertheless, it is also known fact that substrate changes its properties with irradiation. N type silicon can be inverted to P type and for P-type silicon additional affective dopping is rising.

2 Chip design

Mimosa 25 chip was produced in 2 different versions, each with 8 analog outputs read-out in parallel. Each versions contains pixels with different pitch size and diode layouts organised in 16 columns. Properties are summarised in Table 1. The layout is divided into 2 independent parts with their own analog and digital input/output signals. Only one from such composed submatrixes is bonded to the PCB read-out board. Top view of the Mimosa 25 A layout is shown in Figure 1. Left side corresponds to 20μm pitch while right side contains pixels with 30 μm pitch

3 Readout design

Readout of Mimosa 25 chips were organised in not conventional way. Since one analog output is used to read-out 2 columns, read-out scheme of matrix was divided in two cycles. The first read-out cycle is followed by global reset of full matrix when also so called "read-out token" is generated. Then information from pixels which belongs to column 0-7 is read-out simultaneously beginning from one side of the chip (row 0). During the read-out "token" is passing from one row to the next one. When "token" reaches the last row, it is then propagated to the first row of columns 8-15, then second phase of read-out begins and signal from columns 8-15 are available on 8 analog

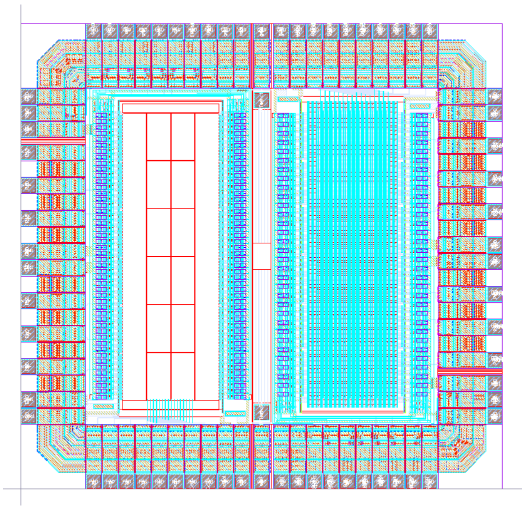

Figure 1: Mimosa 25 top view

outputs. Simplified schematic of Mimosa 25 read-out scheme is provided in Figure 2.

4 Diode designs

Mimosa 25 designs are composed of pixel architectures which have been extensively studied in the framework of designs made using 0.35 μm CMOS process provided by AMS. Since the properties of both architectures are known, exploration of low dopped substrate properties becomes more clear. Properties of both architectures after exposure to ionising and non-ionising radiation were also extensively studied. Three transistor structure - "Standard 3T architecture", uses enclosed layout transistor (ELT) for reset. Enclosed transistors are more radiation hard and after accumulation of ionising dose, they have reasonably low leakage current. Thus, voltage on the diode set-up after reset is supposed to be stable or influenced mostly by leakage current of sensing diode. So called "Standard Self Biased architecture" (later called - "sb_std") uses forwardly biased diode instead of reset transistor in order to recover the voltage level on sensing diode. This diode is implemented as a p+ implant to N-WELL sensing diode. Minimum N-well size available in presented design is 4μm×4μm. Implementing of self-biased diode as p+ implant leads to increase of N-well size to 5μm×6,5μm.

Investigated process offers also possibilities of implementing PIN diode. This diode is made as connection of low dopped substrate material with low

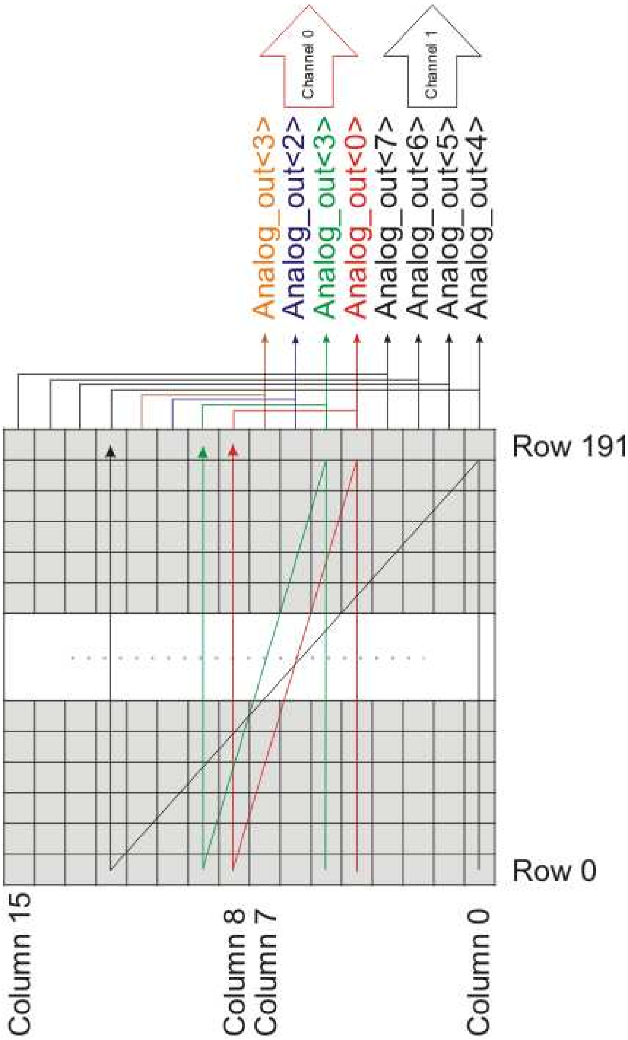

Figure 2: Mimosa 25 read-out scheme

Table 2: Mimosa 25 - summary of pixel architectures

Mimosa 25 versions				
Version	Design name	Pixel size	Pitch	Location
Mimosa 25 A	std	4μm$\times 4\mu$m	20 μm	$\langle$64-95$\rangle$ & $\langle$160-191$\rangle$
	std_SB	5μm$\times 6.5\mu$m	20 μm	$\langle$32-63$\rangle$ & $\langle$128-159$\rangle$
	std_5x6p5	5μm$\times 6.5\mu$m	20 μm	$\langle$0-31$\rangle$ & $\langle$96-127$\rangle$
	std	4μm$\times 4\mu$m	30 μm	$\langle$43-63$\rangle$ & $\langle$107-127$\rangle$
	std_SB	5μm$\times 6.5\mu$m	30 μm	$\langle$21-42$\rangle$ & $\langle$65-106$\rangle$
	PIN	11,4μm$\times$11,4μm	30 μm	$\langle$0-20$\rangle$ & $\langle$64-84$\rangle$
Mimosa 25 B	std_TOX	4μm$\times 4\mu$m	20 μm	$\langle$64-95$\rangle$ & $\langle$160-191$\rangle$
	std_SB_TOX	5μm$\times 6.5\mu$m	20 μm	$\langle$32-63$\rangle$ & $\langle$128-159$\rangle$
	std_TOX_5x6p5	5μm$\times 6.5\mu$m	20 μm	$\langle$0-31$\rangle$ & $\langle$96-127$\rangle$
	std_5x6p5	5μm$\times$6,5μm	40 μm	$\langle$32-39$\rangle$ & $\langle$88-95$\rangle$
	std_11x11	11,4μm$\times$11,4μm	40 μm	$\langle$16-31$\rangle$ & $\langle$64-79$\rangle$
	PIN	11,4μm$\times$11,4μm	40 μm	$\langle$0-15$\rangle$ & $\langle$48-63$\rangle$

dopped N- silicon on top of which N+ contact is made to form P+ N- N + diode. Finally, depleted N-region is available very near to the surface thus such diode can be sensitive to the blue light. There is no much interest given to PIN diode as a possible candidate to use for building particle tracking detectors but nevertheless this design can be interesting for imaging. The minimum size of this diode is 11μm$\times 11\mu$m. Mimosa 25 B contains diode made as radiation tolerant where better radiation hardness is achieved by replacing thick oxide by thin $\sim$10nm gate oxide.