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HELSINKI INSTITUTE OF PHYSICS

Characterization of ALD-grown aluminum oxide field insulators for silicon detectors

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Target

Fabricate MCz-Si n-in-p pixel detectors without p-spray/p-stop implants using an oxide with negative charge as field insulator and dielectric

→ **replace SiO_2 with Al_2O_3**

Investigate effect of process parameters on the electrical properties of alumina

Compare results of corona charge characterization to conventional CV/IV

Outline

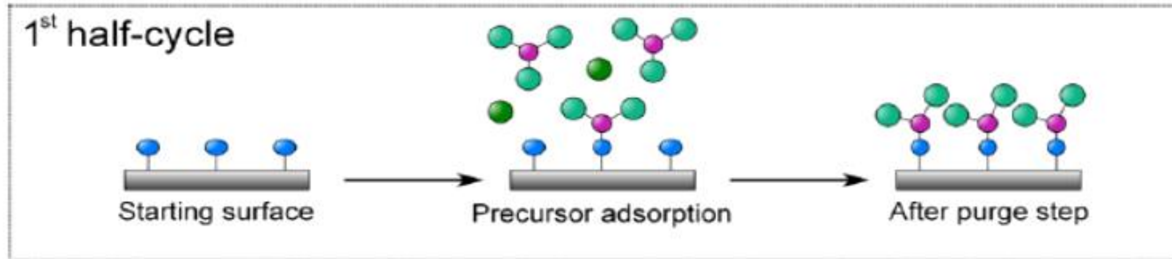
- **Introductions to...**
  - ALD
  - COCOS
- **Thin film characterization results**
- **Device processing**
- **Diode and MOS capacitor characterization**
- **Summary**

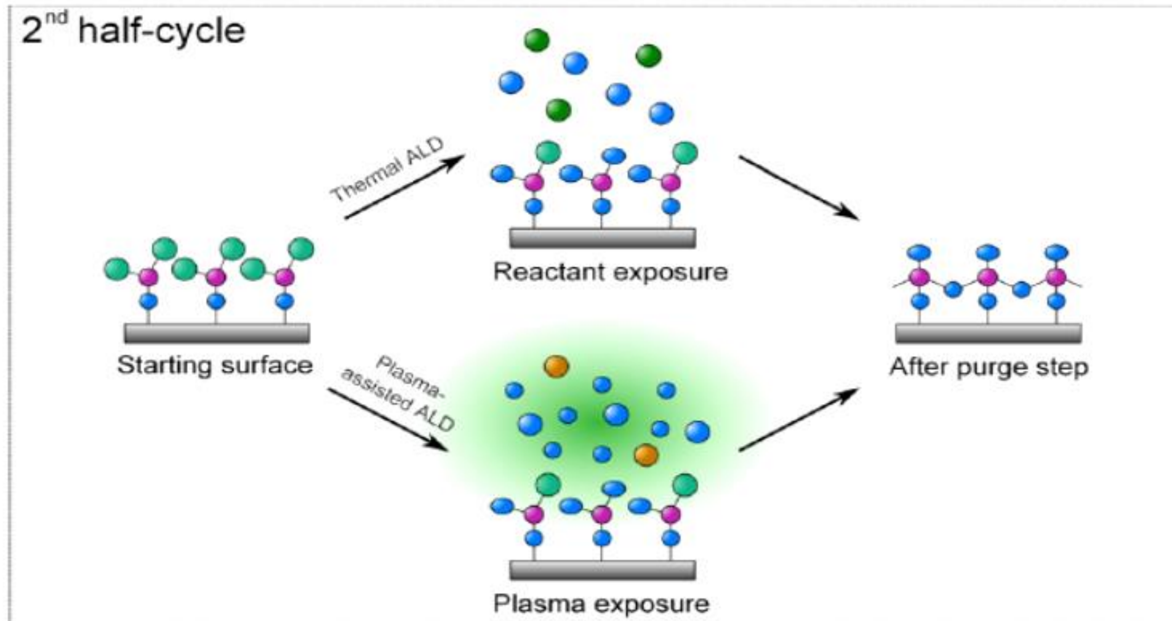
Atomic Layer Deposition

- A film is deposited by alternate pulsing of gaseous precursors over a substrate
- No gas-phase reactions, purges between the precursor pulses → self-limiting surface reactions

- High film uniformity over relatively large areas
- Film growth slow and occuring in cycles → very thin layers can be grown with good accuracy and repeatability

Atomic Layer Deposition





H. B. Profijt et al. J.Vac. Sci. Technol. A (2011)

ALD of Al_2O_3

- **Trimethylaluminium (TMA) + H_2O**

- **Two temperatures**
  - 200 C
  - 300 C

  - For processing: 50 nm at 200 C, 70 nm at 300 C

Corona oxide characterization of semiconductors (COCOS)

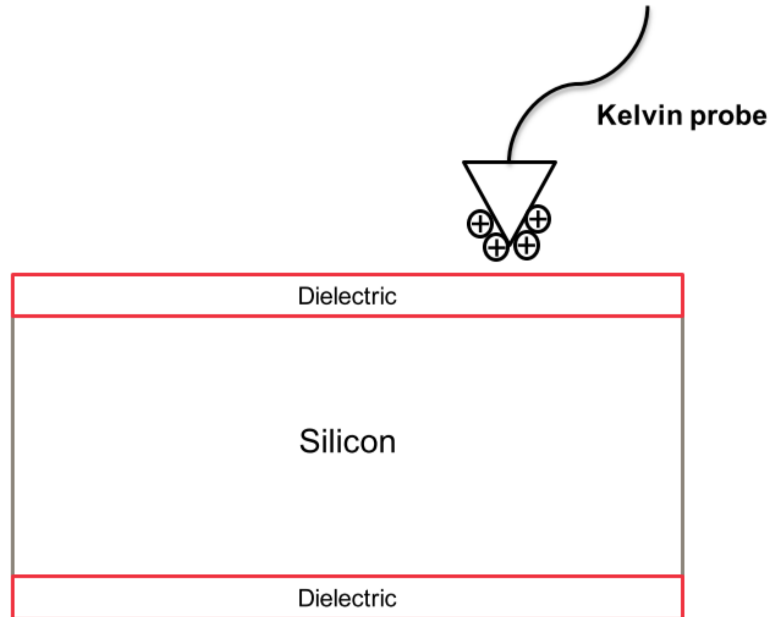
- Corona charge is applied onto the oxide surface and the potential difference is measured - in the dark and under illumination

- Enables determination of dielectric properties from unprocessed thin films

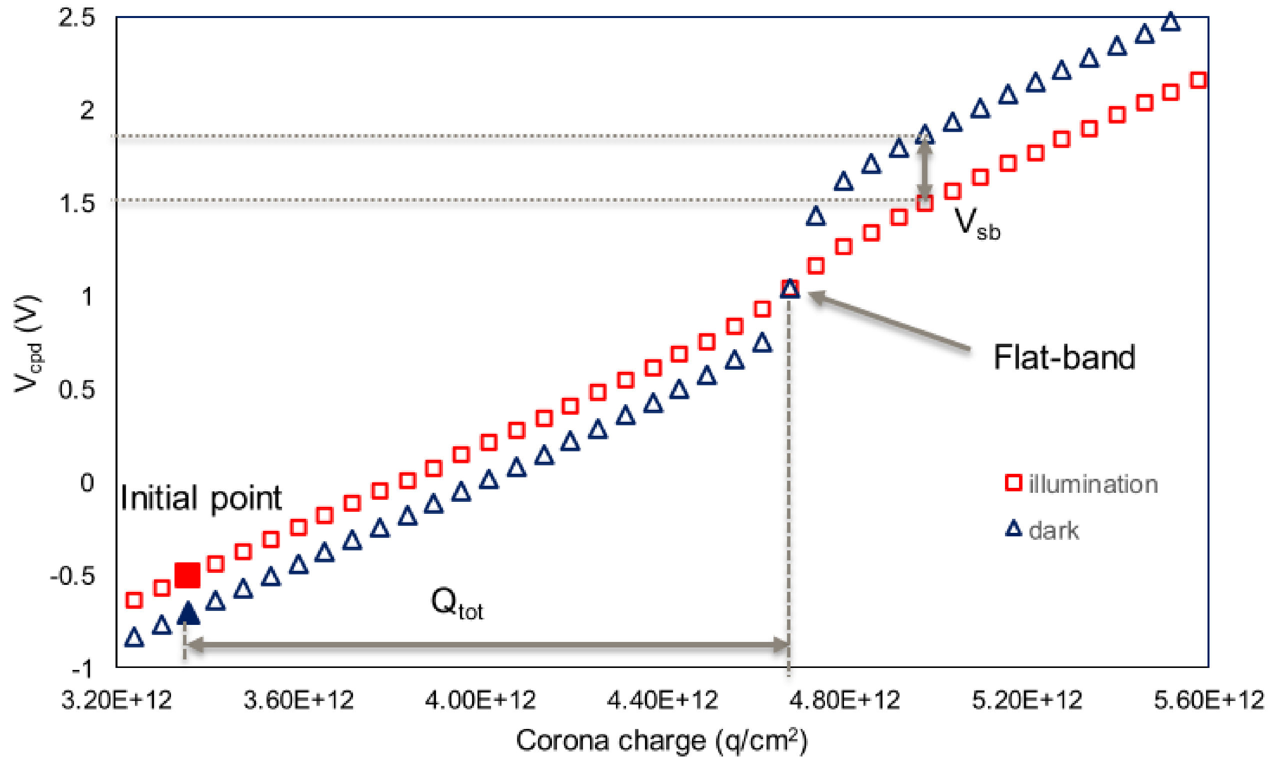
M. Wilson et al. AIP Conf. Proceedings (2001)

Corona oxide characterization of semiconductors (COCOS)

- Main parameters to be extracted: K_{ox},V_{fb}, total oxide charge Q_{tot}, interface defect density D_{it}
- For p-type substrate: sweep from accumulation to depletion and inversion



Corona oxide characterization of semiconductors (COCOS)

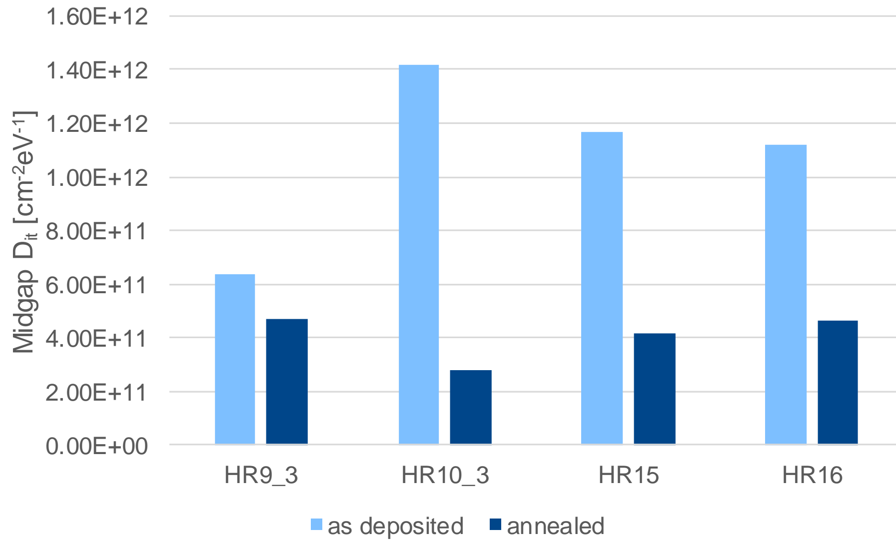


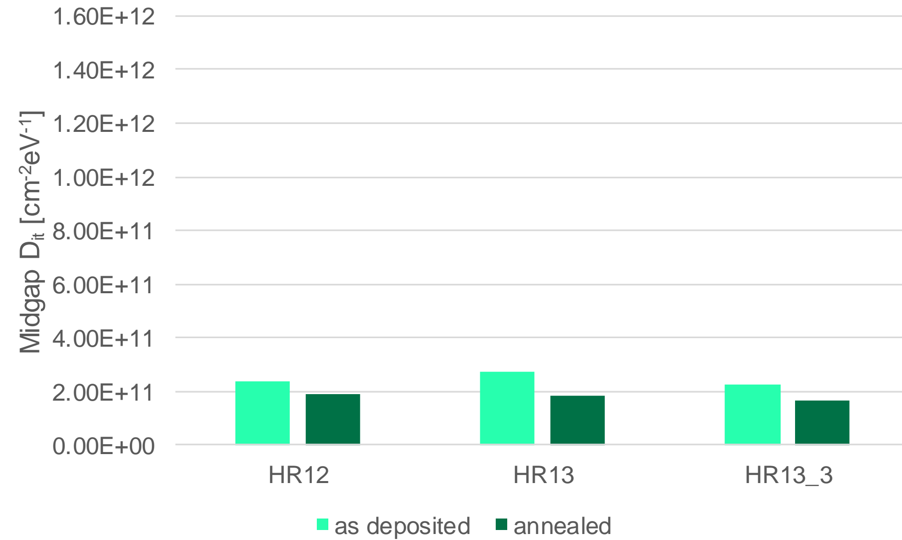
Characterization and results

- **Thin films:**
  - **Pre- vs post-anneal**
  - **200 C vs 300 C**
  - D_{it}, Q_{tot}, V_{fb}
  - (Effective charge carrier lifetimes)

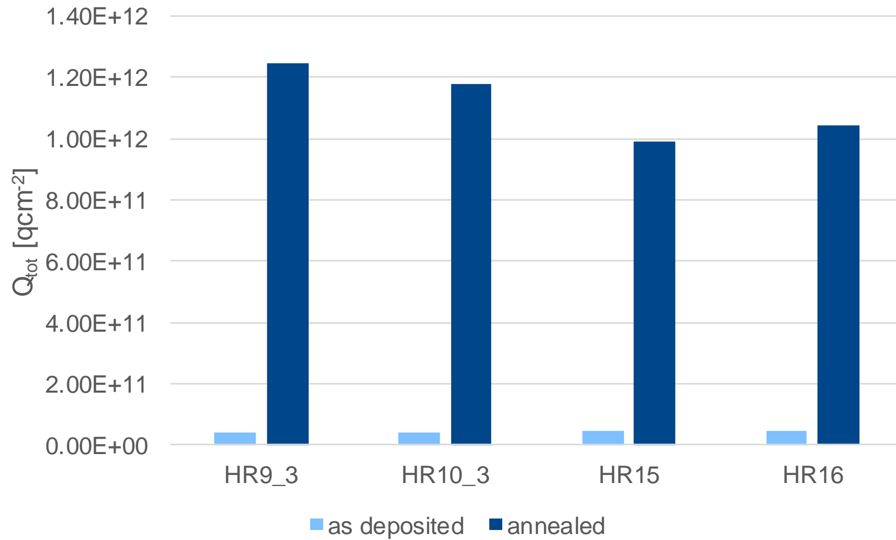
- **Processed structures:**
  - **Diodes and MOS capacitors**
  - CV
  - IV

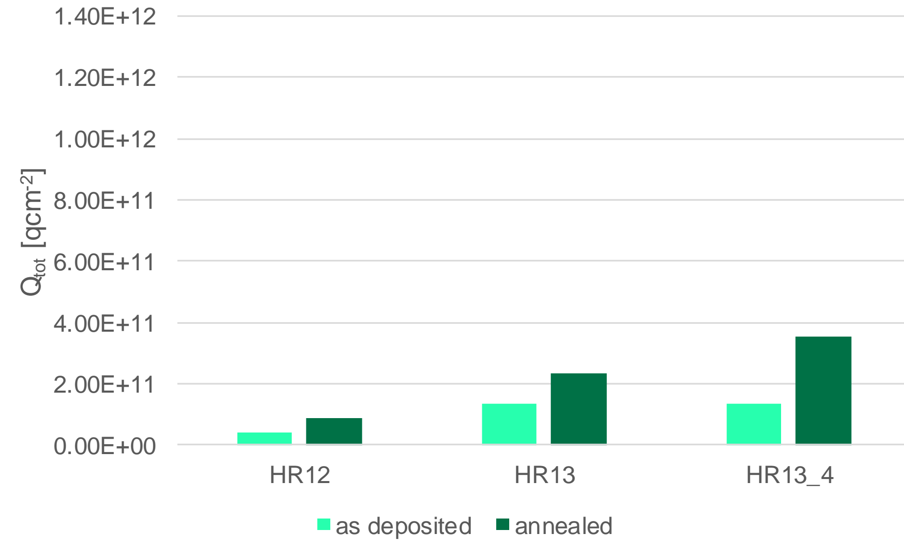
COCOS – D_{it}



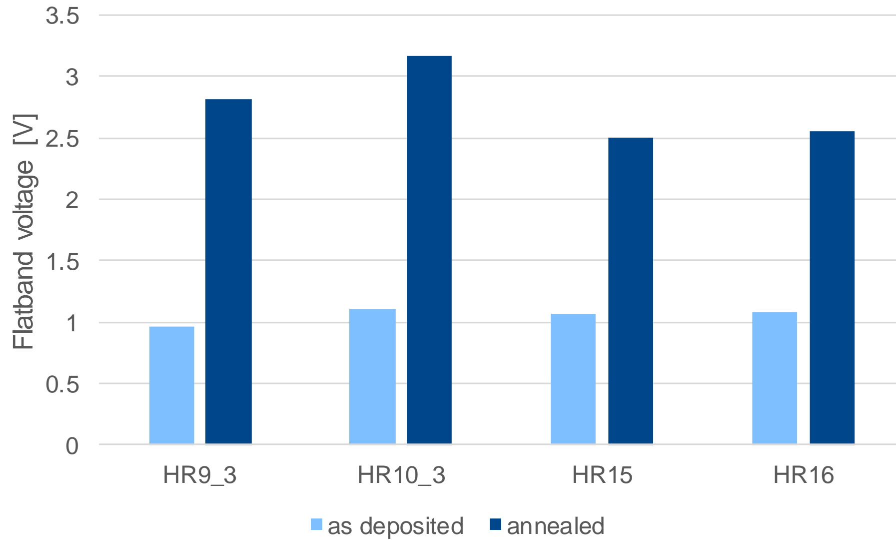


COCOS – Q_{tot}





COCOS – V_{fb}



Characterization and results

- Thin films:
  - **Pre- vs post-anneal**
  - Q_{tot}, D_{it}, V_{fb}
  - (Effective charge carrier lifetimes)

- **Processed structures:**
  - **Diodes and MOS capacitors**
  - CV
  - IV

Processing

High-res p-type 6” Si wafer

Implantation:
front side P, back side B

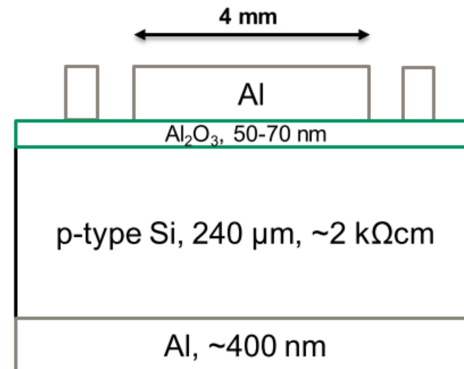
Activation

ALD Al_2O_3

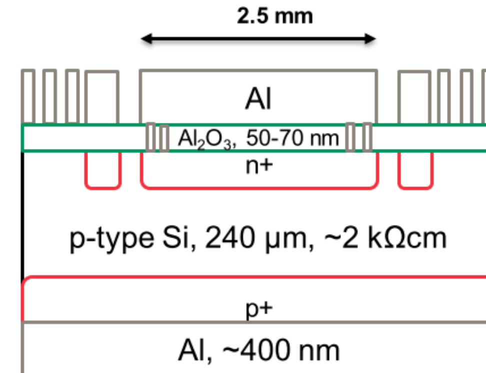
Al metallization

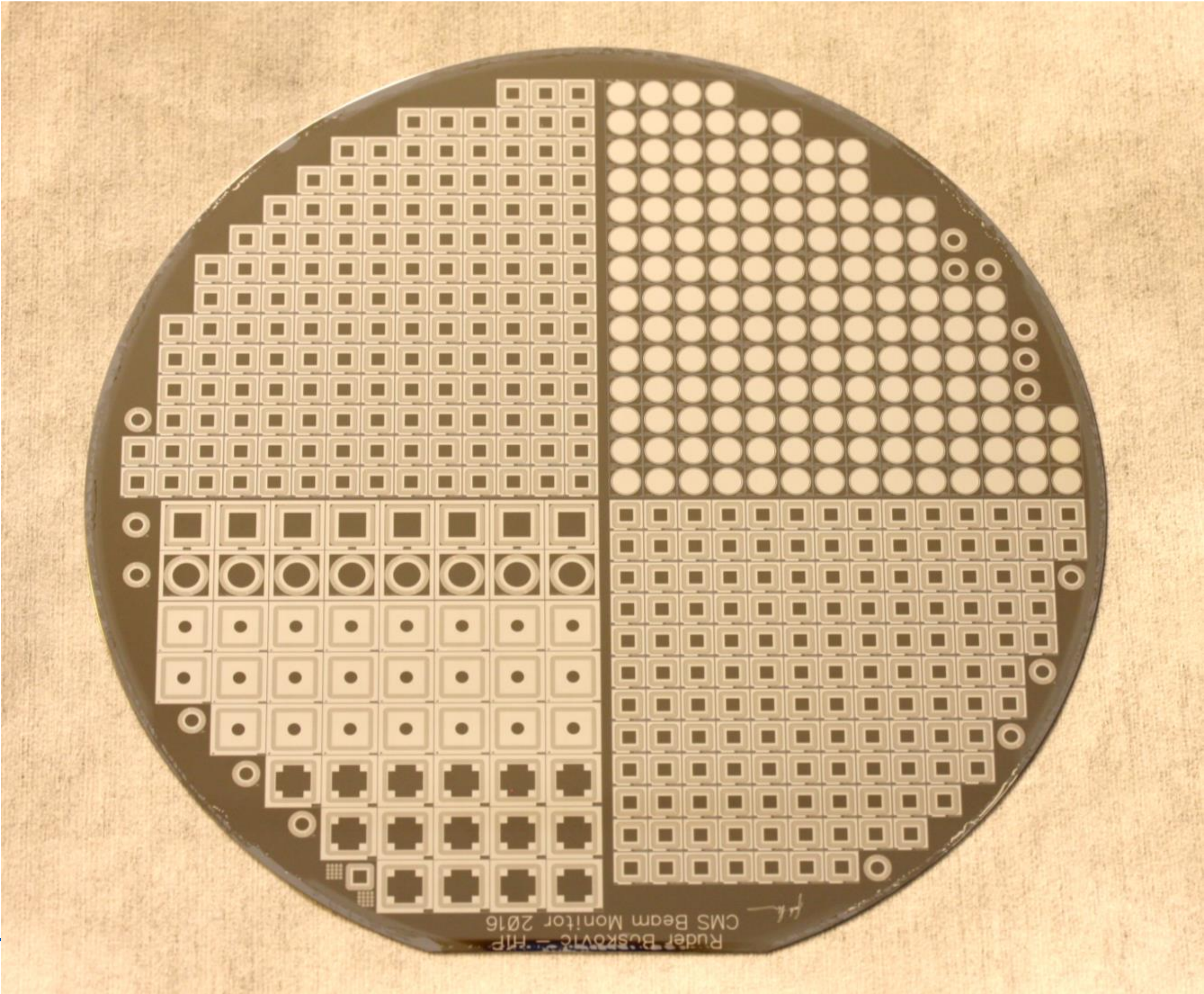
Sintering

MOS capacitor



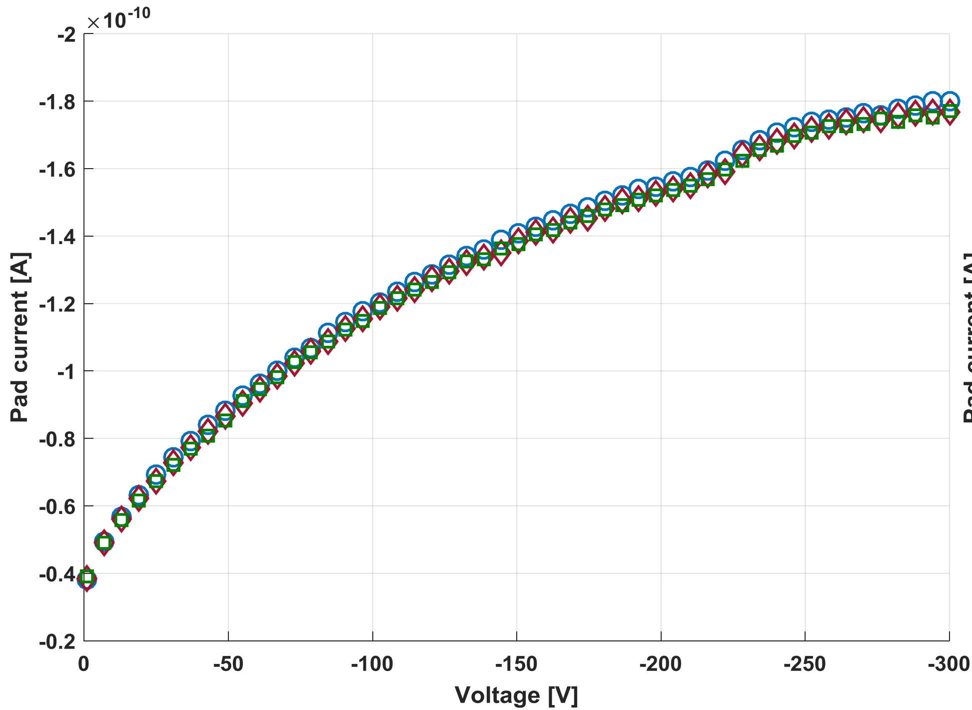
Square diode



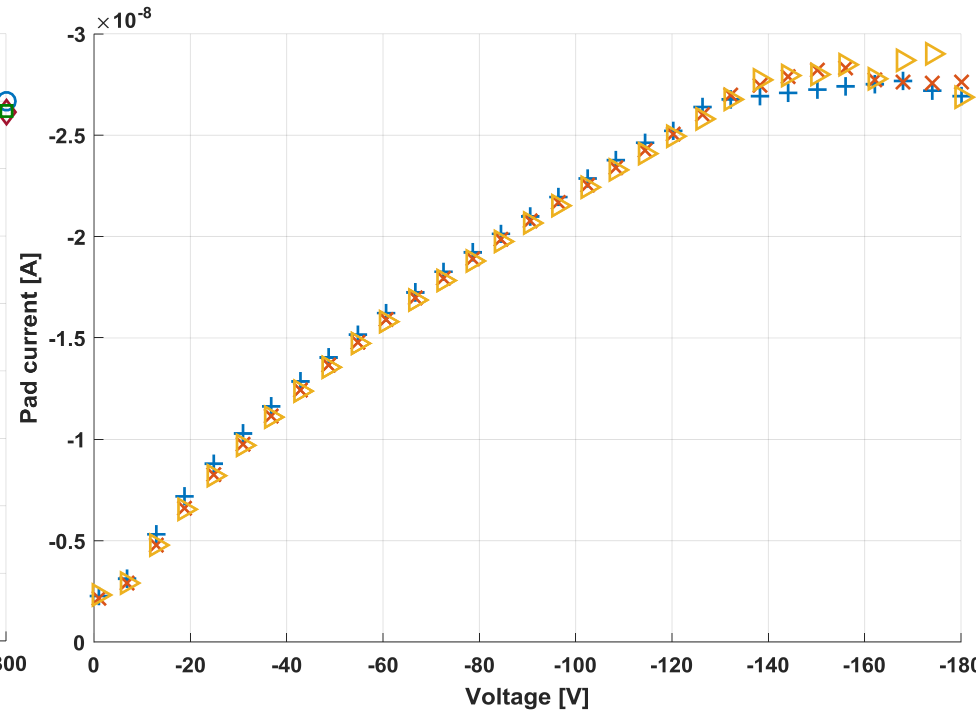

CMS Beam Monitor 2016

Diodes – IV pad current

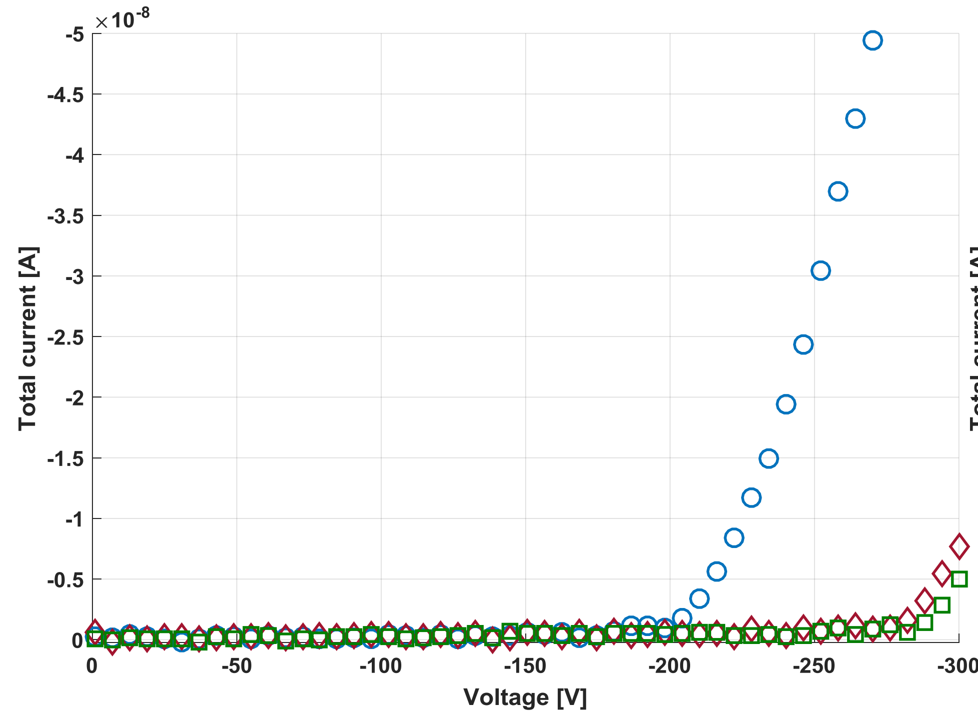
200 C

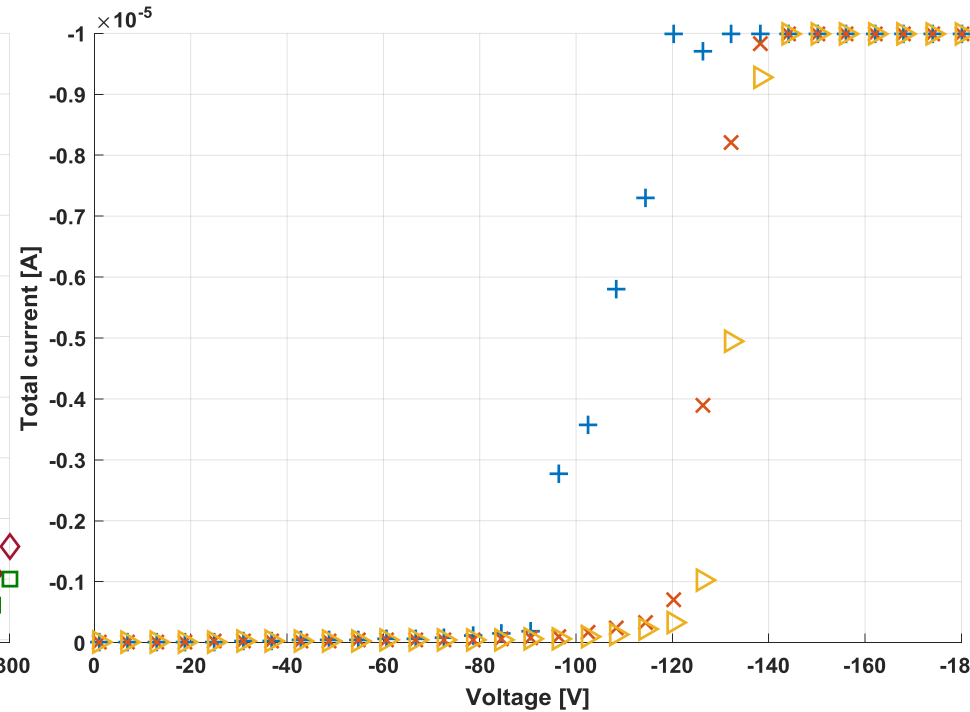


300 C



Diodes – IV total current





Diodes – IV

- **Measured up to -300 V at RT**

→ Very clear difference between film deposition temperatures: films deposited at 300 C are inferior to those deposited at 200 C

→"Creep" in total currents: breakdown shifts to higher voltages in consecutive measurements – potentially due to oxide trapped or interface charges that move at high bias?

MOS capacitors – CV

- **Frequencies 1 kHz, 100 kHz, 500 kHz, 1 MHz**

→ CV very stable over consecutive measurements

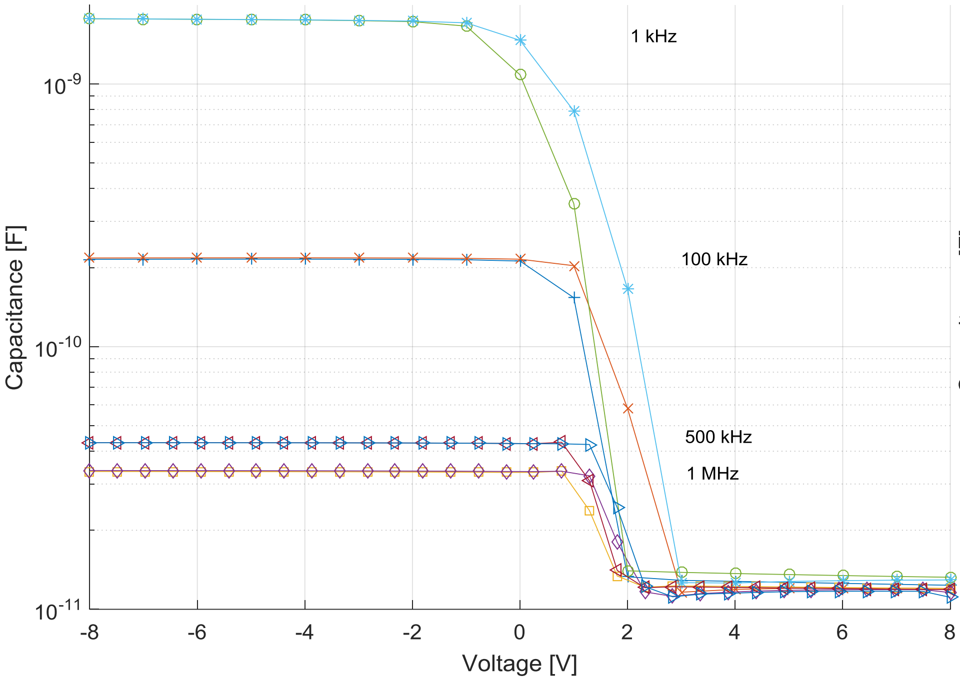
→ Again clear difference for films grown at 200 C and 300 C

→ Hysteresis visible for both film types – another sign of trapped charges?

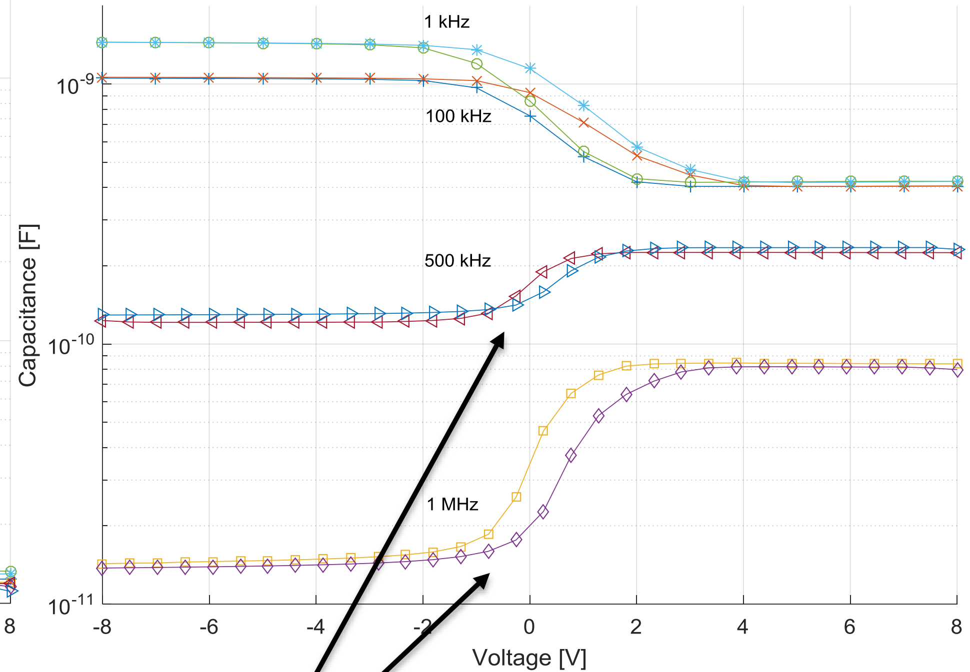
→ CV behavior frequency-dependent – again differences for different temperatures

MOS capacitors – CV frequency scan

200 C



300 C



Inversion layer forming?

Contact CV vs COCOS

- **D_{it}:** conventional CV curve contradictory to COCOS? Stretched-out curve interpreted as presence of interface traps/charge, but COCOS indicates lower D_{it} for 300 C films...

- **Q_{tot}:** appears to correlate with performance in devices in the expected way – film with higher negative charge works better
- **V_{fb}:** cannot be compared directly due to the introduction of the metal contact in processing

Summary

- **Electrical properties of Al_2O_3 thin films were characterized**
  - from pure thin films using the COCOS technique
  - from diode and MOS capacitor structures using conventional CV/IV measurements
- **Al_2O_3 grown at 200 C works reasonably well in diodes**
- **Differences in properties of films grown at 200 C and 300 C**

- **COCOS V_{fb} and Q_{tot} appear to correlate with film performance in diodes – lifetime is not a sufficient indicator**
- **Interesting effects in MOS capacitor CV – need to be understood better**

Plans for the near future

- **Investigate the use of ozone or O plasma in ALD of alumina, try Ti doping of oxide**

- **Reproduce results for different substrates**

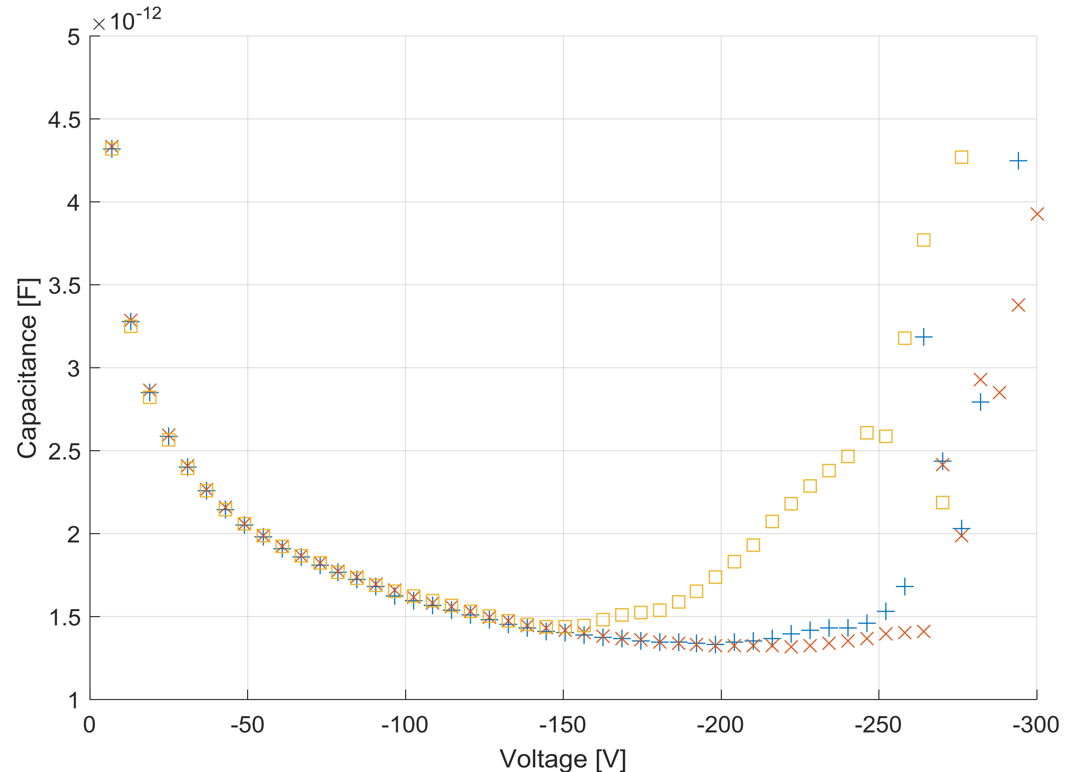
- **Irradiation studies:**
  - High gamma and X-ray doses
  - TCT and DLTS pre- and post-irradiation

Thank you for your attention!

Backup

Diodes – CV

- **Depletion voltage around 200 V – rather high, is due to high resistivity p-type substrate**
- **”Creep” visible**

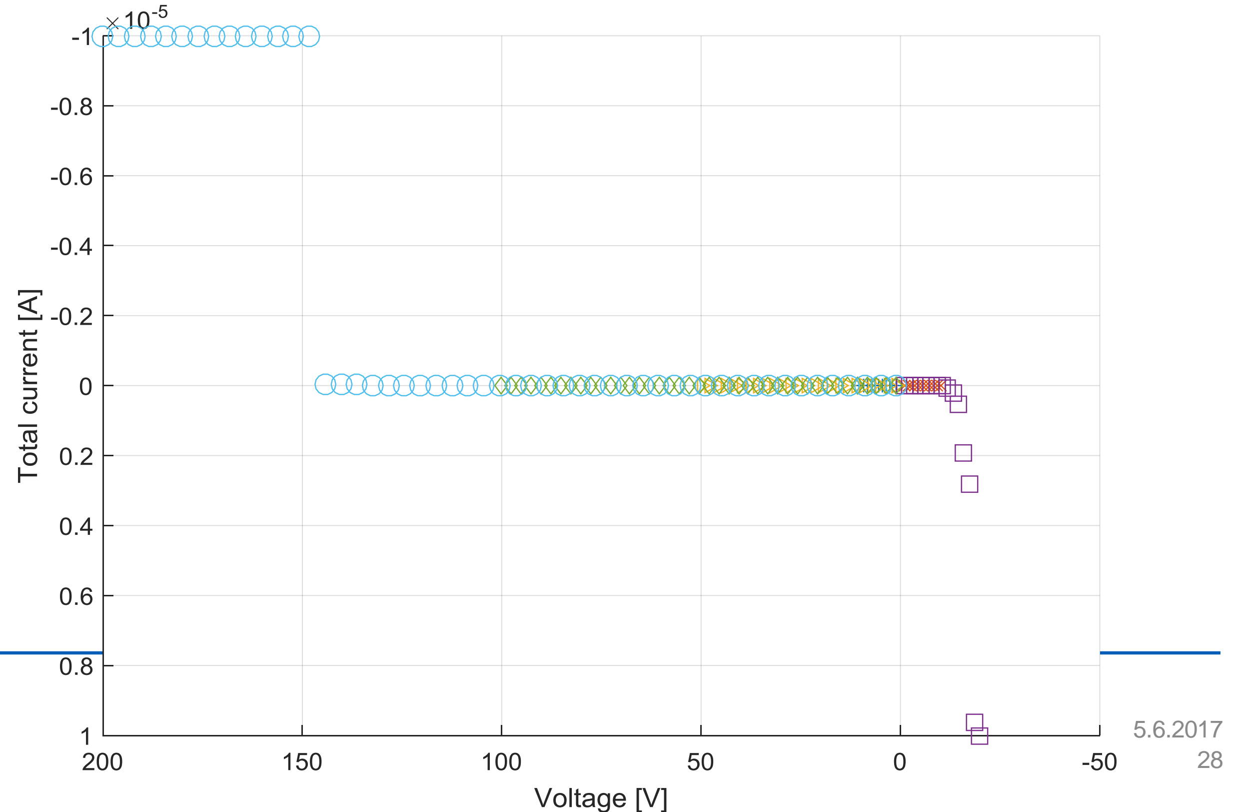


MOS capacitors - IV

- ... In order to see dielectric breakdown

→ IV is not identical in different polarities

  - ➢ due to destructive measurement?



Motivation

- **Vast amount of silicon detectors in high-energy physics experiments with high radiation doses**
- **n-type Si replaced with p-type, Fz with Cz silicon**
  - n-in-p detectors
  - Process temperatures < 400 C
  - Passivation and isolation of segments with SiO_2 not possible without extra implants

→ Solution – using an oxide with negative charge, e.g. Al_2O_3 ?