HELSINKI INSTITUTE OF PHYSICS

Aalto University School of Electrical Engineering

Institut Ruđer Bošković

LUT University

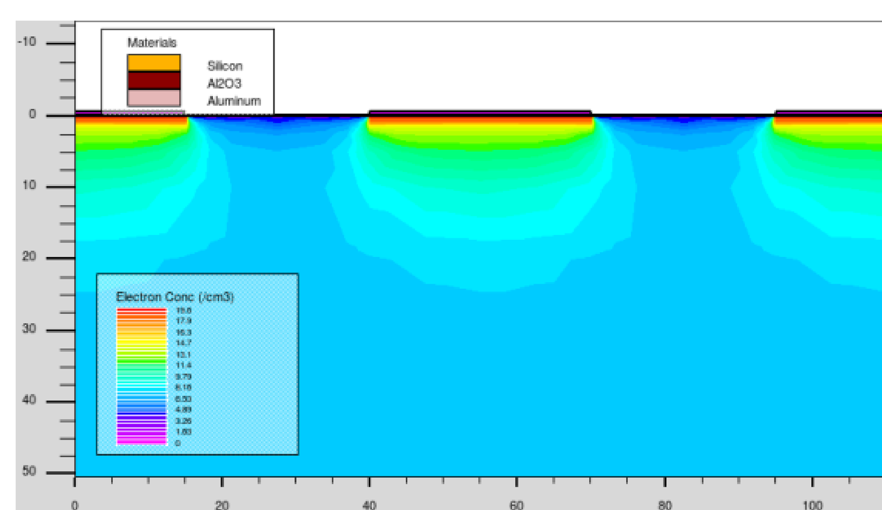
Processing of AC-coupled n-in-p pixel detectors on MCz silicon using atomic layer deposited aluminium oxide

Jennifer Ott[1,2,*], **A. Gädda**[1,3], **M. Golovleva**[4], **T. Naaranoja**[1], **L. Martikainen**[1], **S. Bharthuar**[1], **S. Kirschenmann**[1], **E. Brücken**[1], **V. Litichevskyi**[1], **A. Karadzhinova-Ferrer**[5], **M. Kalliokoski**[5], **P. Luukka**[1], **J. Härkönen**[5]

[1]Helsinki Institute of Physics, Gustaf Hällströmin katu 2, FI-00014 University of Helsinki, Finland
[2]Aalto University, Department of Electronics and Nanoengineering, Tietotie 3, FI-02150 Espoo, Finland
[3]Advacam Oy, Tietotie 3 (P.O. Box 1000), FI-02044 VTT, Finland
[4]Lappeenranta University of Technology, Skinnarilankatu 34, FI-53850 Lappeenranta, Finland
[5]Ruđer Bošković Institute, Bijenička cesta 54, HR-10000 Zagreb, Croatia

Introduction

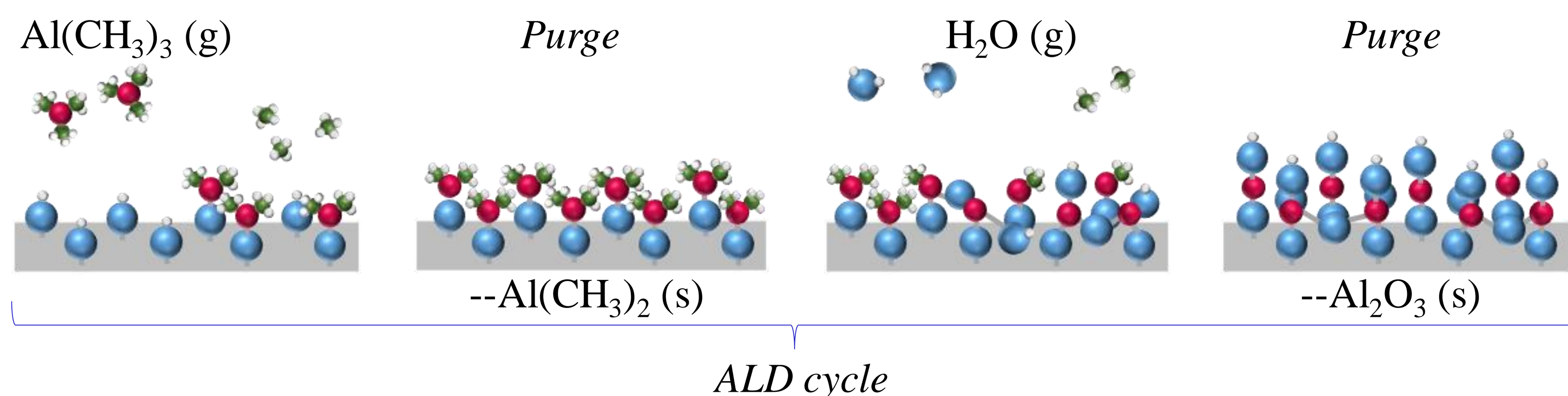
- Magnetic Czochralski (MCz) silicon has been proposed as substrate material for silicon detectors in very high-radiation environments [1]
- AC-coupling of pixels would potentially provide a better signal-to-noise ratio even in irradiated sensors, as the signal is separated from the leakage current DC 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

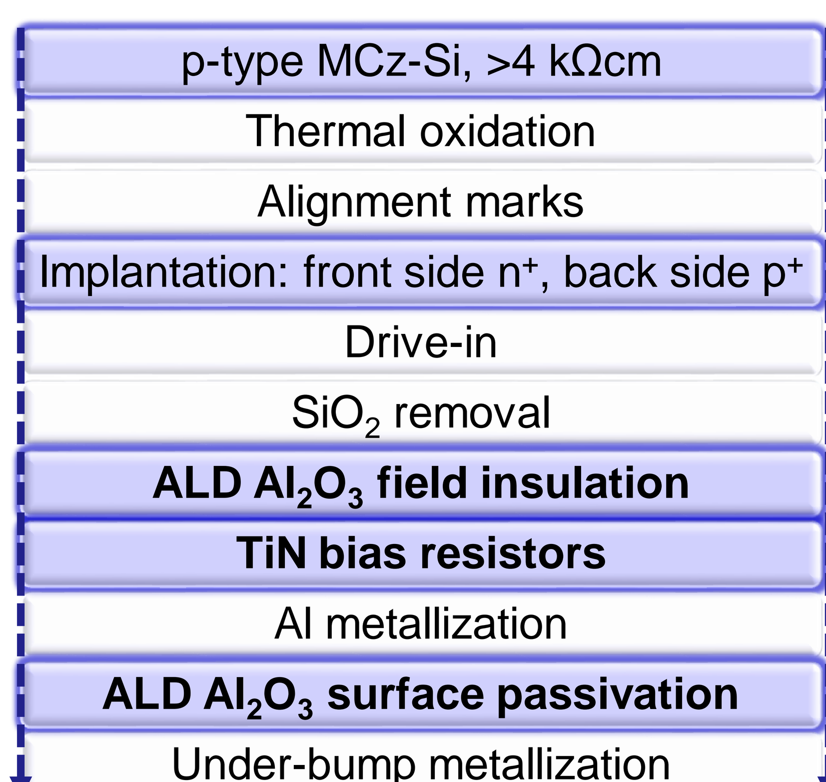
- Atomic layer deposition (ALD) allows precise, layer-by-layer growth of thin films with excellent conformality over large surface areas [5,6]
- Deposition of Al_2O_3 from trimethylaluminium (TMA) and water is one of the most studied ALD processes [6], but requires optimization for detector applications

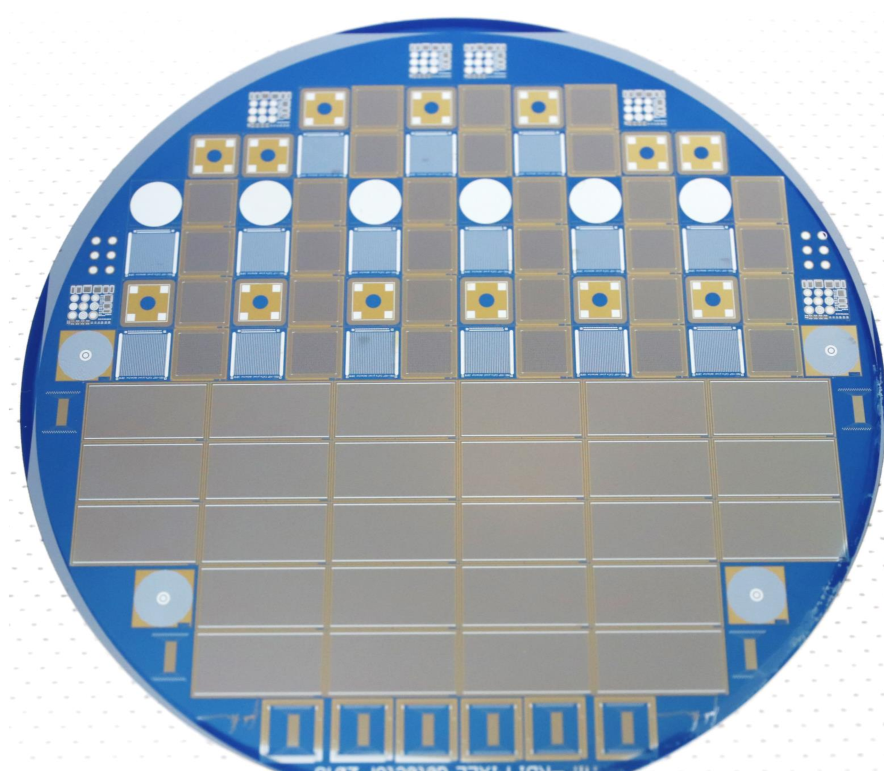


ALD cycle

Process flow

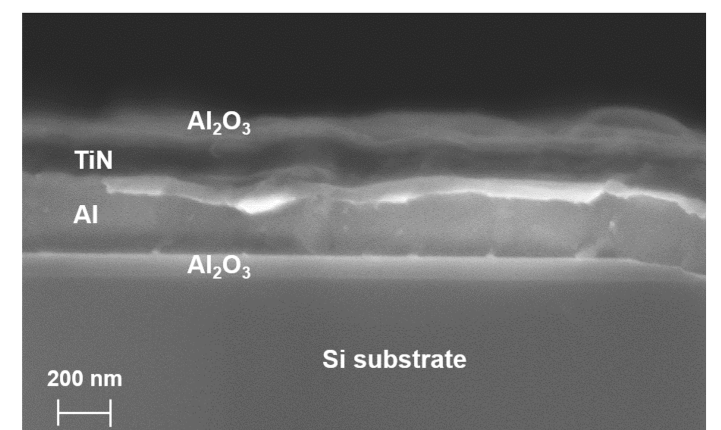
- Starting material: p-type MCz silicon, 6", 320 μm, 4-8 kΩcm
- Only one lithography step and drive-in anneal is needed for ion implantation; no additional p-spray/p-stop
- ALD-Al_2O_3:
  - Grown at 200 C from TMA and water, with additional ozone pulse to increase negative charge and avoid unwanted interface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





Electrical characterization

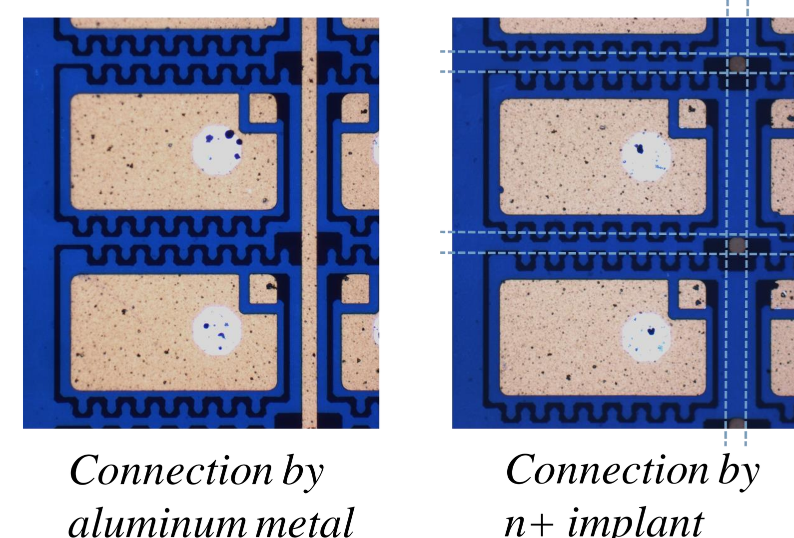
- Leakage current and signal profile studied with single pad detectors
  - I_{leak} < 10 nA/cm^2
- Oxide charge and capacitance based on MOS capacitors
  - Q_{eff} around -3e12 q/cm^2
  - Oxide capacitance 72 nF/cm^2
- Reference structures for pixel resistors
  - ~15 kΩ per pixel



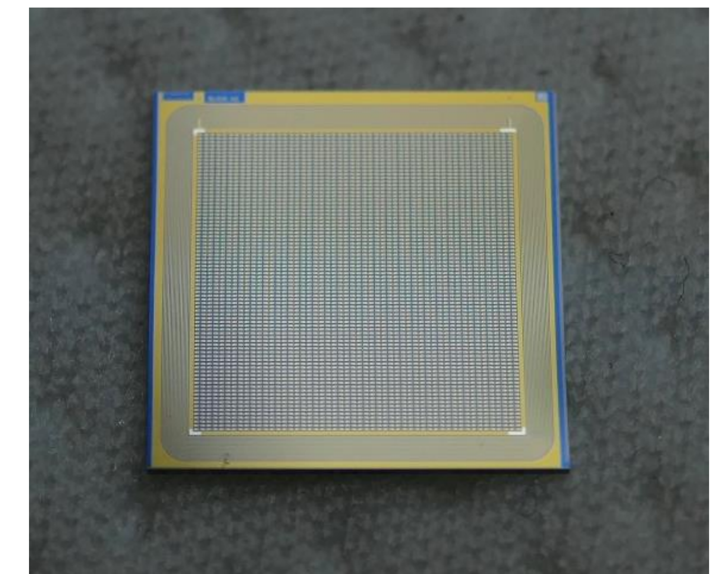
SEM cross-section of a pad detector, showing very uniform Al_2O_3 layers.

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

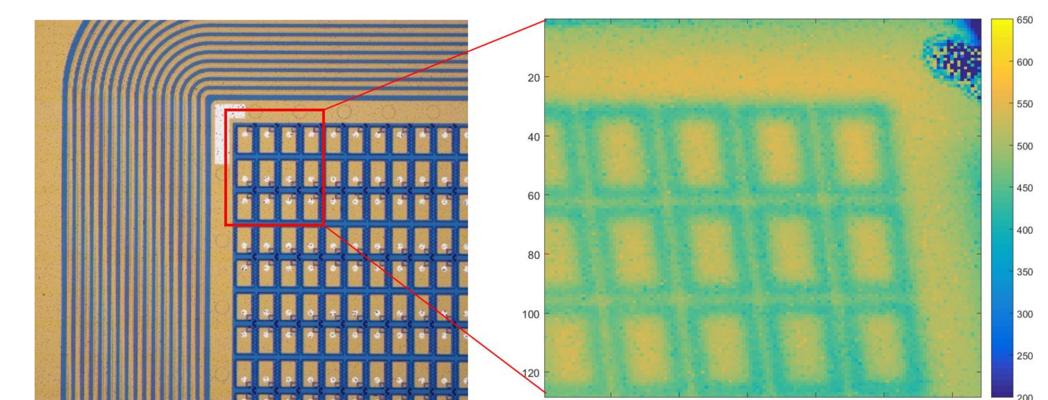


Connection by aluminum metal — *Connection by n+ implant*



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 indicated 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

[1] L. Spiegel *et al Nucl. Instrum. Methods Phys. Res. A* 628, 242-245 (2011)
[2] J. Härkönen, J. Ott, M. Mäkelä, T. Arsenovich, A. Gädda, T. Peltola, E. Tuovinen, P. Luukka, E. Tuominen, A. Junkes, J. Niinistö, M. Ritala, *Nucl. Instrum. Methods Phys. Res. A* 831, 2-6 (2016)
[3] M. Christophersen, B.F. Phlips, *2011 IEEE NSS Conference Record*, 113-117 (2011)
[4] J. Härkönen, E. Tuovinen, P. Luukka, A. Gädda, T. Mäenpää, E. Tuominen, T. Arsenovich, A. Junkes, X. Wu, Z. Li, *Nucl. Instrum. Methods Phys. Res. A* 828, 46-51 (2016)
[5] S.M. George, *Chem. Rev.* 110, 111-131 (2011)
[6] R.L. Puurunen, *J. Appl. Phys.* 97, 121301-1—52 (2005)

*jennifer.ott@helsinki.fi