Development of 3D Trenched-Electrode Pixel Sensors with Improved Timing performance

G. Forcolin on behalf of the TIMESPOT Collaboration
3D Sensors

- **Advantages:**
  - Low Depletion Voltage
  - Lateral Drift
    - Fast Response
    - Low Sensitivity to mag. fields
  - Short inter-electrode distance
    - Fast Response
    - Reduced trapping probability => more rad hard

- **Disadvantages**
  - Non-Uniform Electric Field
  - High Capacitance
  - Complicated + expensive manufacturing process
3D sensors at HL-LHC

• 3D Sensors already used in ATLAS IBL

• Requirements:
  - higher hit-rate
  - increased granularity
  - higher radiation tolerance
  - lighter detectors

• To meet Requirements:
  - Produce thinner sensors (~100μm)
  - Reduce electrode spacing (~30μm)
  - Narrower electrodes (5μm)
  - Small/Active edges (<100μm)
Timing in 3D Trench Sensors

- 3D trench sensors being investigated for timing applications
- Some sensors produced at CNM in 2013, sensors worked but with high leakage current

Advantages:
- High average field
- Uniform weighting field
- Initial pulse (largely) independent of position
- Very Radiation Hard

Drawbacks:
- Difficult fabrication process
- High electrode capacitance

A. Montalbano et. al.
NIMA 765 (2014), 23

5*10^{15} n_{eq}/cm^2 at 100 V

2*10^{16} n_{eq}/cm^2 at 100 V
3D Sensor production

- Electrodes produced using Deep Reactive Ion Etching (DRIE) by the Bosch process
- Alternating etch cycles ($\text{SF}_6$) and passivation cycles ($\text{C}_4\text{F}_8$)
- Can achieve high aspect ration (~30:1 or better) and good uniformity

G.-F. Dalla Betta et al., NIMA 824 (2016) 386 and 388
Use single sided process with support wafer

- Can reduce active thickness without compromising mechanical properties
- Active edges
- Post processing required to thin support layer and deposit metal
- Front side layout => processing can be complicated

3D Sensor production

- Handle wafer to be thinned down
- Metal to be deposited after thinning

P- high Ωcm wafer
p++ low Ωcm wafer
SiO₂
p-spray

Metal to be deposited after thinning
Handle wafer to be thinned down
3D Sensor production

• Production steps (FBK process):
  - Etch ohmic electrodes > active thickness
  - Fill with Poly-Si (at least partially)
  - Etch junction electrodes < active thickness
Trenched Sensors

- Investigating TIMEPIX compatible trench sensors
- Trenches are dead area, so minimize thickness (~4μm)
- Design optimized with TCAD simulations
- First batch of sensors produced (9 wafers)
- First characterisation measurements and test beam measurements have taken place
Trenched Sensors Fabrication

- Fabrication process is very challenging and densely packed wafers fragile → reduce number of devices per wafer for now

- Use stepper for photolithography
  - Minimum feature size 350nm
  - Alignment accuracy 80nm
  - Projection => low defect level
  - Max exposure area ~2x2cm²
Trenched Sensors

- Batch 1 containing TIMEPIX compatible device
- Test devices including strip and pixel devices and technological test devices
- Temp metal layer included for wafer tests
Trenched Sensors Fabrication

- First devices production looks good
- Problems observed when metallization crosses trenches → change for next batch
3 different geometries investigated, with range of different trench dimensions

Wafer measurements using Temp Metal carried out on pixel devices (18x18 for test devices, 16x256 for TIMEPIX device)

Experimental measurements can be compared to simulations
Trenched Sensors

- Measurements carried out on wafer:
  - Observe low yield of devices
  - Measure ~10 pA/pixel on working devices

TIMEPIX devices

Test Pixel Devices
Trenched Sensors

- Measured IV of smaller devices
- Good devices mostly breakdown between 150V and 200V
Capacitance Measurements

- Measure n-p electrode capacitance of strip devices
- Isolate and remove contribution of metal pads using connected strips
Capacitance Simulations

- Strong dependence of trench dimension on inter-pixel capacitance
- Small change in capacitance between opposite electrodes due to trench dimensions
• Simulated Capacitance ~80-85fF/pixel; measured Capacitance ~70-75fF/pixel, Difference in observed capacitance from simulation likely explained by differences between simulated device and real device

• Measured n-p capacitance independent of pixel geometry or trench dimensions, in agreement with simulation

• Expect interpixel capacitance to have strong dependence on trench dimensions, unable to measure yet due to small size of contacts and small values of individual pixels
Test beam measurements (PSI)

- A campaign of test beam measurements has been carried out at PSI
- Looked at both pixel strip and single pixel readout structures and measured timing performance
- First results will be presented by A. Lai on Wednesday (Contribution #247)
- New batch of devices being designed to better test the timing properties, as well incorporating lessons learnt from first batch
Design for Batch 2

- Design beginning for second batch of devices (to be finalised in January)
- Make smaller pixel devices to make them safer while process is improved, (active area ~1.5x3mm²)
- Remove/modify devices that did not work
- Add new devices that allow us to better test some aspects of the technology
Conclusions and Outlook

- 3D trench devices being investigated to provide good position+timing resolution
- Fabrication of first batch has been completed
- First measurements of devices look promising, with capacitance ~70-75 fF/pixel and leakage ~10 pA/pixel
- First test beam measurements have been carried out (see Contribution #247)
- Production yield quite low → work needed on fabrication process
- Two wafers sent for bump bonding
- Design of second batch in progress