Processing of AC-coupled n-in-p pixel detectors on MCz silicon using atomic layer deposited aluminium oxide

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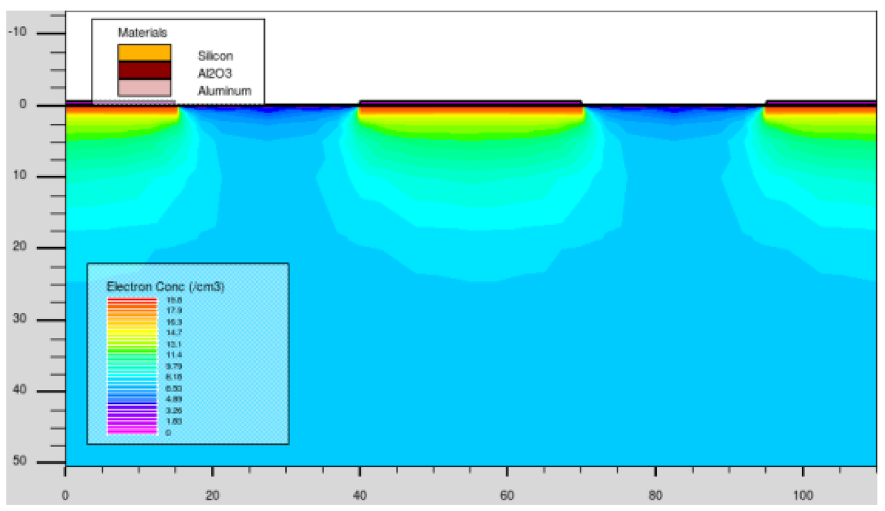
Introduction

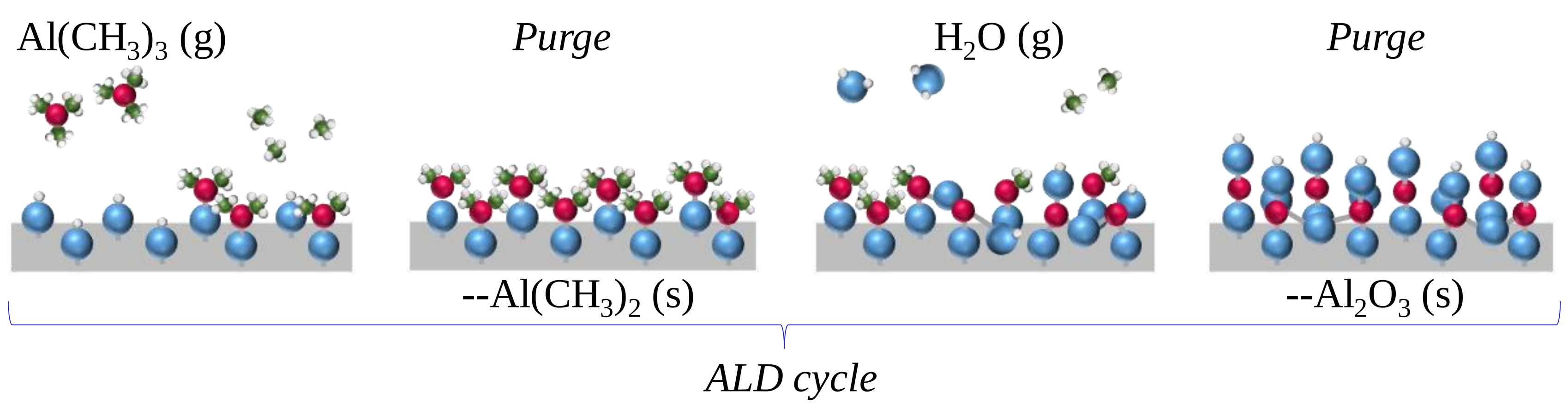
- Magnetic Czochralski (MCz) silicon has been proposed as substrate material for silicon detectors in very high-radiation environments [1]
- AC-coupling of pixels with titanium nitride (TiN) would provide a superior signal-to-noise ratio even in irradiated sensors, as the signal is separated from the leakage current DC component [2]
- Aluminum oxide (Al_2O_3) has been demonstrated in strip detectors as an alternative to p-spray/p-stop insulation between detector segments, due to its high negative oxide charge [3,4]



2D simulation of Al_2O_3 insulation between pixels.

Atomic Layer Deposition of Alumina

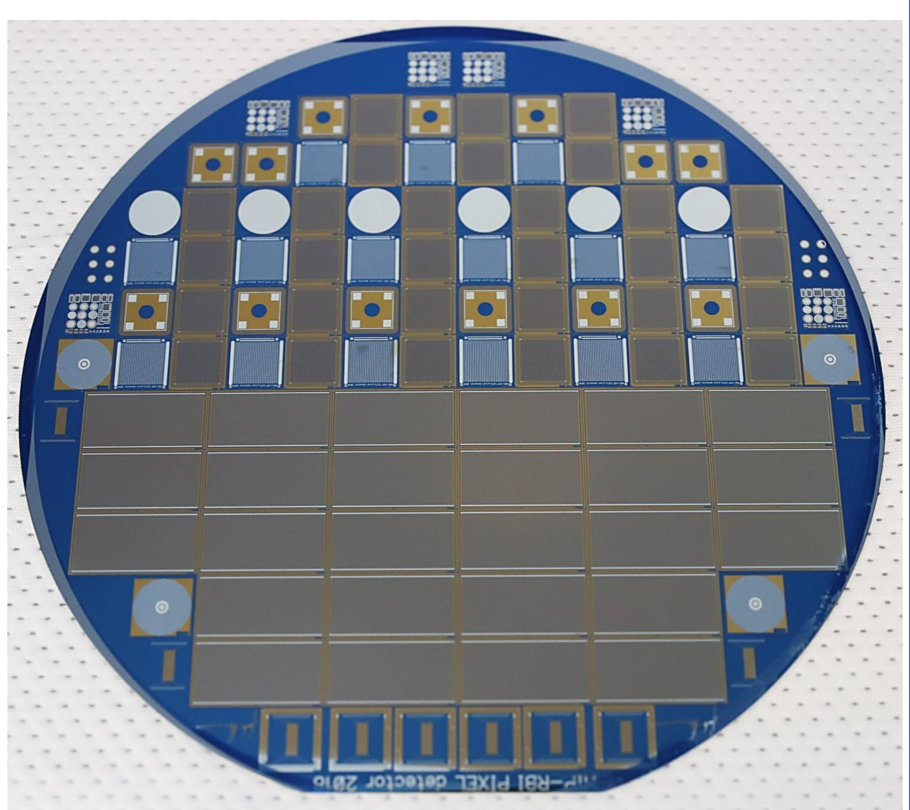
- Atomic layer deposition (ALD) allows precise, layer-by-layer growth of thin films with excellent conformality over large surface areas [5,6]
- Deposition of Al_2O_3 from trimethylaluminium (TMA) and water is one of the most studied ALD processes [6], but requires optimization for detector applications



Process flow

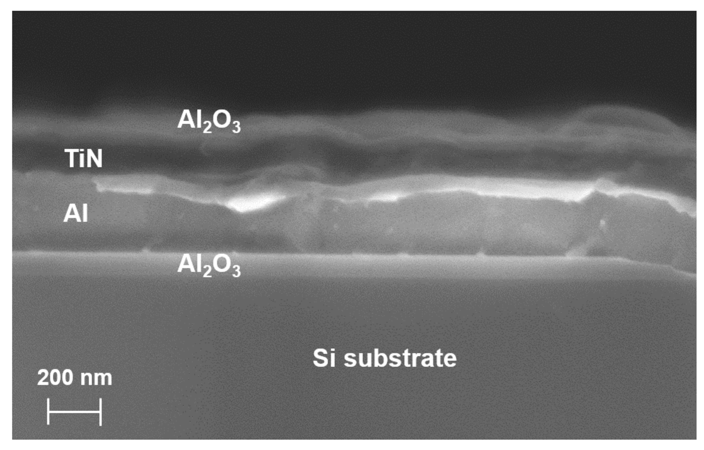
- Starting material: p-type MCz silicon, 6”, 320 µm, 4-8 kΩcm
- Only one lithography step and drive-in anneal is needed for ion implantation; no additional p-spray/p-stop
- ALD-Al_2O_3:
  - Grown at 200 C from TMA and water, with additional ozone pulse to increase negative charge and avoid unwanted interface effects
  - Wet-etched with standard Al etchant
  - Stabilized by subsequent anneal at 370 C

- p-type MCz-Si, >4 kΩcm
- Thermal oxidation
- Alignment marks
- Implantation: front side n⁺, back side p⁺
- Drive-in
- SiO_2 removal
- **ALD Al_2O_3 field insulation**
- **TiN bias resistors**
- Al metallization
- **ALD Al_2O_3 surface passivation**
- Under-bump metallization



Electrical characterization

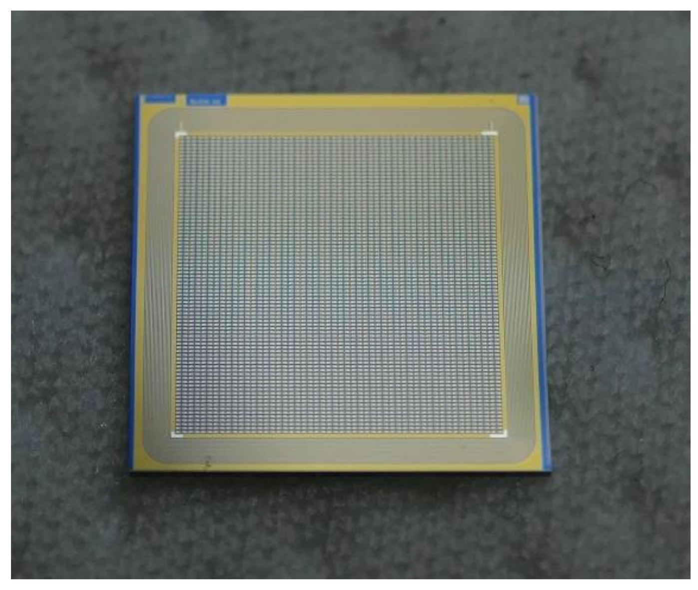
- Leakage current and signal profile studied with single pad detectors
  - I_{leak} < 10 nA/cm²
- Oxide charge and capacitance based on MOS capacitors
  - Q_{eff} around -3e12 q/cm²
  - Oxide capacitance 72 nF/cm²
- Reference structures for pixel resistors
  - ~15 kΩ per pixel

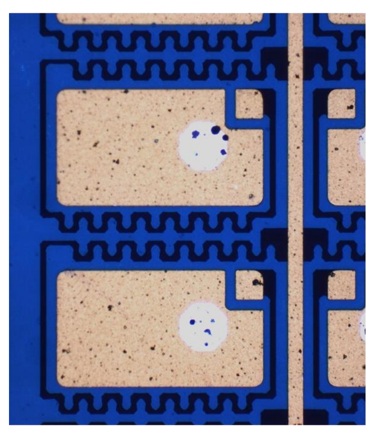


SEM cross-section of a pad detector, showing conformal Al_2O_3 layers.

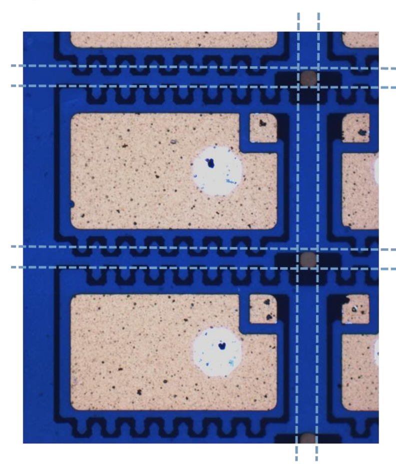
AC-coupled pixel detectors

- 4160 pixels in double columns, matching the geometry of the CMS PSI46dig readout chip
- Two different schemes for connection of pixels to bias ring





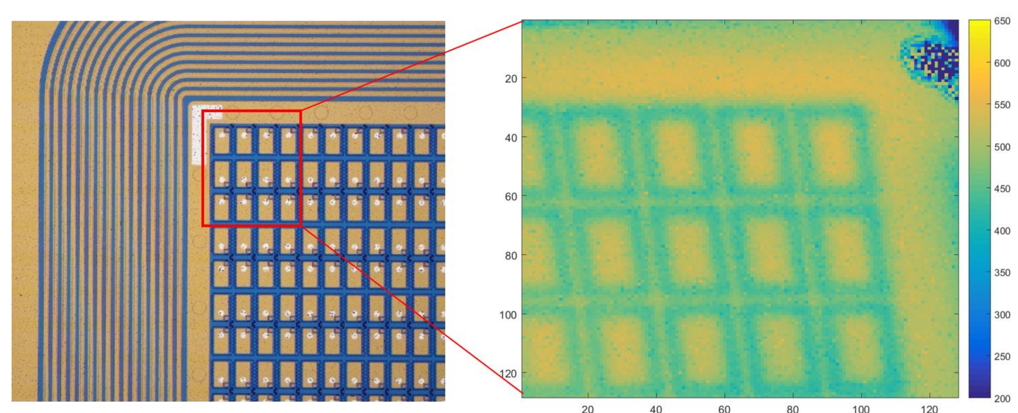
Connection by aluminum metal



Connection by n+ implant

Performance estimation

- Translating measurements into properties of an individual pixel:
  - Cutoff frequency over the coupling capacitor dielectric: ~1 MHz
  - $C_{pixel} << C_{coupling}$, factor ~2000
- First tests with ion beam induced current using a 2 MeV proton microprobe indicate uniform charge collection



Microscope image of an AC-coupled pixel detector (left), with a section of it scanned by proton microprobe (right).

Conclusions

- An ALD process for alumina was optimized for detector processing on high-resistivity, 6” MCz-Si with emphasis on negative charge and good surface properties
- AC-coupled pixel detectors were realized by combining ALD-grown Al_2O_3 as coupling dielectric with TiN biasing resistors
- Electrical characterization through reference structures is promising; for test-beam campaigns sensors need to be flip-chip bonded to readout chip

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