TCT study of H35Demo test structures

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HV-CMOS in HEP

Several productions from different foundries have been made
Each with its production technology and wafer resistivity:

- AMS 350nm, $\rho = 20\Omega \cdot \text{cm} \text{ (CHESS-1)}$
- AMS 180nm, $\rho = 10\Omega \cdot \text{cm} \text{ (HV2FEI4)}$
- LFoundry 150nm, $\rho = 2k\Omega \cdot \text{cm}$
- X-FAB 180 nm, $\rho = 100\Omega \cdot \text{cm}$

Interesting results have been obtained but it is hard to compare devices from different foundries because of different technologies, substrate doping and well properties.

G Kramberger, 27th RD50 Workshop
H35Demo Chip

Main features:
- Different substrate resistivities:
  - $20\ \Omega\cdot\text{cm} \ (\text{standard}), \ 80\ \Omega\cdot\text{cm}, \ 200\ \Omega\cdot\text{cm}, \ 1\ \text{k}\ \Omega\cdot\text{cm}$
- AMS 0.35 $\mu$m High Voltage CMOS (H35)

Areas (from top to bottom):
- Standalone nMOS matrix
  - Digital pixels with in pixel nMOS comparator
  - Standalone readout
- Analog matrix (2 identical arrays)
  - Different flavors in terms of gain and speed
- Standalone CMOS matrix
  - Analog pixels with off pixel CMOS comparator
  - Standalone readout

Test structures:
- Central pixel w/ 8 neighbor + output buffer
- Central pixel w/ 8 neighbor
**H35Demo test structure**

The test structures are on the side of the chip
→ Incomplete chips on the periphery of the wafer can be used

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**H35Demo chip on the PCB**
*Designed by C. Puigdengoles*

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**Detail of the test structures**

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**Tested devices**

<table>
<thead>
<tr>
<th>Name</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin</td>
<td>UNIGE</td>
<td>IFAE</td>
<td>KIT</td>
</tr>
<tr>
<td>Nominal $\rho$ [(\Omega \text{cm})]</td>
<td>200</td>
<td>200</td>
<td>1000</td>
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H35Demo test structure

The tested structure is a matrix of 3x3 pixels of $50 \cdot 250 \text{ um}^2$ each

- 3 deep N wells in each pixel
  - central $50 \cdot 110 \text{ um}^2$
  - external $50 \cdot 70 \text{ um}^2$
- no electronics inside the pixels
- deep P well inside the deep N well of the central N well
- deep N wells covered by a layer of polysilicon in the external N wells
- central pixel (marked in red in the drawing) is read out individually
- signals of the 8 external pixels are shorted together

*from Eva Vilella*
TCT Setup

Scanning TCT from Particulars

Laser properties
- Red or IR laser (640 nm and 1064 nm) available
  - all results shown have been obtained with the IR laser beam
- Beam spot ~10 um FWHM
- Laser pulses of ~500 ps

Readout through DRS4 evaluation board
- 700 MHz bandwidth
- 5 GSPS
- 200 ns sampling depth
- 4 channels
  - 1 for trigger
  - 1 for beam monitor
  - 2 readout channels
**S1 - Top TCT**

This sample has been kindly provided to us by M. Benoit, Geneva University

Each waveform is integrated in a 25 ns wide time interval (45-70 ns) to obtain the charge collected by the pixel.

The sub-structures of the pixel are visible.
The low value regions correspond to the metal lines on the pixels.
The region with the highest collected charge corresponds with the deep P well.
S1 - Top TCT

I selected three regions of 10 \( \mu m \cdot 30 \mu m \) to compute the average collected charge in the structure with deep P well inside the deep N well and in the structure with the only deep N well.

The external wells collect \( \sim 64\% \) of the central one at any voltage.

Two possible explanations:
- The silicon layer on top of the external well reflects+adsorbs part of the light.
- The central well efficiency is higher than external one.
S1 – Edge TCT

Collected charge obtained by the waveform integral over a 25 ns time interval

The separation of the three deep N wells is slightly visible in the charge collection map. The design distance between the central and the lateral N wells is 20 μm.
S1 – Edge TCT

The y profile of the 2D map shows the evolution of the depletion depth with the bias voltage
At $x = 165 \, \mu m$, at the position of the deep p-well inside the n-well
At $x = 240 \, \mu m$, at the center of the external structure w/o p-well

The difference of collected charge between the wells observed with Top TCT is not present in this case
S1 – Depletion depth

The depletion depth is given by the formula:

\[ d = d_0 + \sqrt{\frac{\varepsilon S_i \varepsilon_0 V}{q N_{eff}}} = d_0 + \alpha \sqrt{\rho V} \]

The measurement points are given by the full width half maximum of the charge collection profile. The fit returns a resistivity of \( \rho_{\text{meas}} \sim 50 \ \Omega \cdot \text{cm} \) that is significantly smaller than the nominal value.

Simulations by Lingxin show that this data fits with the 80 \( \Omega \cdot \text{cm} \) simulation.

I repeated the measurements with another sample of nominal resistivity 200 \( \Omega \cdot \text{cm} \).
S2 – Depletion depth

This sample comes from the IFAE wafer with nominal resistivity 200 $\Omega \cdot \text{cm}$

The depletion depth vs $V_{\text{bias}}$ plots do not overlap with the one of sensor S1

The measured resistivity is $\rho_{\text{meas}} \sim 180 \Omega \cdot \text{cm}$

Measurements on other devices with nominal resistivity 80 $\Omega \cdot \text{cm}$ and 200 $\Omega \cdot \text{cm}$ should be done to investigate this inconsistency
S3 – Edge TCT

This sample has been kindly provided to us by I. Peric, KIT

At $V_{\text{bias}} > 50\,\text{V}$ and depth $>150\,\mu\text{m}$ the central pixel collects charge generated underneath its neighbors on the short pixel direction.
S3 – Depletion depth

The FWHM can be taken as measure of the depletion depth for the *external* and *central + external* plots.

The resistivities obtained are:

\[ \rho_{\text{meas}}^{\text{ext}} = 1840 \, \Omega \cdot \text{cm} \pm 20\% \]

\[ \rho_{\text{meas}}^{\text{cntr+ext}} = 4280 \, \Omega \cdot \text{cm} \pm 7\% \]
Problems with other samples

Other three devices with nominal resistivities 20, 80 and 200 $\Omega\cdot$cm have been tested on the edge TCT set-up but the sampled waveforms showed very low current pulses.

The waveforms shown here are from the 20 $\Omega\cdot$cm sample biased at 170V and using a laser intensity much higher than usual, lowering the laser intensity the signal would disappear.

Integrating the first pulse and drawing a charge collection map just some spots are obtained.
Conclusions

- Edge TCT measurements on test structures of nominal resistivity $\rho = 200 \ \Omega \cdot \text{cm}$ and $\rho = 1000 \ \Omega \cdot \text{cm}$ completed
- The two $200 \ \Omega \cdot \text{cm}$ samples have different behaviors and return two different values of measured resistivity
- Unexpected behavior observed in the $1k \ \Omega \cdot \text{cm}$ sample

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<td>4280 / 1840</td>
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Outlook

- Measure samples of $\rho = 20 \ \Omega \cdot \text{cm}$
- Increase the statistic of tested devices
- Start an irradiation campaign

In the meantime at IFAE the readout of the stand alone matrices is being developed and the first pulses from a $^{90}\text{Sr}$ source have been detected
Thanks