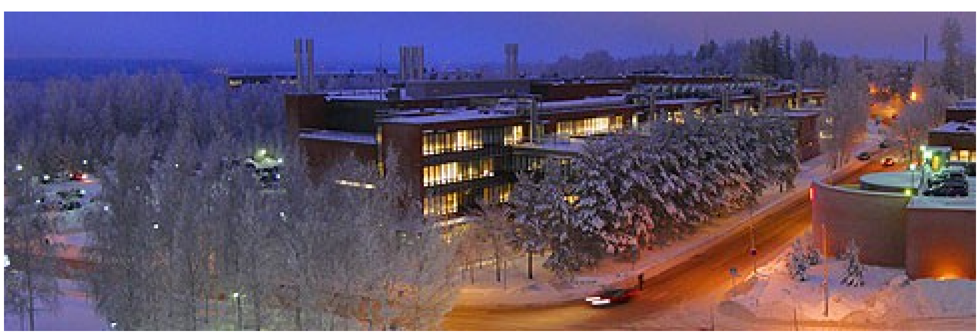
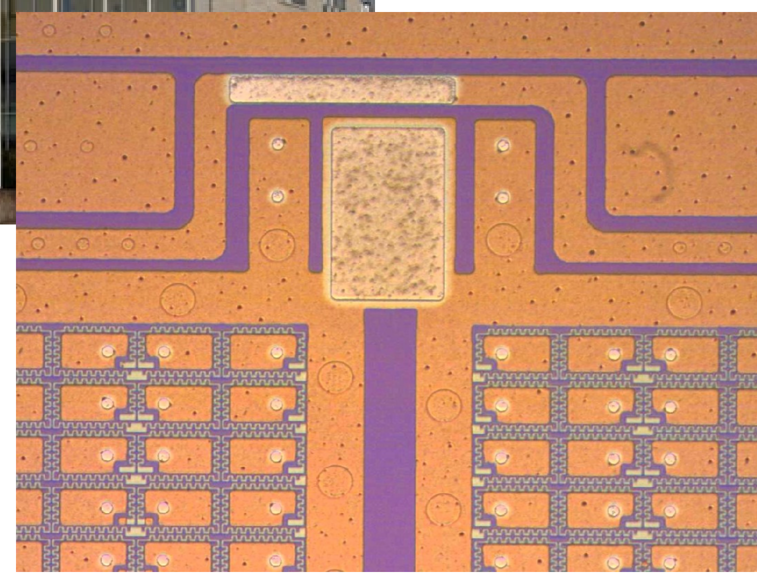
Development of AC-coupled planar silicon pixel detectors at HIP

Helsinki Institute of Physics – CMS Upgrade project

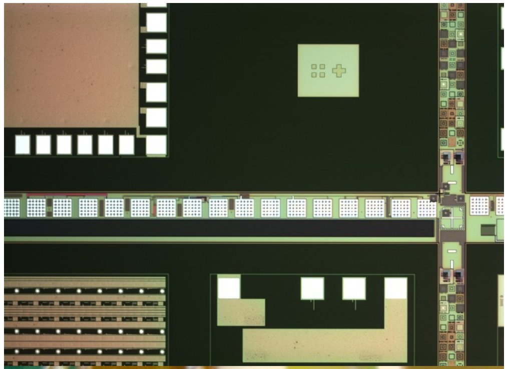


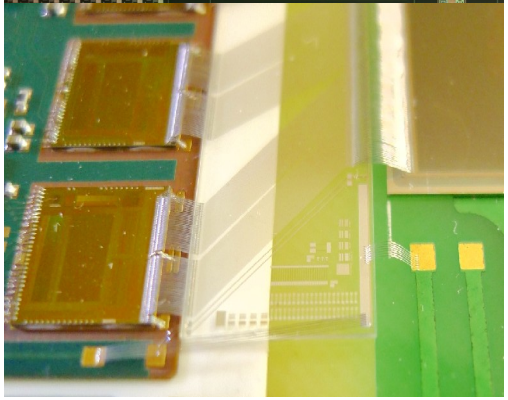


Panja Luukka, Helsinki Institute of Physics

Outline

- Who are we?
- Our activities – CMS experiment upgrade and detector R&D.
- Detector processing at Micronova
- Atomic Layer Deposition (ALD).
- Tungsten Nitride (Wnx) thin film metal bias resistor.
- Results of n+/p-/p+ strip sensors.
- Development of AC-coupled planar silicon pixel detectors.





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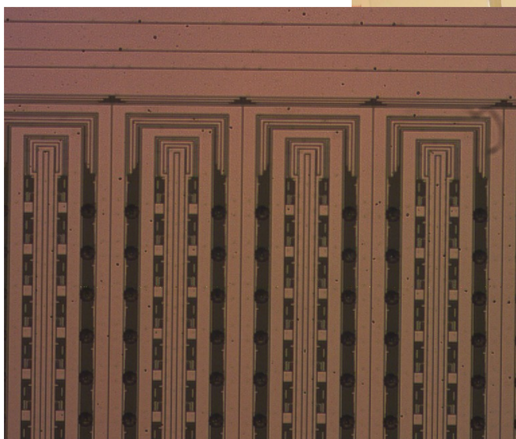
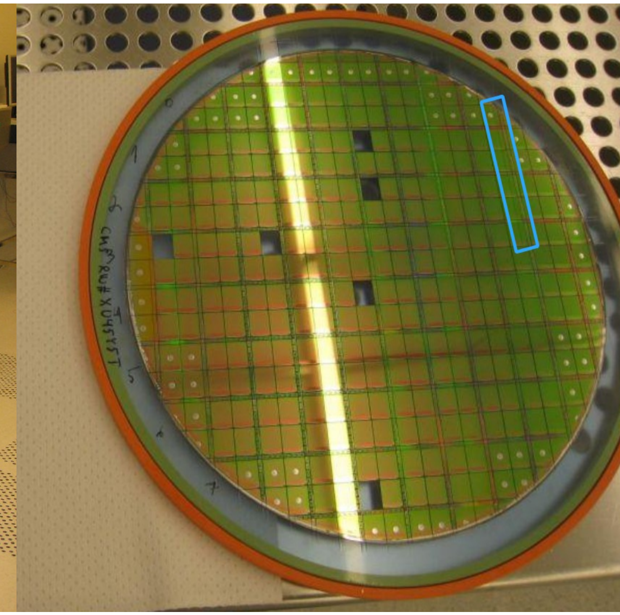
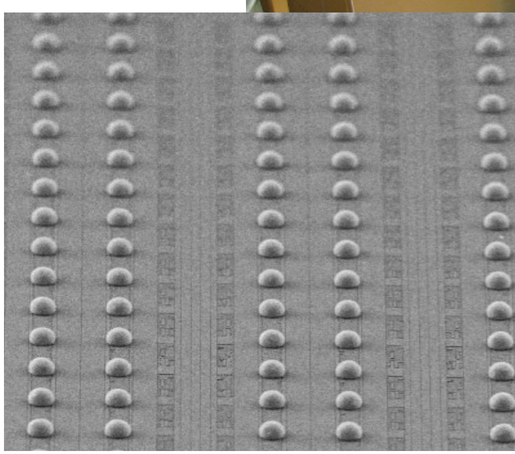
On-going activities







- Finland has committed to deliver in-kind 50% of the pixel modules of CMS Barrel Pixel Layer 3.
- 4000 read-out ASICs (250 pixel modules) will be flip-chip bonded in Micronova.
- In addition, R&D for next generation pixel sensors utilizing the potential of ALD technology.

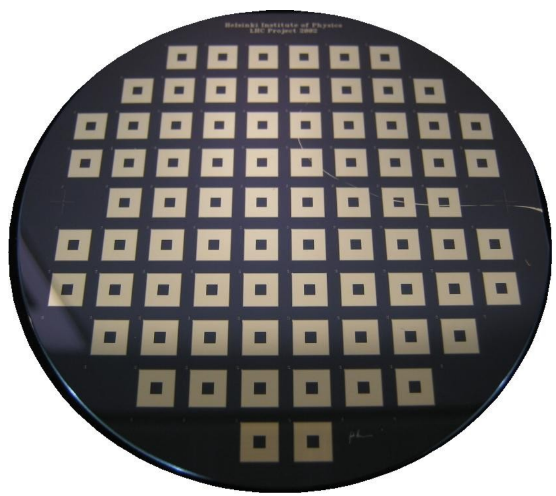
Detector processing at Micronova

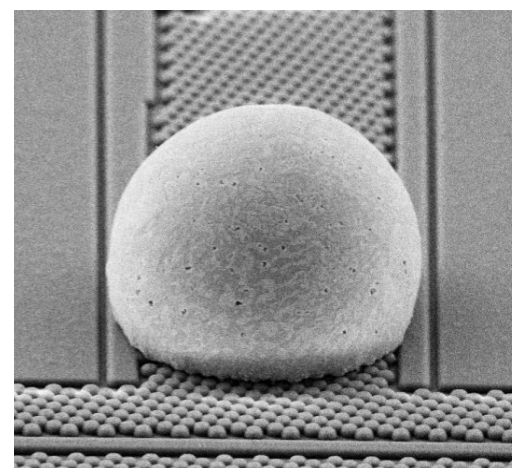
Micronova is the most modern and largest R&D clean room facility in Scandinavia.

Micronova Centre of Micro and Nanotechnology, Finland:

www.micronova.fi

Access to this facility allows HIP researchers to experiment with different kinds of detector technologies and materials without the need of ordering the detectors from commercial manufactures.





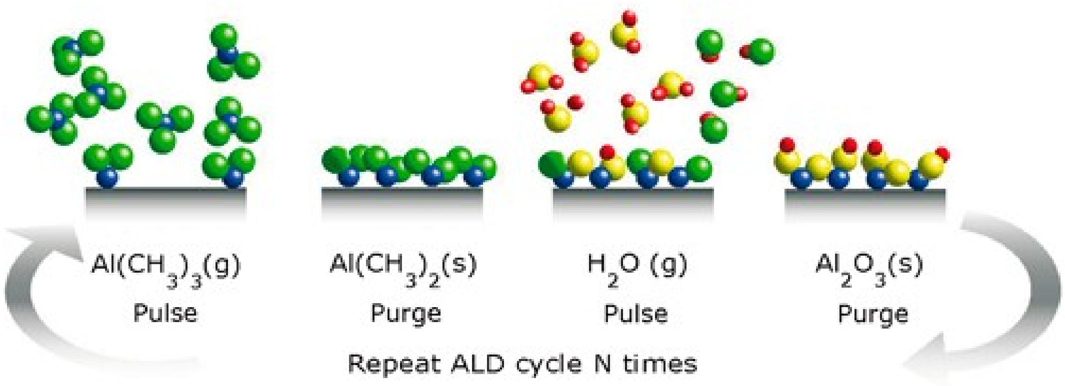
Atomic Layer Deposition (ALD)

http://en.wikipedia.org/wiki/Atomic_layer_epitaxy

Originally developed and discovered by Dr. Tuomo Suntola.

ALD was developed at the Electron Physics Laboratory of Helsinki University of Technology (HUT) in early 1970's.

ALD is nowadays key-technology in developments for post-Moore's Law CMOS.



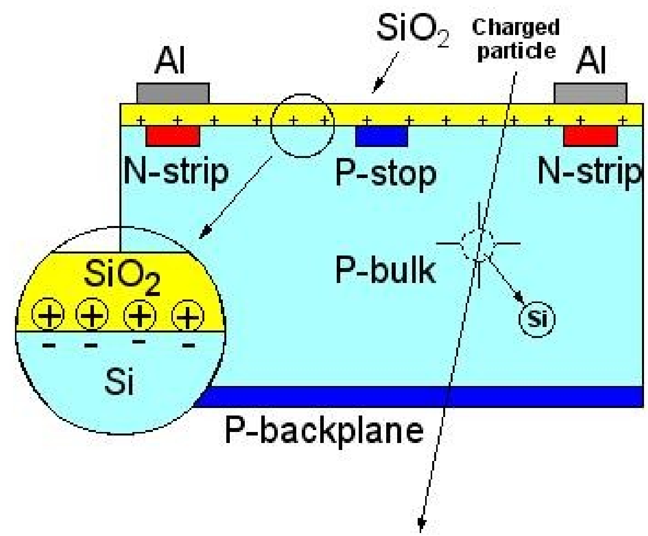
ALD is based on surface controlled thin film deposition. During coating, two or more chemical vapors or gaseous precursors react sequentially on the substrate surface, producing a solid thin film. The film thickness depends only on the number of reaction cycles, which makes the thickness control accurate and simple. (http://www.beneq.com/atomic-layer-deposition.html)

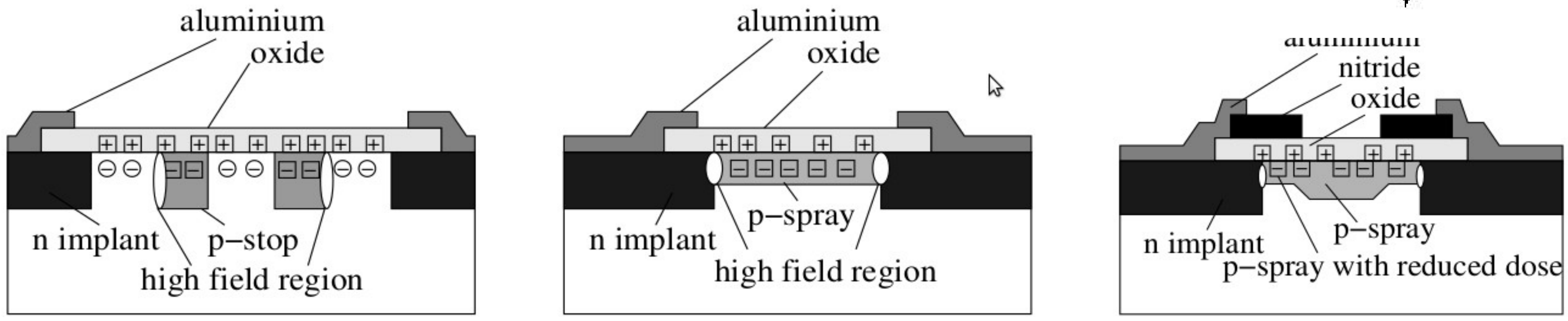
Commercial applications include:

Semiconductors
Lighting
Solar photovoltaics
Corrosion protection
Optics and displays
Decorative coatings

Why would ALD be good for radiation detectors?

- Trapping can significantly be reduced, if detector structure is $n^+/p^-/p^+$ (n on p) instead of usual p+ implants.
- This is due to 3×higher mobility of electrons.
- Oxide charge is positive → electron accumulation at Si/SiO_2 interface.
- Elevated surface charge can be eliminated by different p-spray (B field implantation) and p-stop (segmented B implant).



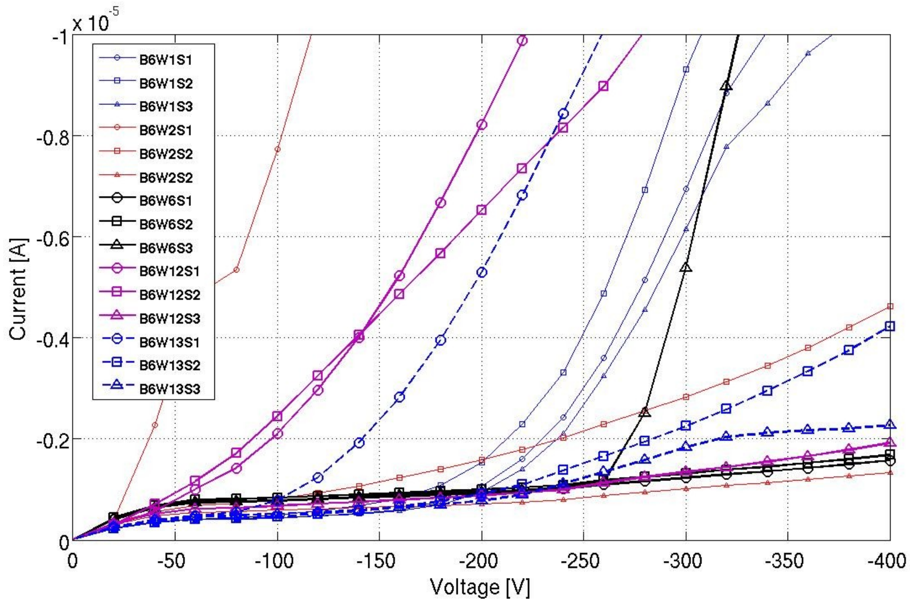


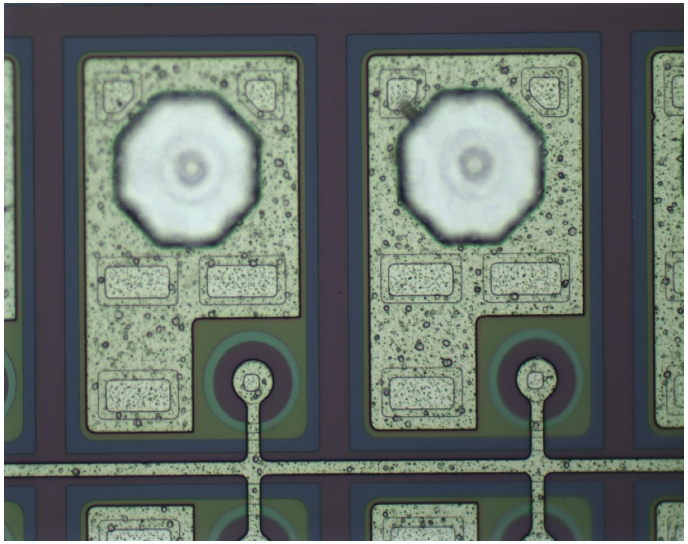
(a) *p*-Stops (b) *p*-Spray (c) moderated *p*-Spray

Picture by T. Rohe.

Problems with p-stop and p-spray implants

- Require more
  - Mask levels (=price)
  - High temperature processing steps
- Finer granularity increases local electric fields → lower breakdown voltage
- More implants mean higher capacitances (=noise, lower rise time of signal)





Possibilities of ALD for radiation hard detectors

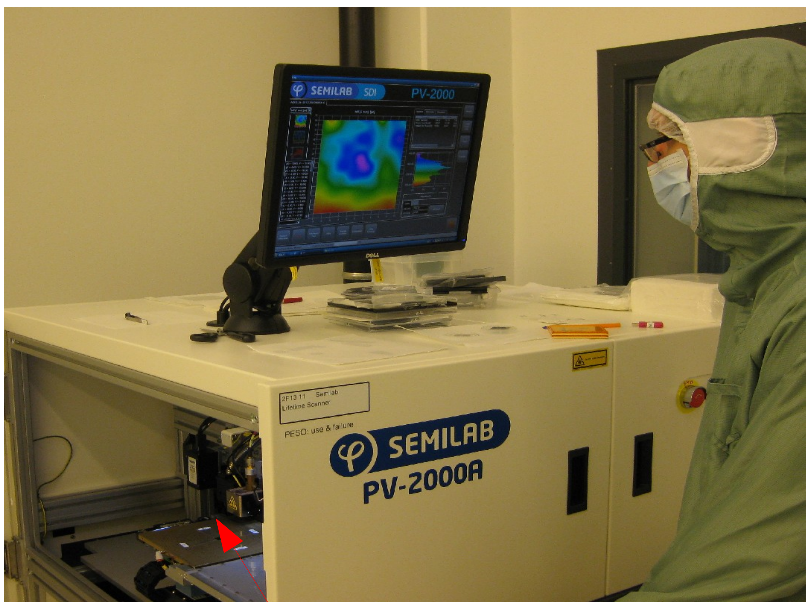
- ALD provides many potentially interesting material systems, e.g. high ε materials HfO_2, ZrO_2 etc.
- ALD-grown films are extremely conformal and uniform in thickness.
- ALD is pinhole free deposition.
- With ALD one can tailor amount and type of oxide charge.
- ALD is applicable on large surfaces.
- ALD is low temperature process, typically 300^0C.

Beneq TFS-500 ALD system at Micronova Cleanroom facility.

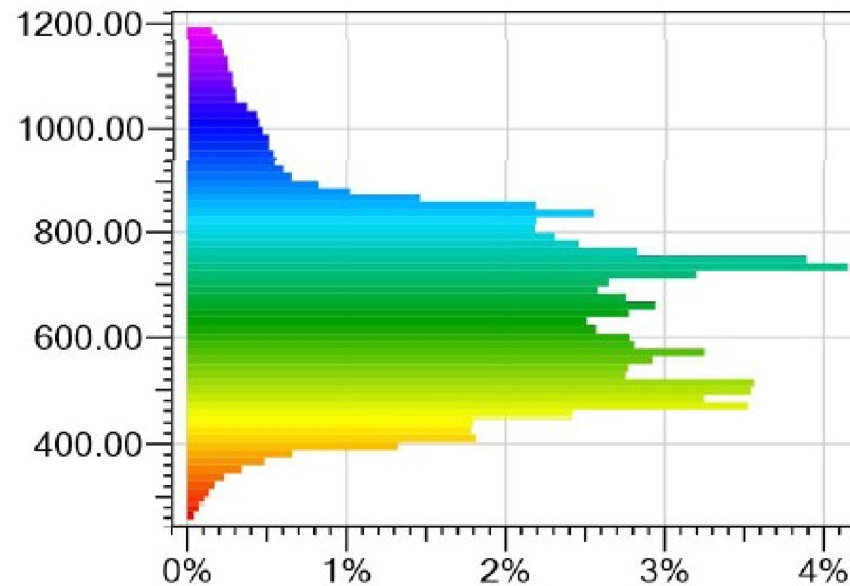
University of Helsinki Laboratory of Inorganic Chemistry (LIC) Finnish Centre of Excellence in Atomic Layer Deposition.

Ta_2O_5 passivates Si similary as thermal SiO_2

- Sample: 150mm Si wafer used as oxidation furnace contamination monitor at Micronova (=wafer has been oxidized many times, lifetime measured after every oxidiation/furnace cleaning cycle)
- Oxidized wafer has been diced+ oxide removal+ALD Ta_2O_5 deposition
- We measure essentially same effective lifetime as in original sample > $\tau_{eff} \approx \tau_{bulk}$ and $s_{srv} \approx 0$

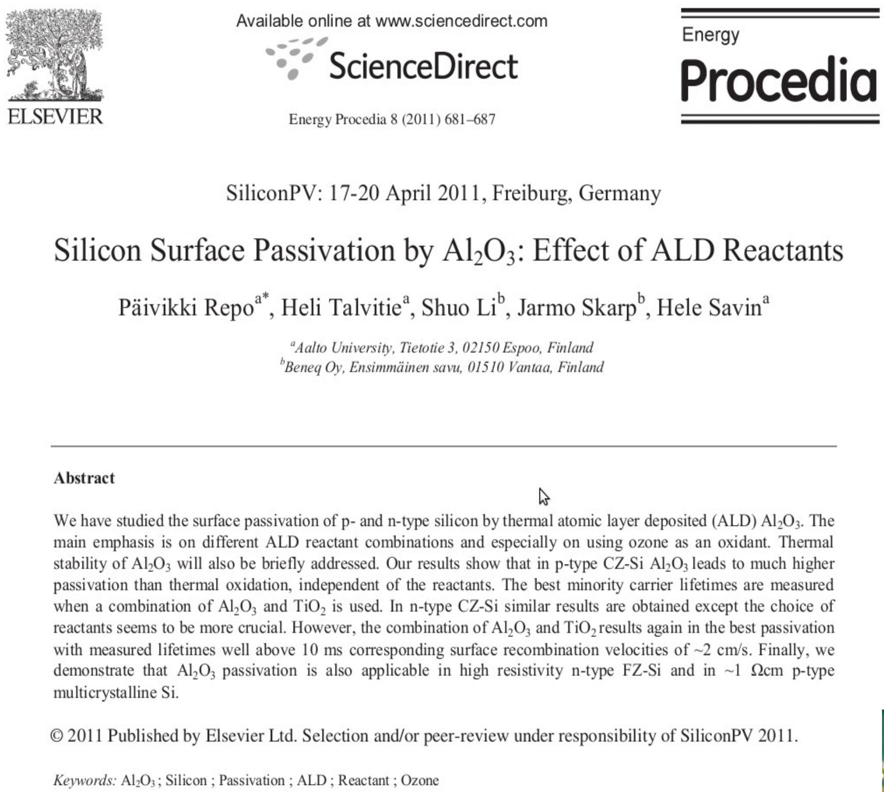


Diced samples under PCD probehead



Distribution of effective minority carrier lifetime in Ta_2O_5 passivated Si

Earlier work utilizing ALD thin films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Energy Procedia 8 (2011) 681–687

Energy Procedia

SiliconPV: 17-20 April 2011, Freiburg, Germany

Silicon Surface Passivation by Al_2O_3: Effect of ALD Reactants

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Abstract

We have studied the surface passivation of p- and n-type silicon by thermal atomic layer deposited (ALD) Al_2O_3. The main emphasis is on different ALD reactant combinations and especially on using ozone as an oxidant. Thermal stability of Al_2O_3 will also be briefly addressed. Our results show that in p-type CZ-Si Al_2O_3 leads to much higher passivation than thermal oxidation, independent of the reactants. The best minority carrier lifetimes are measured when a combination of Al_2O_3 and TiO_2 is used. In n-type CZ-Si similar results are obtained except the choice of reactants seems to be more crucial. However, the combination of Al_2O_3 and TiO_2 results again in the best passivation with measured lifetimes well above 10 ms corresponding surface recombination velocities of ~2 cm/s. Finally, we demonstrate that Al_2O_3 passivation is also applicable in high resistivity n-type FZ-Si and in ~1 Ωcm p-type multicrystalline Si.

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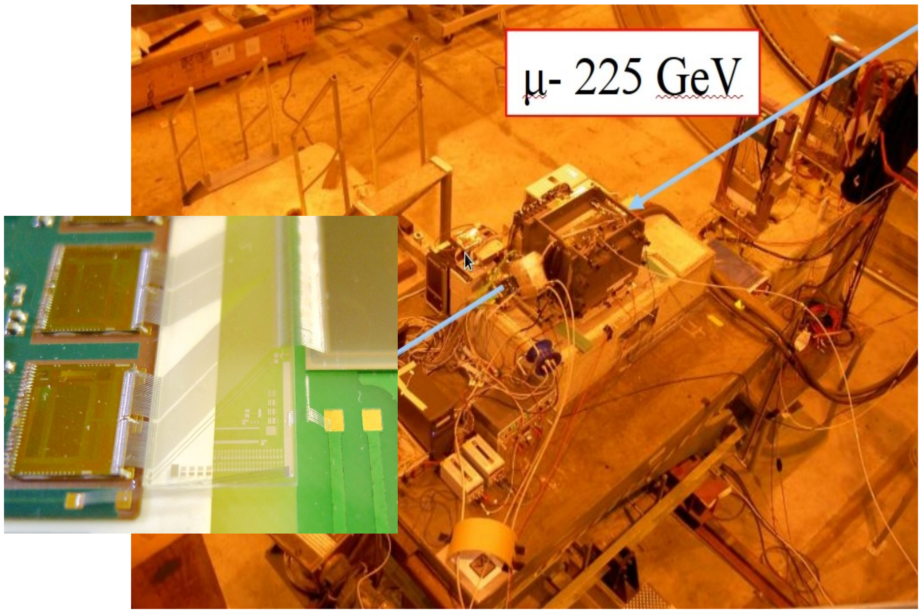
Keywords: Al_2O_3 ; Silicon ; Passivation ; ALD ; Reactant ; Ozone

At HIP, research ongoing since 2006.

The concept of n on p MCz-Si strip sensors with ALD coupling insulator and surface termination proved to be functional.

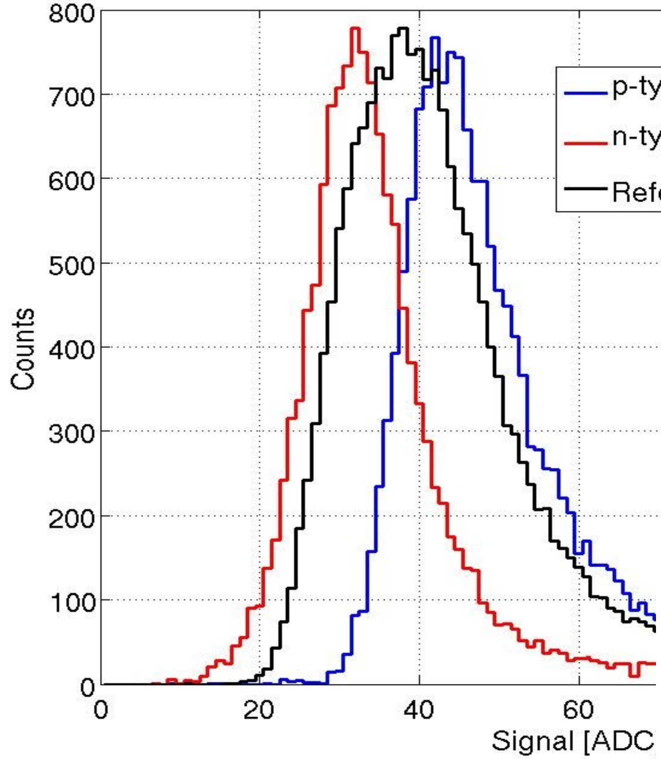
Strip sensors with alumina tested in SPS muon beam with SiBT setup in 2008 and 2011.



It is well-know that ALD grown Al_2O_3 can have negative fixed oxide charge.

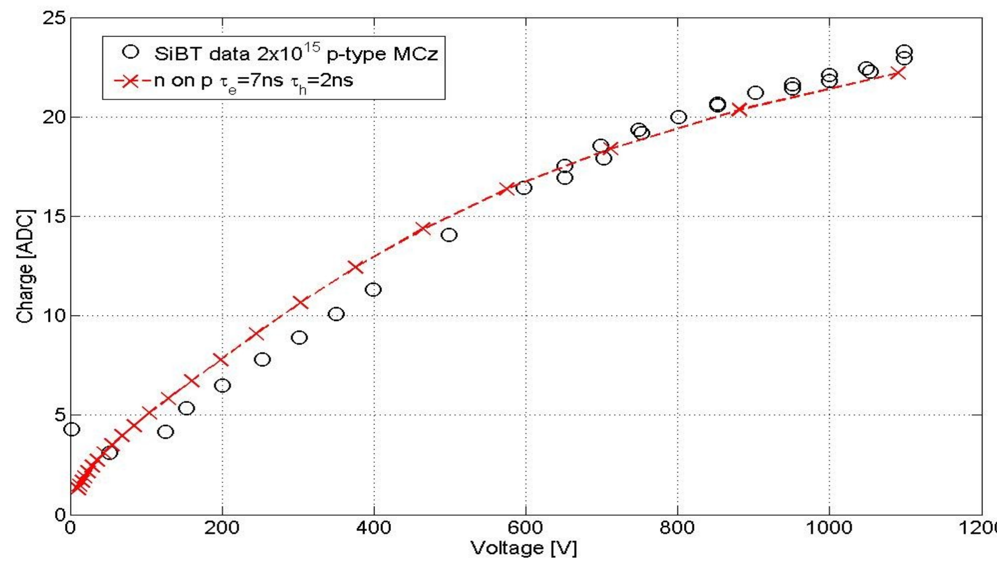
Negative Q_{ox} is widely applied in e.g. silicon solar cells.

Helsinki SiBT results – 2×10^{15} irradiation

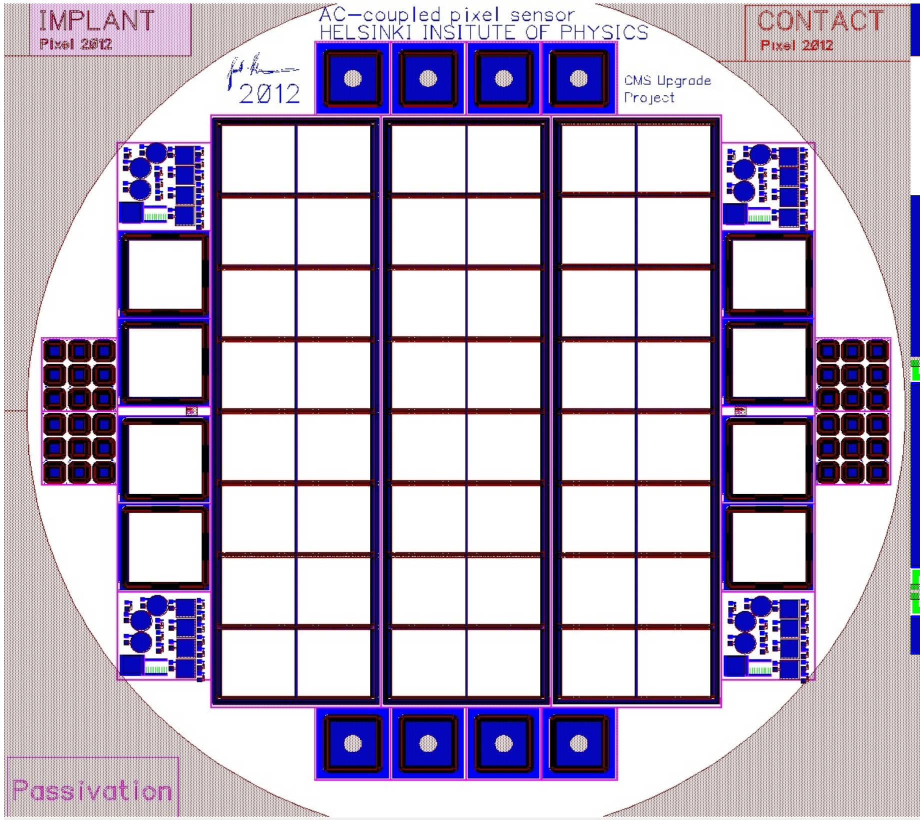


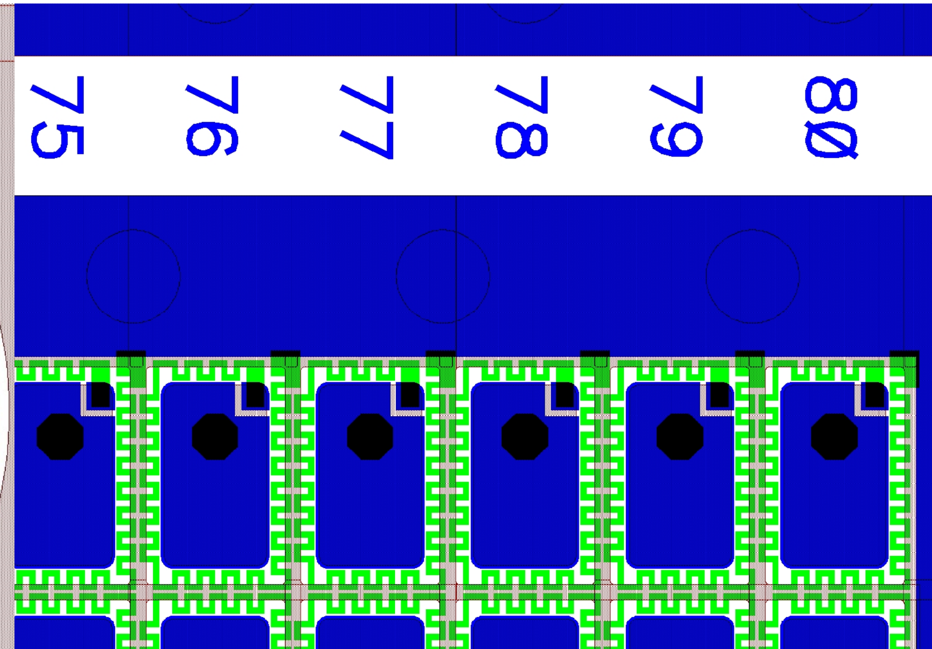
P-type MCz-Si sensor processed in Micronova in 2007.
No p-spray or p-stop.
Measured at SPS in 2008.
CCE @600V > 40%.

Full charge ≈ 40 ADC (average of 8 reference planes; HPK made n-type Fz-Si sensors made for FNAL D0 experiment)



HIP AC-coupled pixel sensors



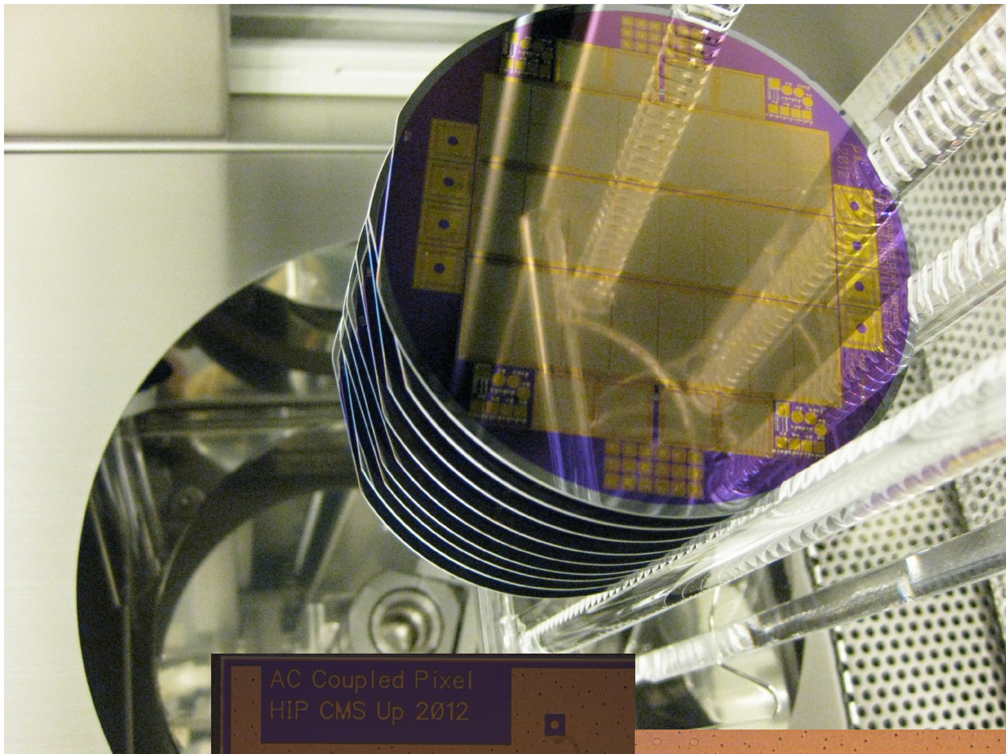


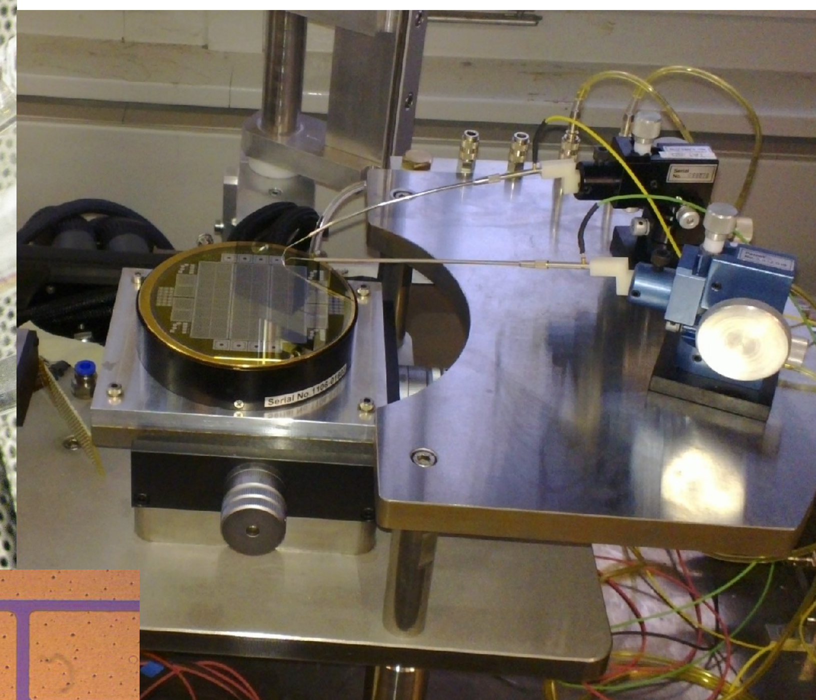
Basic wafer layout similar to current CMS pixel wafer:
Three large (2x8 ROC) sensors + 8 single chip sensors.

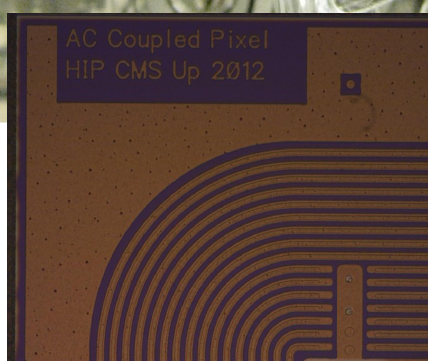
- Biasing via WNx thin film resistors.
  - Easy process: room temperature sputter deposition + RT wet/plasma etching.
  - Poly-Si resistor = 2 implants + high temp poly CVD + high temp activation.
- Coupling insulator ALD Al_2O_3.
- No p-spray or p-stop.

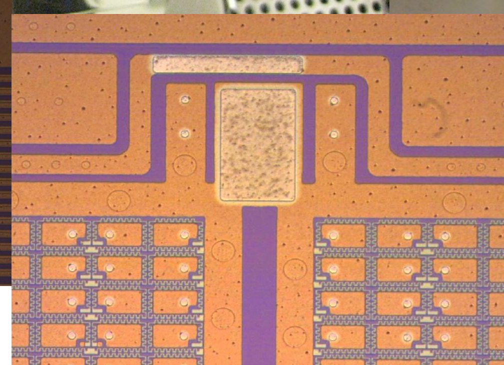
HIP AC-coupled pixel sensors

First batch processed in 2013.

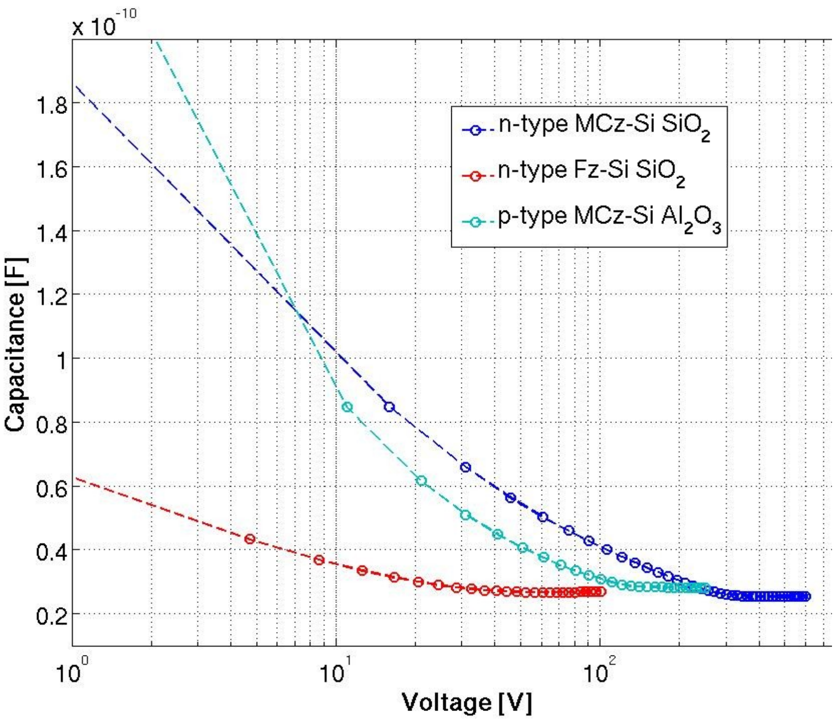




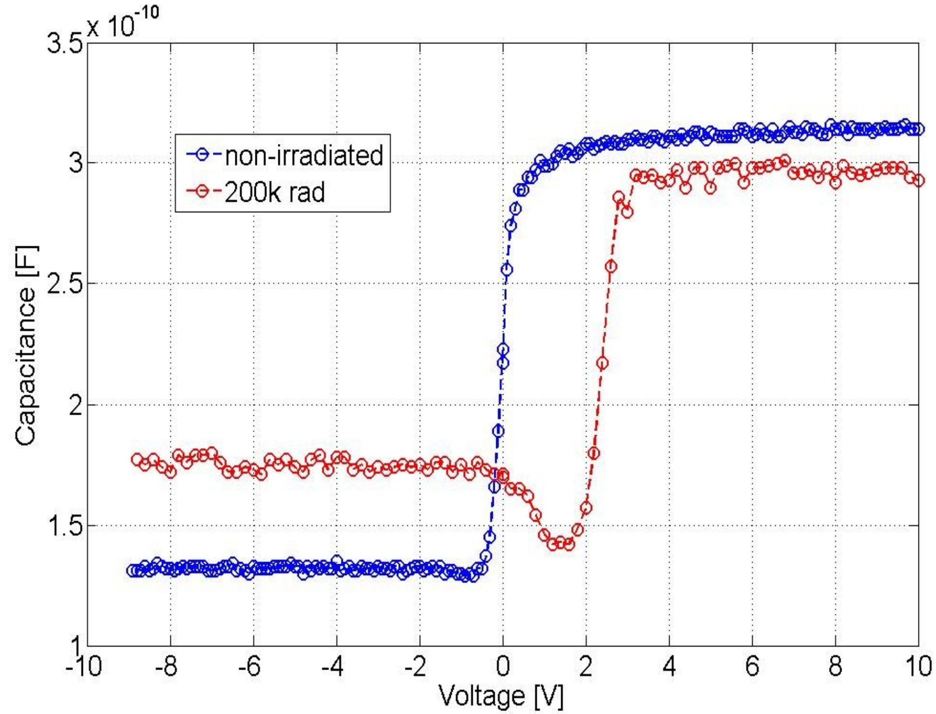




AC-coupled pixel sensors



CV of AC-coupled pixel p-MCz detector with Al_2O_3 field insulator.
V_{fd} ~120V.



Co60 gamma irradiated Al_2O_3 capacitor.
Flat band voltage shift towards right indicates accumulation of negative oxide charge.

Summary

Benefits of ALD:

- Pinhole free thin films (very important for AC-coupled particle detectors).
- Thin films with very good dielectric strength.
- Almost perfect step coverage.
- Low temperature process, deposition typically <400^{0}C.
- It is possible to adjust type of oxide charge negative ↔ positive.
- Negative oxide charge accumulates during the irradiation.

- Strip sensors utilizing ALD thin film show comparable signal and noise with HPK commercial detectors = good capacitive coupling.
- Thin films with very high κ → potentially interesting for AC coupling of pixel sensors.
- n on p detector made by simply one field insulator significantly reduces the complexity and price of sensor processing.
- Pixels can be AC coupled via tungsten nitride thin film resistors → very simple process.
  - Metal (amorphous material) resistor is very robust against radiation damage.
  - The WNx bias resistors have been tested in several test beam campaings with the SiBT setup in AC-coupled strip sensors → functional concept.