Recent results on 3D double sided detectors at IMB-CNM

G. Pellegrini, C. Fleta, M. Lozano, D. Quirion,
Centro Nacional de Microelectrónica (IMB-CNM-CSIC) Spain

S. Grinstein, A. Gimenez, A. Micelli, S. Tsiskaridze
Institut de Física d'Altes Energies (IFAE) Spain
IMB-CNM facilities

Clean Room
- 1.500 m², class 100 to 10,000
- Micro and nano fabrication technologies.

Processes
- 4” complete
- 6” partial

Available technologies:
- CMOS, BiCMOS, MCM-D, MEMS/NEMS,
- power devices
- Bump bonding packaging
- Silicon micromachining

Laboratories:
Characterization and test
- DC and RF (up to 8 GHz)
- Wafer testing
- Thermography
- Radiation testing

Reverse Engineering
Simulation
CAD
Mechanical Workshop
Chemical sensors
Bio-sensors
Optical sensors
Radiation sensors
Pixel Status: AFP

Pixel detectors: technology choice in high-energy physics for innermost tracking and vertexing.

3D detectors: candidates to be installed in new Insertable B-Layer (IBL) of ATLAS experiment. Production already finished.

• AFP: detect very forward protons at 220m from IP, with pixel detectors for position resolution and timing detectors for removal of pile up protons.
• Both Si and timing detectors mounted in movable beam pipe
• Silicon detector has to have small dead inactive region on side into beam
• Non-uniform irradiation of the detectors.

220m to ATLAS P1
4” silicon wafer
285um FZ high resistivity wafers (n and p- types)
All fabrication done in-house

- ICP etching of the holes: Bosch process, ALCATEL 601-E
- Holes partially filled with LPCVD polysilicon doped with P or B
- P-stop ion implantation

Double side process proposed by CNM in 2006
First fabrication of 3D double sided in 2007.
Since 2007 runs ongoing continuously.
In 2010 CNM started the fabrication on 230um thick wafers.

Devices tested under extreme radiation fluences.
- Different test beam successfully carried out on device before and after irradiation at SHLC fluences ($2 \times 10^{16}$ cm$^2$ 1 MeV n Eq.).

3D Features:
- High electric field
- Short path collection
- Low depletion voltage
Technology:

- Aluminum pad
- p-stops
- n-type poly
- Boron diffusion
- p-type poly
- Oxide barrier
- n-type poly

200µm

10µm
3D process flow

1- wafer preparation

P-type

2- p-stop definition

3- polysilicon resistor (optional)

4- holes etching, backside

5- holes p-type doping

6- holes etching, front side

7- holes n-type doping

8- Poly/metal contact

9- metallization and passivation

G. Pellegrini
Instituto de Microelectrónica de Barcelona
Production

• Part of IBL 3D sensors fabricated at CNM
• Common layout within the Atlas 3D collaboration (http://test-3dsensor.web.cern.ch/test-3dsensor/).
• Sensors produced for the geometry of the FE-I4 chip:
  • 50um x 250um
  • 210um columns in 230um p-bulk
  • 2E configuration (2 readout electrodes/pixel)
• Extensive characterization and testing being done at Barcelona with un-irradiated and irradiated devices up to 5.11x 10^{15} neq/cm^{2}

http://dx.doi.org/10.1016/j.nima.2012.07.058
Irradiated IBL Devices

- Several planar and 3D IBL devices irradiated to IBL fluencies (5E15 neq/cm²)

<table>
<thead>
<tr>
<th>Device</th>
<th>Irradiation ([\text{neq/cm}^2])</th>
<th>Irr Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCC36</td>
<td>p-irrad (6 \times 10^{15})</td>
<td>KIT</td>
</tr>
<tr>
<td>SCC34</td>
<td>p-irrad (5 \times 10^{15})</td>
<td>KIT</td>
</tr>
<tr>
<td>SCC97</td>
<td>p-irrad (5 \times 10^{15})</td>
<td>KIT</td>
</tr>
<tr>
<td>SCC100</td>
<td>p-irrad (2 \times 10^{15})</td>
<td>KIT</td>
</tr>
<tr>
<td>SCC82</td>
<td>n-irrad (5 \times 10^{15})</td>
<td>TRIGA</td>
</tr>
<tr>
<td>SCC81</td>
<td>n-irrad (5 \times 10^{15})</td>
<td>TRIGA</td>
</tr>
</tbody>
</table>

- Critical to characterize devices before and after irradiation.

For 3D devices irradiated to IBL fluencies power dissipation is not an issue.
Voltage scan for p-irradiated devices shows that 160V is the optimal operating voltage

Optimal voltage for CNM 5E15neq/cm² irradiated devices ~ 160V

http://dx.doi.org/10.1016/j.nima.2012.03.043
Test-beam Results

CNM devices have been tested in the CERN testbeam and have shown efficiencies >97% after irradiation (according to IBL specifications)

Pixel efficiency map: fold efficiency to 1 (±0.5) pixel (match track in 3x3pixel window)

CNM55: un-irradiated
0deg incidence
HV=20V
eff=99.4%

CNM81: n-irradiated
0deg incidence
HV=160V
eff=97.5%

CNM34: p-irradiated
15deg incidence
HV=160V
eff=98.9%

Prototype ATLAS IBL Modules using the FE-I4A Front-End Readout Chip, submitted to JINST (2012)
Post processing for slim edges

What can be improved for HEP or other applications?

Reduce the dead area at the detector edges. Laser-Scribing and Al2O3 Sidewall Passivation of P-Type Sensors: (see Vitaliy Fadeyev´s poster)

Negative charges induced by Al₂O₃ deposited by ALD process, isolate the sidewall surface cut in p-type wafers reducing surface current.

Work done in collaboration with:

Marc Christophersen, Bernard F. Phlips (NRL) Naval Research Laboratory U.S.

and within RD50 collaboration (CERN)

Vitaliy Fadeyev, Scott Ely, Hartmut F.-W. Sadrozinski (SCIPP, UCSC) University of California, Santa Cruz U.S.
• Annealing of alumina layer reduces leakage current (same effect as seen for solar cells).
• Formation of native oxide (wrong surface charge) ↑ leakage current.
• Native oxide forms rapidly (within seconds/minutes) in air.
• Native oxide: ~ 2 nm thick, high charge trap density.

• Laser-scribing and cleaving common in LED industry
• Automated tools for scribing and breaking of devices on wafer-scale
XeFe$_2$ etching and cleaving

Laser cutting and ALD done at NRL
Marc Christophersen

SEM micrographs (bird’s-eye view)
New samples with slim edges (Atlas FE-I4 pixels)

Detectors ready for flip chip.

Spare 3D FE-I4 detectors from IBL production done at CNM. Normally from damaged wafers.
New samples with slim edges (Atlas FE-I3 pixels)

Guard ring

P-stop

100um

Full current after flip chip, measured through FE.

• Flip-chipped by IFAE (to 700um-thick old FE)
• Wirebonded by CNM
Charge collection

Charge collection of CNM AFP01

- Sr 90 charge collection vs HV
- ToT: time over threshold in 25ns units
- Full depletion at 20V for these devices

Atlas FE-I3 Geometry
• Threshold set to 3200e (same as current ATLAS Pixel detector – FEI3)
• Noise of the order of 100e (un-irradiated)
• Noise stable vs bias voltage
In-Homogeneous Irradiation and Test-beam Results

- AFP devices will receive an in-homogeneous irr dose (up to 2E15 neq/cm2)
  - Irradiation done at CERN (24 GeV protons)
- IBL-sensors were irradiated ‘a la-AFP’ and their performance evaluated with beam
- Work done with the ATLAS IBL, 3D and AFP groups

Preliminary results for CNM(57) device:

- Operated at 130V
- Beam pointing to “irradiated side”
- Cooled with dry-ice (-30C)

Preliminary efficiency: 98.3%
Conclusions

- At Barcelona we have the full chain for sensor production, assembly and testing available.
- The CNM sensors for the Atlas-IBL perform as specified after being irradiated.
- The first tests of the proposed cleavage procedure have been shown.
- For AFP, even a small yield can guarantee the procurement of the needed sensors for the first installation.
- A production of special sensors for AFP can be started at CNM once the IBL production is finished.
- If technological issues are solved we might have them ready for the first installation opportunity of AFP.

Future Work

- Test beam data under analysis.
- Some detectors have been sent for irradiation.
- Flip chip to FE-I4 electronics (when FE available to CNM-IFAE).
- Next test beam in October 2012 at CERN.
Back up slides
Previous work at CNM with high-k dielectrics

Irradiations were performed at Takasaki-JAERI in Japan
2 MeV electrons for three different fluences: $\phi = 1 \times 10^{14} \text{ e/cm}^2$, $1 \times 10^{15} \text{ e/cm}^2$ and $1 \times 10^{16} \text{ e/cm}^2$

The total ionizing doses were about 2.5 Mrad-Si, 25 Mrad-Si and 250 Mrad-Si
Irradiation was performed at room temperature and capacitors not biased.