OVERMOS
CMOS HR detector for HEP applications

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on behalf of OVERMOS project collaboration

HSTD11 – Okinawa, Japan - Dec 2017
Overview

- OVERMOS1 description
- First test results of irradiated / non–irradiated OVERMOS1
- TCAD simulation
- Conclusions and next steps
Introduction – CMOS MAPS & HEP

<table>
<thead>
<tr>
<th></th>
<th>ATLAS HL LHC</th>
<th>ATLAS</th>
<th>ILC</th>
<th>ALICE</th>
<th>STAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>TID[Mrad]</td>
<td>$10^3$</td>
<td>80</td>
<td>0.4</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Fluence[$n_{eq \ cm^{-2}}$]</td>
<td>$10^{16}$</td>
<td>$10^{15}$</td>
<td>$10^{12}$</td>
<td>$10^{13}$</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>P.Rate[kHz mm$^{-2}$]</td>
<td>$10^4$</td>
<td>$10^3$</td>
<td>$2.5 \times 10^2$</td>
<td>15</td>
<td>$10^2$</td>
</tr>
<tr>
<td>Timing[ns]</td>
<td>25</td>
<td>25</td>
<td>350</td>
<td>$2 \times 10^4$</td>
<td>$2 \times 10^5$</td>
</tr>
</tbody>
</table>

CMOS MAPS detectors solutions are and are going implemented in HEP. Further improvements needed for more challenging HEP use.
To improve the CMOS MAPS radiation hardness a drift component needs adding, as the diffusion based charge collection drastically reduces their CCE past $10^{13}$ cm$^{-2}$ 1 MeV $n_{eq}$.

- As the depletion region $\sim \sqrt{\frac{\rho V_{bias}}{\text{well}}}$, one can either increase the resistivity $\rho$ (HR CMOS) and/or the biasing $V_{bias}$ (Hv CMOS).

- Ultimately the sought end result is the same, i.e. a depleted CMOS MAPS (DMAPS).
OVERMOS is a RAL project, in collaboration with IHEP, aimed at investigating and modelling performances of HR CMOS MAPS fabricated using:

- TJ 180 nm Hi-res 18 μm thick epitaxial layer 1kOhm –cm
- Small (4 x 4 μm²) 4 collecting nodes within each pixel
- CMOS DPW or INMAPS, originally proposed TPAC for DECAL of ILC
OVERMOS1 description

- The ASIC logically consists of PASSIVE and ACTIVE structures, i.e. without and with in-pixel electronics respectively;
OVERMOS1 description

2: Basic Passive: 5x5 of 40 x 40 um

3: Basic Passive Large: 5x5 of 40 x 400 um merged

4: Basic Passive Large: 5x5 of 40 x 400 um

1: Symmetric Passive: 5x5 of 40 x 40 um

8: Basic Active Large 5x5 of 40 x 400 um

7: Basic Active Large Merged 5x5 of 40 x 400 um

6: Basic Active AC Large 5x5 of 40 x 400 um independent diode biasing AC coupled

5: Basic Active: 5x5 of 40 x 40 um

PASSIVE

ACTIVE

- The PASSIVE pixels consist of arrays of pixels with different arrangements of the 4 collecting nodes (of the same size) within each pixel
- The ACTIVE pixels, i.e. with in-pixel electronics, all allow analogue readout of the pixels
OVERMOS1 description

- The ACTIVE pixels include a charge amplifier, shaper and Voltage follower with each output being routed out.
- Some flavours feature AC coupling to the RO, allowing for relatively high voltage biasing to the pixels.
OVERMOS1 description

- All the pixels in the OVERMOS1 include an p++ region around each diode to isolate them from neighbouring ones, an issue that plagued previous version of OVERMOS
- The OVERMOS1 ASIC ‘basic passive’ has been tested before and after n-irradiation for DC and charge collection
OVERMOS1 irradiation

- OVERMOS devices have been irradiated at Ljubljana in October 2017 to $1E13$, $5E13$, $1E14$ and $5E14$ n fluence

- Estimated around 30% of fluence consisting of high energy neutrons ($>100$keV)
OVERMOS1 Charge collection

Charge collection studies performed using Laser injection:

1: Amptek A250CF calibrated using mV voltage pulses injected through (measured) 1.2 pF capacitor to get V(Q). RMS Noise ≈ 76 e⁻@ OVERMOS capacitance

2: Trilite Laser 1064 nm calibration using a 300 um Si sensor, 1um top passivation. Laser beam size 5 x 5 um² (measured with beam profiler), 4.1 ns FWHM (measured with FEMTO 2 GHz optoreceiver), 50 Hz repetition rate. Up to 5 points measured on sensor to calculate average injected charge
3: the calibrated Laser was used to inject \( <Q \text{ injected} > = 541.66 \text{ fC} \) or \( 1.805 \text{ fC/um} \) (corresponding to the Laser attenuation settings which gave the minimum error %) (not taking into account IR reflection on ASIC’s top)
OVERMOS1 Charge collection

- Total collected charge vs. Vbias, points A, B, C. Integration time 400 ns
- $\langle Q \text{ injected} \rangle = 1.805$ fC/um
- HVbias $= 10$ V provided through the A250CF, via a 400 Meg resistor chain
- T = 21°C in all tests
Laser injection test results (1064 nm, 5 x 5 um2 beam size)
Vbias = 10V
<Q injected> = 1.805 fC/um
Laser injection test results (1064 nm, 5 x 5 um$^2$ beam size)

$V_{bias} = 10V$

$<Q \text{ injected}> = 1.805 \text{ fC/um}$
Laser injection test results (1064 nm, 5 x 5 um² beam size)
Vbias = 10V
<Q injected> = 1.805 fC/um

OVERMOS1 Charge collection

φ=1E14

Q[fC]

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OVERMOS1 collection time

\[ \tau_{FtotA} \approx 123.9 \text{ ns} \]
\[ \tau_{FtotB} \approx 152.18 \text{ ns} \]
\[ \tau_{FtotC} \approx 166.2 \text{ ns} \]

Collected charge vs. time, points A, B, C Vbias = 10V, \( \Phi = 0 \)
\[ <Q \text{ injected}> = 1.805 \text{ fC/um} \]

AMPTEK A250CF
\[ \tau_{RAMP} = 15 \text{ ns} \]
\[ \tau_F \sim \sqrt{(\tau_{Ftot})^2 - (\tau_{RAMP})^2} \sim \]

A: 123 ns
B: 151.4 ns
C: 165.5 ns
OVERMOS1 DC test

- DC test results of leakage currents test of single pixel 4 with substrate and other pixels floating
- Linear increase with fluence, as expected

\[ I = I_0 + K \Phi \]

\[ K = 1.121 \times 10^{-24} \pm 3.52 \times 10^{-26} \]
• Individual doping profiles for OVERMOS were obtained using SPROCESS, to simulate a (simplified) CMOS fabrication by using TJ foundry process information
• These (1D) doping profiles were then implemented in SDE
• Huge reduction in mesh size (O(3e5) points) and computation time
TCAD DC initial results
Leakage currents

- Leakage current for tested non-irradiated pixel and TCAD results differ by ~3 max
- Surface Recombination velocity SRV = 1e4
- SiO2/Si trap density 1e11

\[ R \approx 2.85 \text{ Max} \]

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Conclusions and next steps

• First test results of OVERMOS1 basic flavor were presented

• Measured with Laser injection, initial increase in CCE observed for irradiated device

• Charge collection drops by tenfold at $\Phi = 1e14 \text{ w.r.t } \Phi = 0$

• DC tests showed expected leakage increase with n-fluence

• Initial TCAD simulations for DC only off by $\sim 3$

• Next step: to fully characterise the remaining sensors, both passive and active and TCAD simulations comparisons

THANK YOU
Leakage current is measured between P wells (top and substrate).

For constant current and assuming only drift component,

\[ j = q_p \mu_p F \]
\[ p = \frac{j}{q_p \mu_p F} \]
\[ \frac{\partial}{\partial x} F = \frac{j}{\varepsilon_0 \mu_p F} \]

\[ \int_0^x F \left( \frac{\partial}{\partial z} F \right) dz = \int_0^x \frac{2j}{\varepsilon_0 \mu_p} dz \]
\[ F^2 = \frac{2jx}{\varepsilon_0 \mu_p} \]

\[ -\left( \int_0^{Z_{epi}} F \, dx \right) = V_{SS} \]

\[ j = \frac{9 \varepsilon_0 \mu_p V_{SS}^2}{8 Z_{epi}^3} \]
Backup slides - Leakage currents

$\Phi=0$

$\Phi=5E13$

$\Phi=5E14$

Fitting @ 5E13 shows a nearly ideal $V^2$ dependence.
The power coefficient depends on the fitting.
Only one device/each radiation level.
Asymmetry w.r.t. Vss may be due to conductive glue at the substrate.
Some approximations as a result but more affordable for big 3D simulations:
- No B sucking
- No lateral spread doping information
- Coarser doping profiles
BACKUP slides – Laser beam width

Laser beam size vs. focusing – Measured beam size with beam profiler
OVERMOS next steps

Determine Neff by measuring depletion width vs. bias
We use the Trilite Laser (~ 3 um minimum b.w. @ 1064 nm) to sample the OVERMOS1 along the edge