HDST12
296

AC-coupled n-in-p pixel detectors on MCz silicon with atomic layer deposition (ALD) grown thin film process

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

[1] Helsinki Institute of Physics (HIP), Helsinki, Finland
[2] Ruđer Bošković Institute (RBI), Zagreb, Croatia
[3] Advacam Oy, Espoo, Finland
[4] Lappeenranta University of Technology
[5] Aalto University

Outline

1. HIP CMS upgrade and research projects
   - HIP location and background
   - Project members

2. Detector R&D
   - For prototype processing
   - Detector process flow

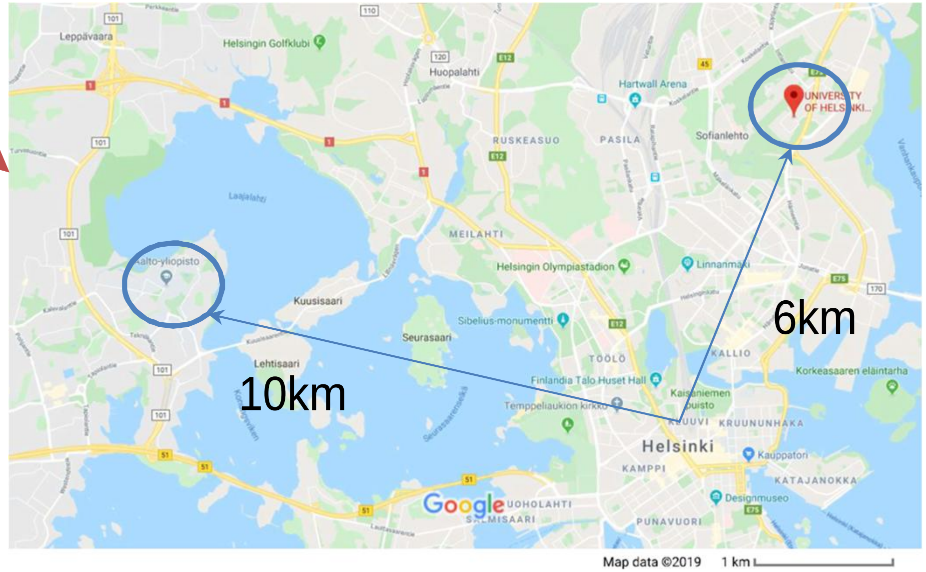
Dr. Jaakko H.(Photograph **2004)**

3. Characterization and selected results

Summary

HIP location and background

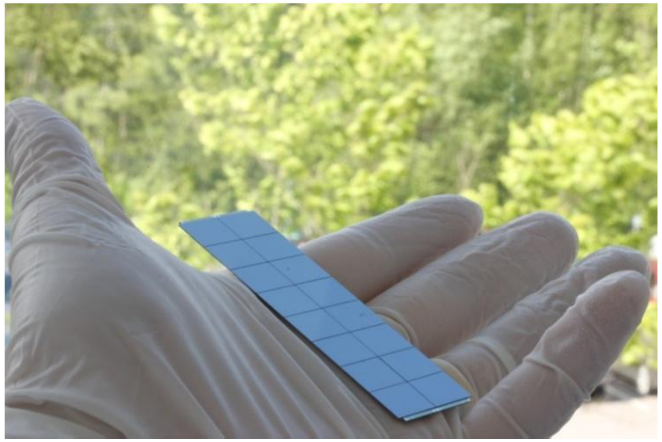
- The institute is responsible for the Finnish research collaboration with CERN.
- The HIP CMS Upgrade Project is in charge of the Finnish participation in the CMS Tracker and its future upgrade, as well as participation in the (silicon) endcap region of the CMS MIP Timing Detector.



CMS experiment upgrade and detector R&D

Compact Muon Solenoid (CMS) experiment at CERN LHC

- Finland had a significant role in the Phase I pixel upgrade: delivery of 250 full pixel modules +
- Currently the modules in the innermost layer of the CMS pixel detector need to be replaced
  - UBM, Plating and
    Flip chip bonding: Advacam
  - BB Quality assurance: HIP



HIP CMS upgrade and RBI PaRaDeSEC project teams

HELSINKI INSTITUTE OF PHYSICS

LUT University

Institut Ruđer Bošković

Dr. Jaakko Härkönen

Prof. Dr. Panja Luukka

Dr. Eija Tuominen

Dr. Erik Brücken

Msc. Stefanie Kirschenmann*

Msc. Jennifer Ott*

Dr. Vladyslav Litichevskyi

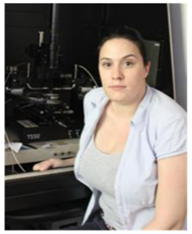
Msc. Akiko Gädda*

Msc. Shudhashil Bharthuar*

Msc.Pirkitta Koponen

Msc.Laura Martikainen*

Dr. Matti Kalliokoski



Dr. Aneliya Karadzhinova-Ferrer

Msc. Mihaela Bezak*

Dr. Valery Chmill

PhD student

CMS experiment upgrade and detector R&D

- Next generation pixel sensor
  (general requirements)
  - Radiation hardness
  - Relatively low costs
  - Feasibility in large scale / industrial production
  - Robustness

Measurement and characterization

→ HIP knowledge and skills

FOR PROTOTYPE PROCESSING

Micronova and Nanofabrication Center cleanroom facilities in Espoo

Main Cleanroom spec.

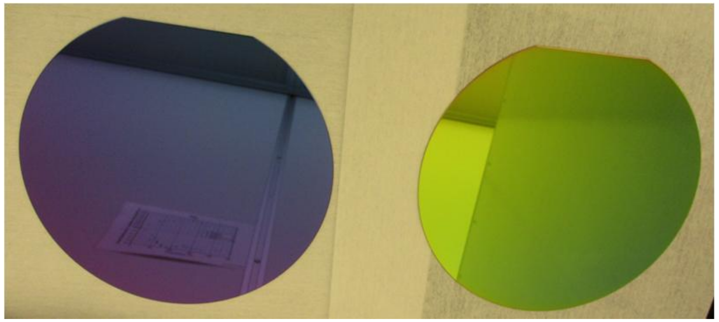
Total Area	2 600 m^2
(M1, M2 with Aalto Univ.)	
Process tool	IC, non IC
Wafer size	4 - 8 inch
Cleanroom Classification	
	ISO 4…ISO 6 (10…1000)
Clean bays	
Temperature	21 °C ± 0,5 °C
Relative humidity	45 % ± 5%

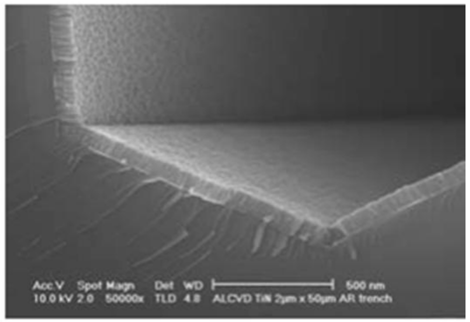
Magnetic Czochralski silicon (MCz-Si)

- High resistivity MCz-Si
  - High level of oxygen (typically 10^{16}-10^{17} cm^{-3})
  - Adjustable oxygen content by magnetic fields
  - Available over 150 mm wafer sizes
  - Depletion layer affected by
    a) oxygen concentration
    b) thermal history (process)
- Cost effectiveness compared to FZ

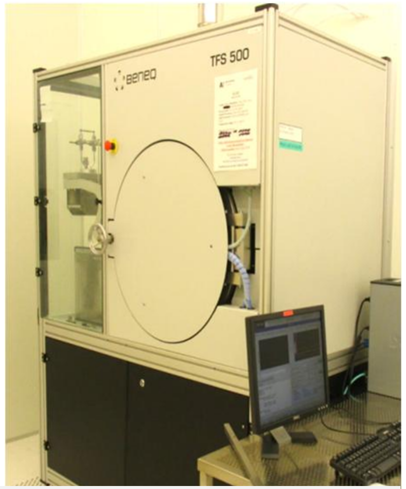
Atomic Layer Deposition (ALD)

- ALD is pinhole free deposition
- ALD results in conformal conformal coating
- ALD provides interesting material thin films
  - Metal oxides e.g. Al_2O_3, TiO_2, SnO_2, ZnO, HfO_2 etc.
- ALD can tailor amount and type of oxide charge

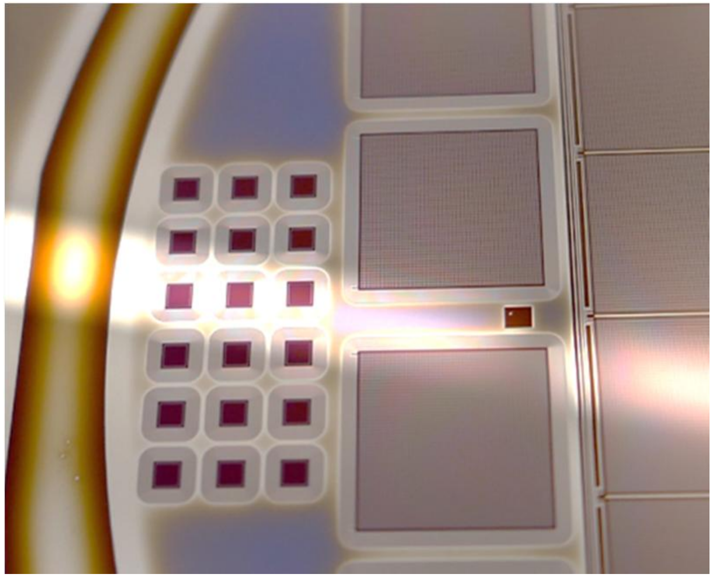




Conformal coverage in ALD
[1]S.Franssila



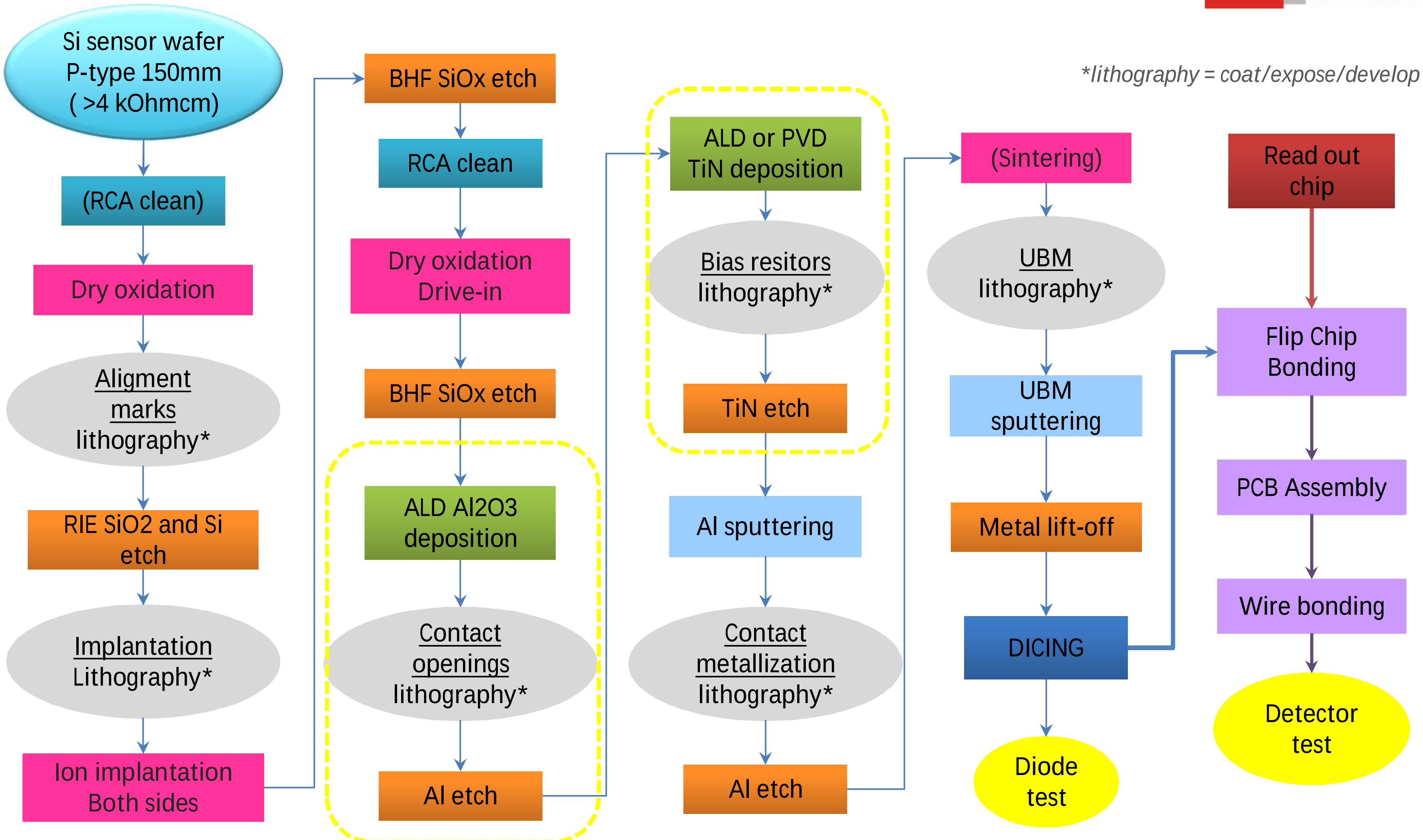
Beneq TFS-500 batch-type ALD reactor



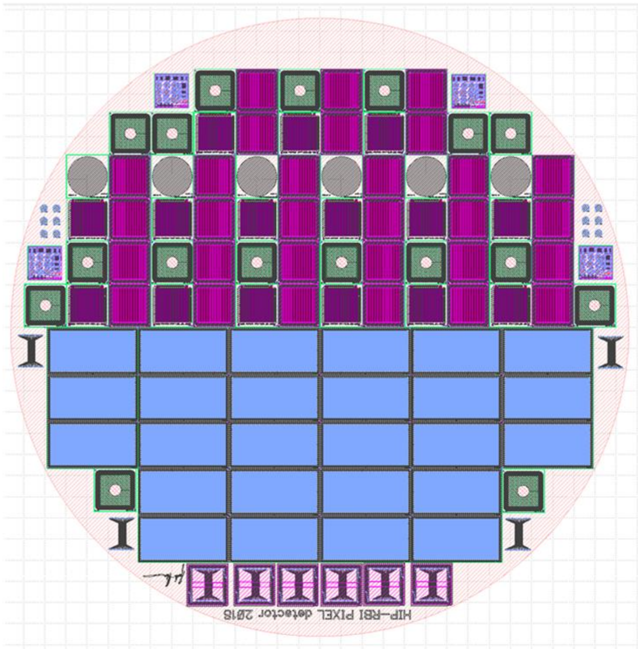
DETECTOR PROCESS FLOW

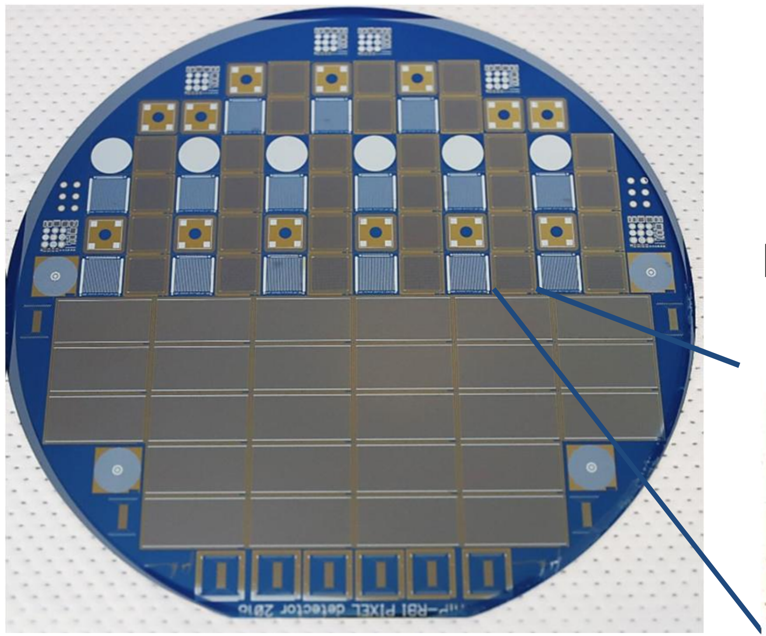
Process Flow

*lithography = coat/expose/develop

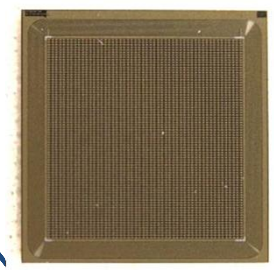


Detector design and outcome





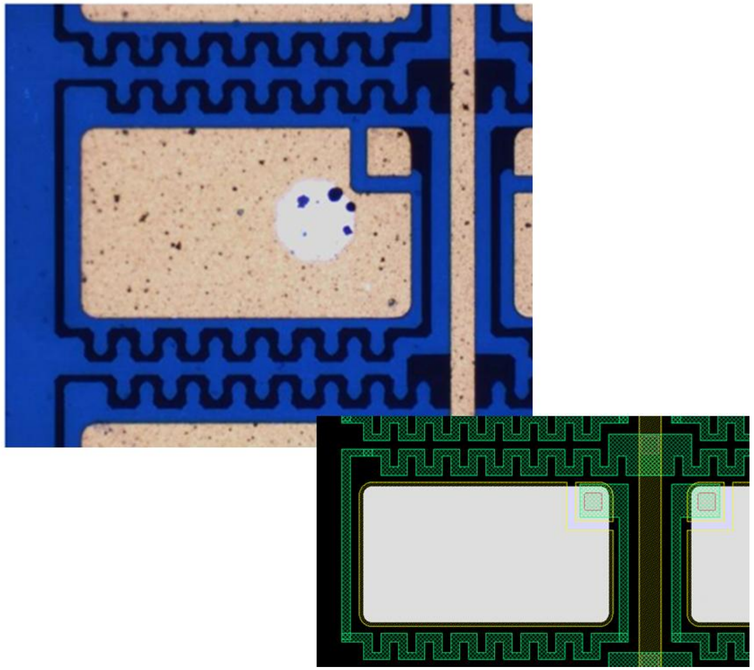
PSI46dig pixel detector



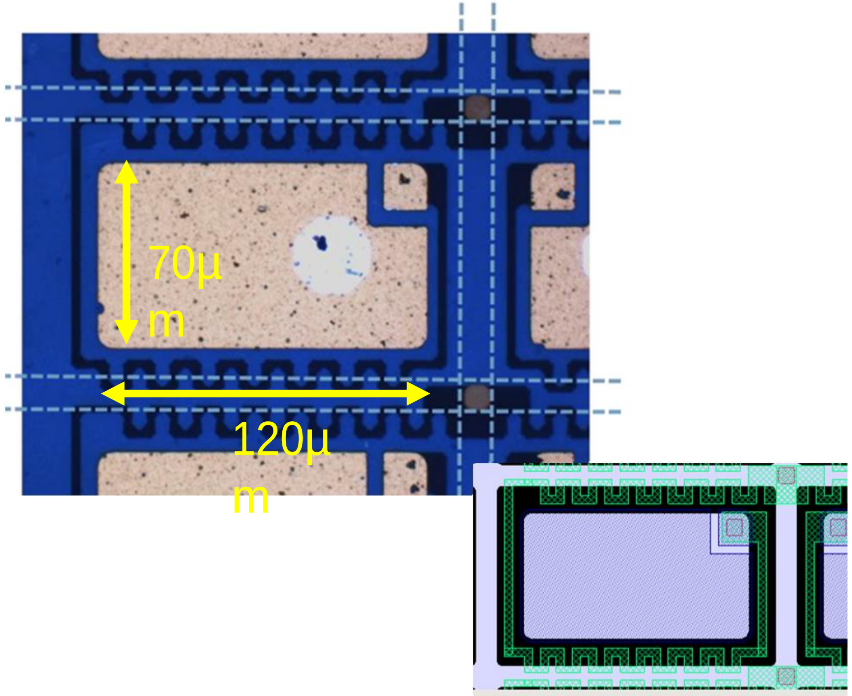
Pixel array:
52 columns × 80 rows
= 4160 pixels

Detector bias design

PSI46dig pixel detector



Bias connection via Al metal line



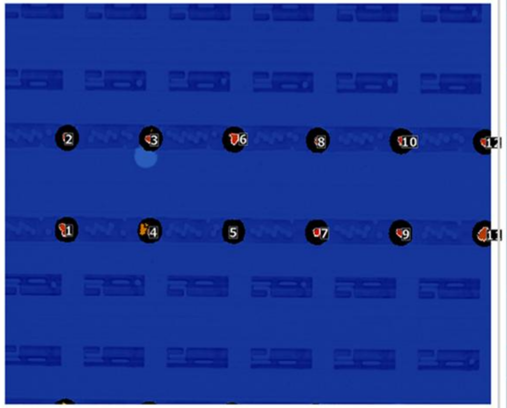
Bias connection via Implantation window

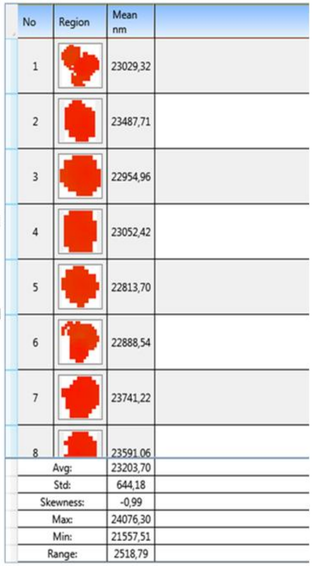
[2] J. Ott et al., [3] Jaakko Härkönen

Solder bumps

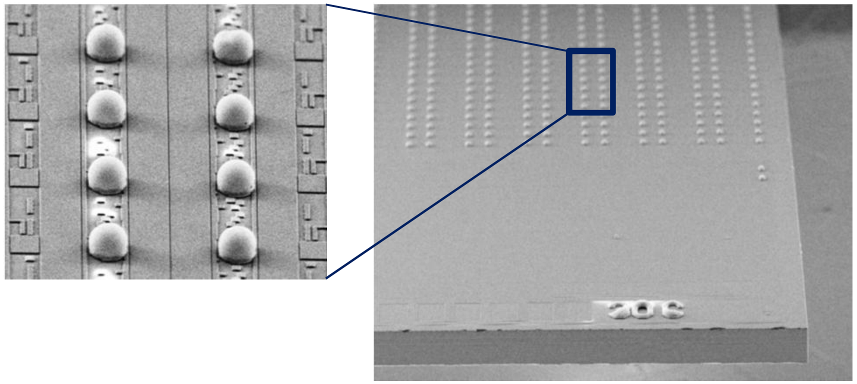
- The read out chip (ROC) is PSI46dig used in CMS experiment.
- Solder bump (~29um dia.)

Bump height uniformity





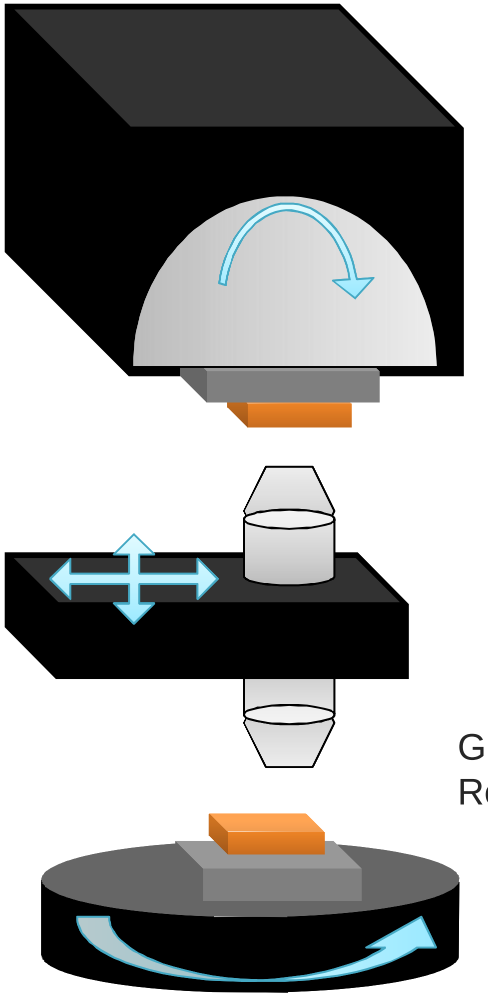
No	Region	Mean nm
1		23029,32
2		23487,71
3		22954,96
4		23052,42
5		22813,70
6		22888,54
7		23741,22
8		23591,06
	Avg:	23203,70
	Std:	644,18
	Skewness:	-0,99
	Max:	24076,30
	Min:	21557,51
	Range:	2518,79



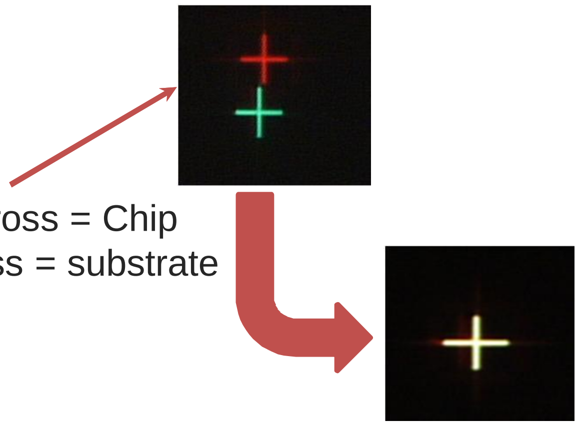
Very high uniformity

➡ +/- 1.5 um

Hybridization

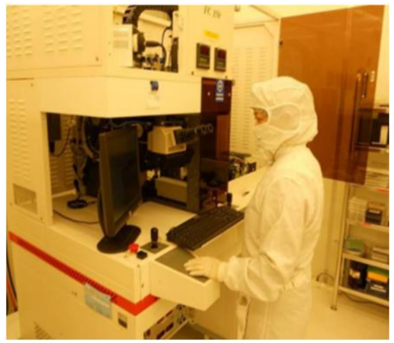


- Flip Chip bonder
  - Align X,Y and Ө (microscope optics)
  - Leveling (autocollimator)
  - Thermocompression bonding (ºC, Kg ,Sec.)
    - ➢ Alignment accuracy: 0.5um
    - ➢ Post_biond accuracy: 3um



Green color cross = Chip
Red color cross = substrate

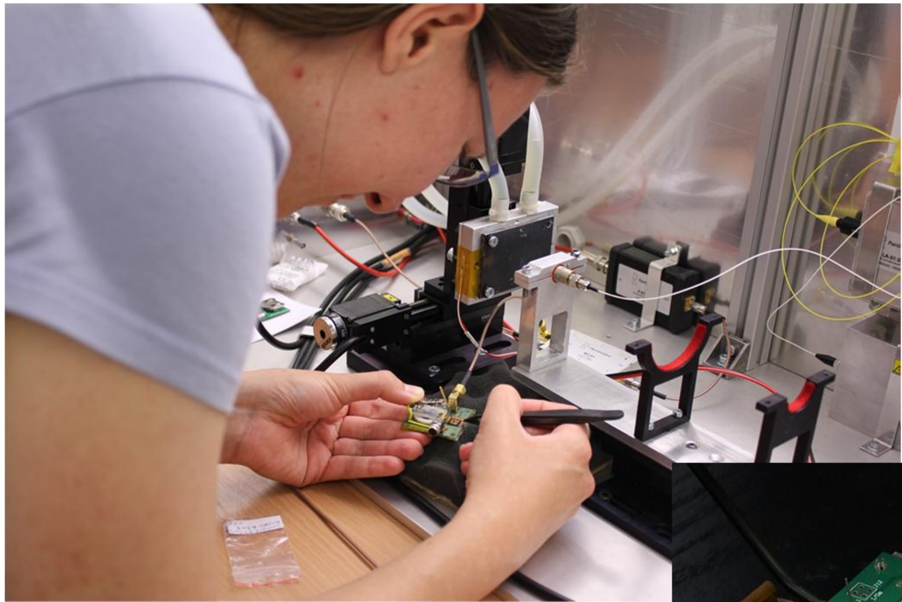
Aligned

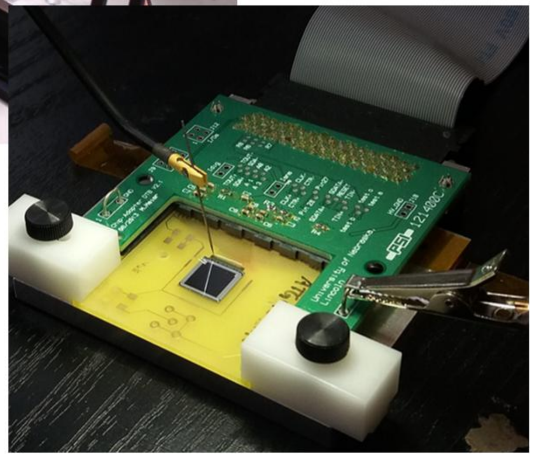


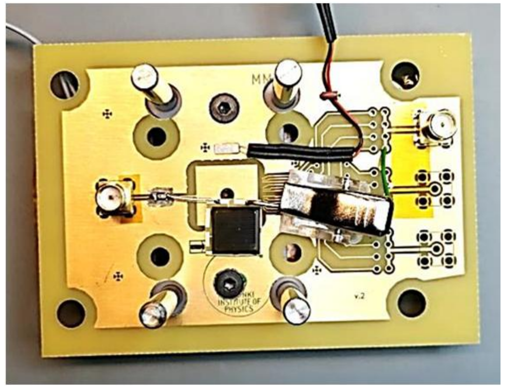
HELSINKI INSTITUTE OF PHYSICS

LUT University

Institut Ruđer Bošković



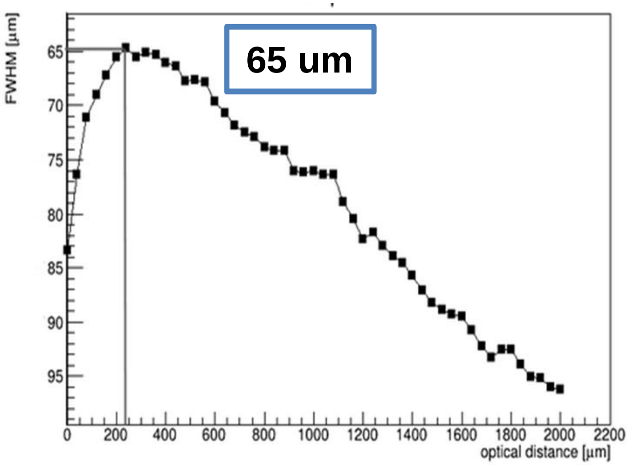




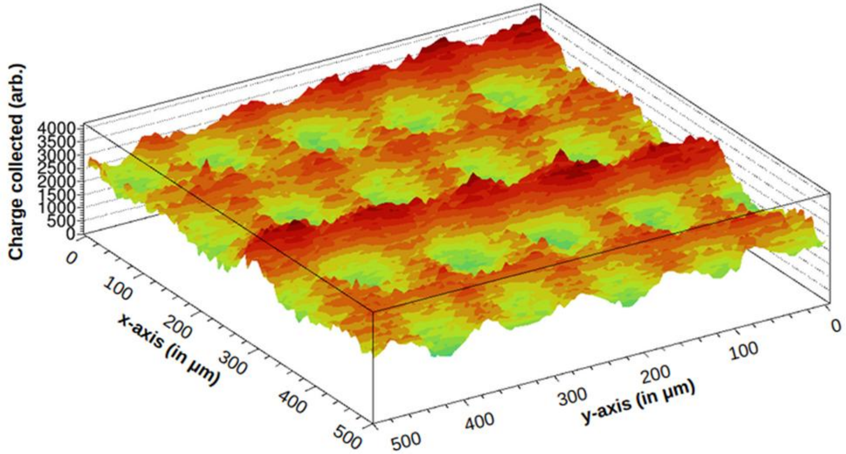
CHARACTERIZATION AND SELECTED RESULTS

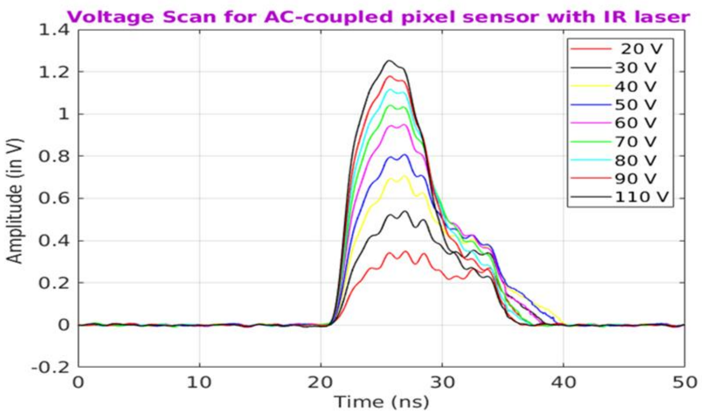
TCT measurements at HIP

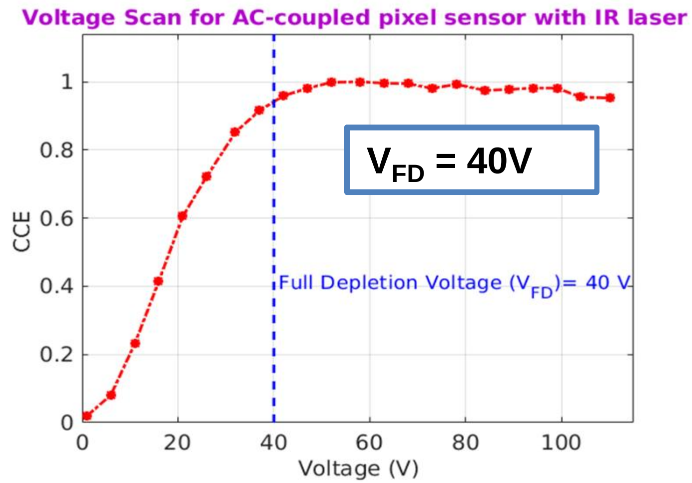
Voltage scan with IR (670nm)



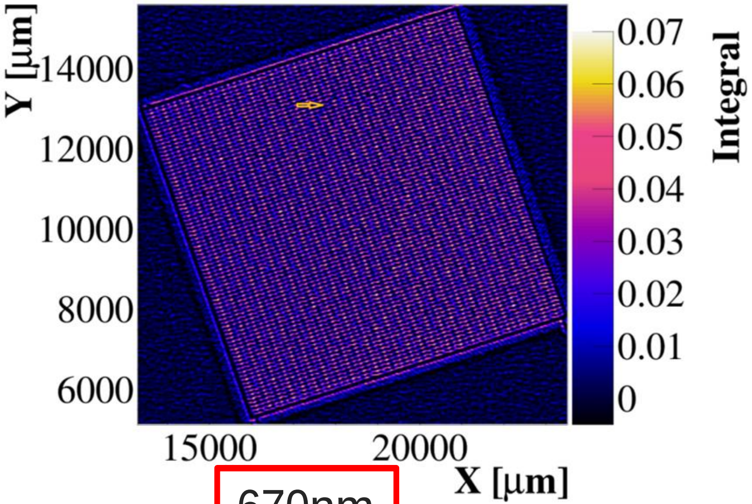
spatial scan performed at 100V



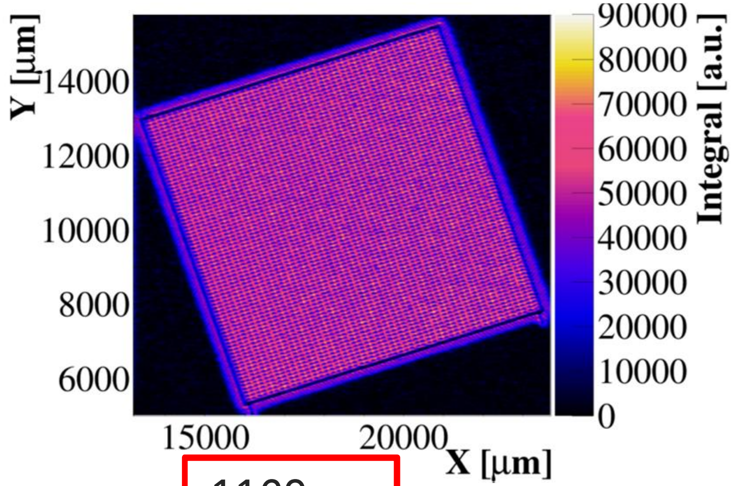




TCT xy-area scans for pixel detectors

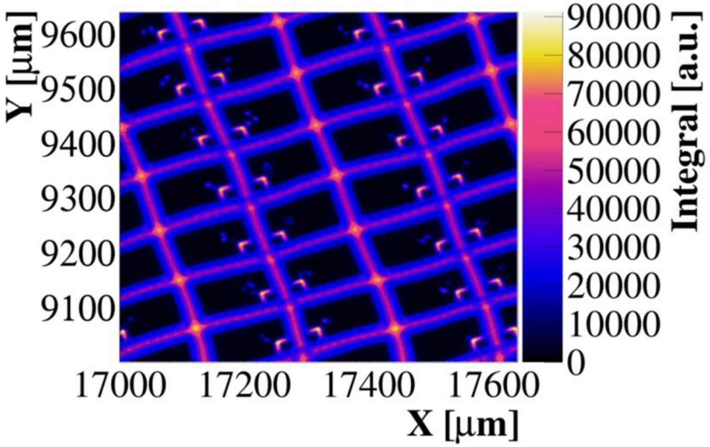


670nm



1160nm

- Each TCT xy-scan is about 60 000 data points.
- The amplitude of the signal is converted into color scale.

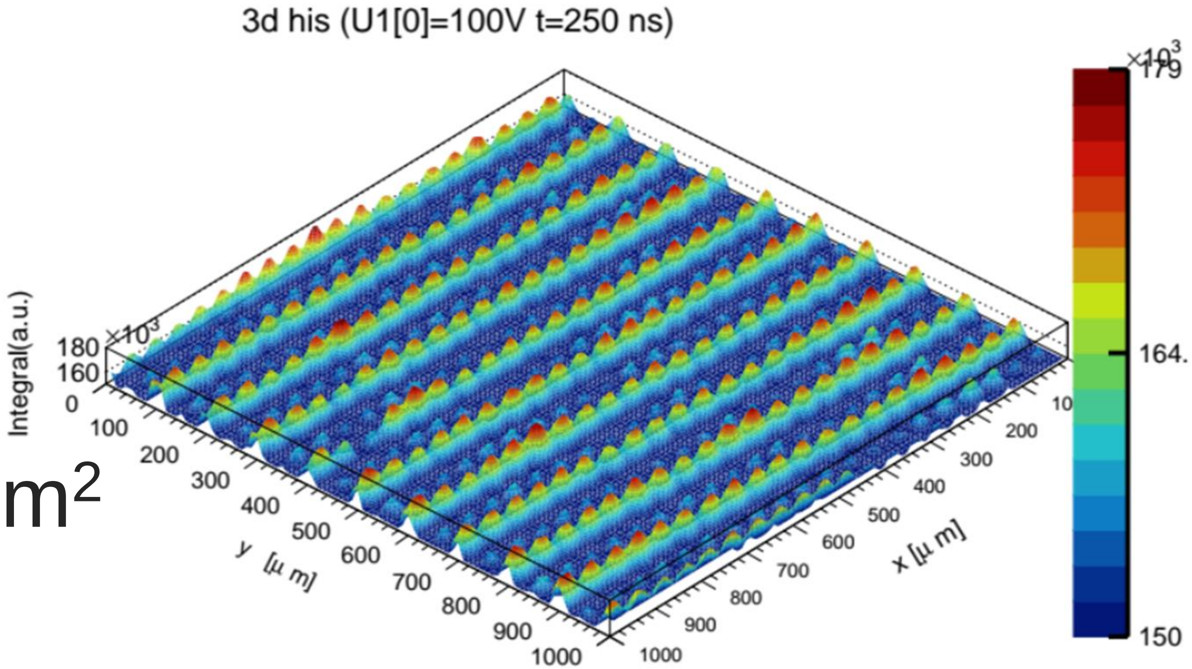


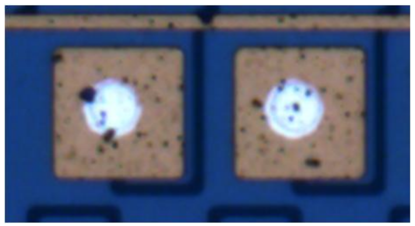
[3] Jaakko Härkönen

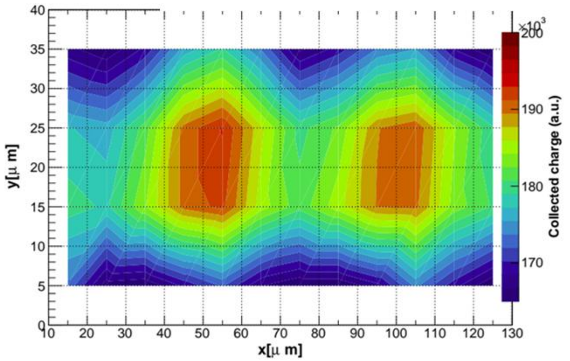
TCT area scans for 50 μm pixels

Laser Settings:

- 1064 nm
- 50 Hz
- 1000 x 1000um^2

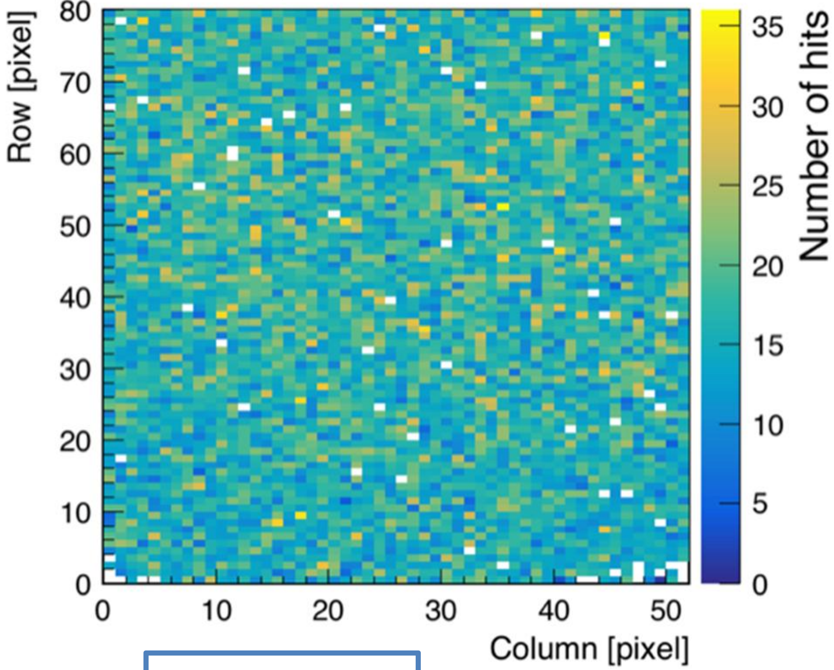




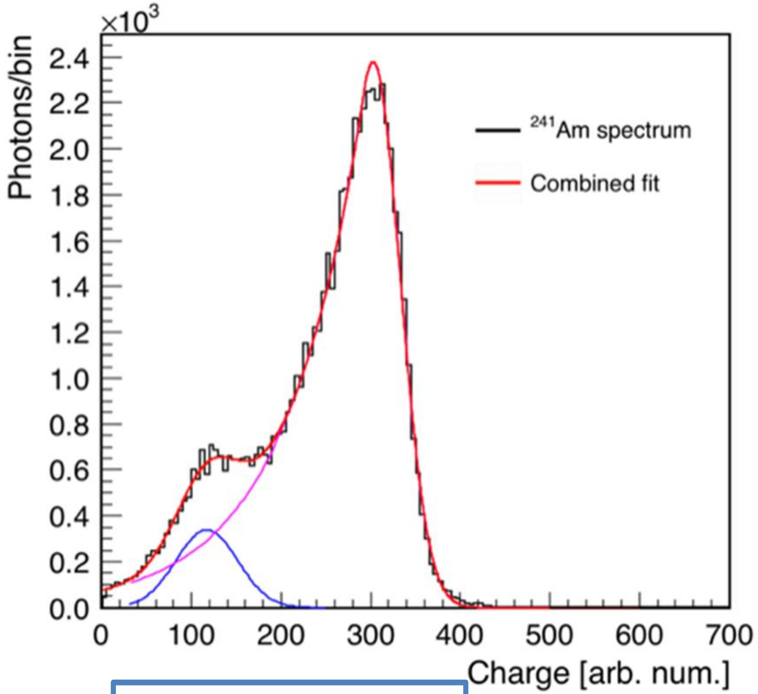


Source test
HIP AC-coupled pixel detector

- -PSI46digi design
- -Flip chip bonded detector
- -60keV Gamma from Am-241
- - 8000-15000s irradiation time
- - 3cm distance



34/4160 < 1%

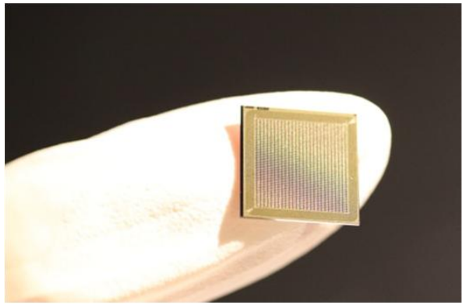


Am241 spectrum

Summary

** Citation slide is available late slide*

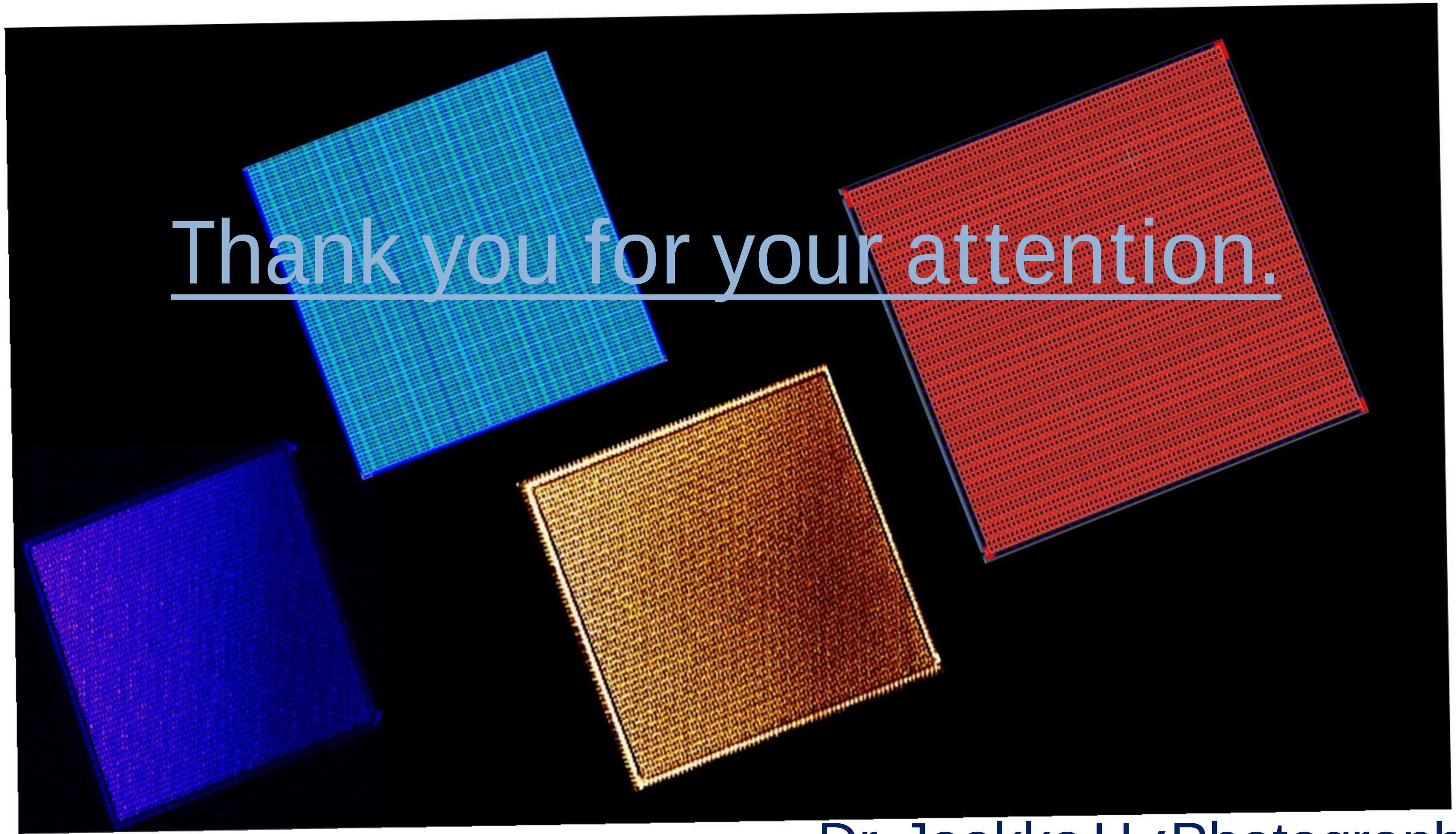
- We fabricated 150mm p-MCz Si wafers with our sensor design.
- Detectors are processed at Micronova / Nanofabrication center in Finland.
- Atomic Layer Deposition (ALD) technology has many properties for radiation detector fabrication processes.
- AC-coupling of small pixels connected with each other by metal-nitride thin film bias resistors.
- Flip-Chip bonding of sensor and CMS PSI 46dig CMOS ROC was performed.
- Pixel detectors were tested both HIP and RBI.
- Currently, protective passivation by ALD-HfOx is being researched (ref: see slide 11 right picture).



HELSINKI INSTITUTE OF PHYSICS

LUT University

Institut Ruđer Bošković



Thank you for your attention.

Dr. Jaakko H. (Photograph)

* Citations

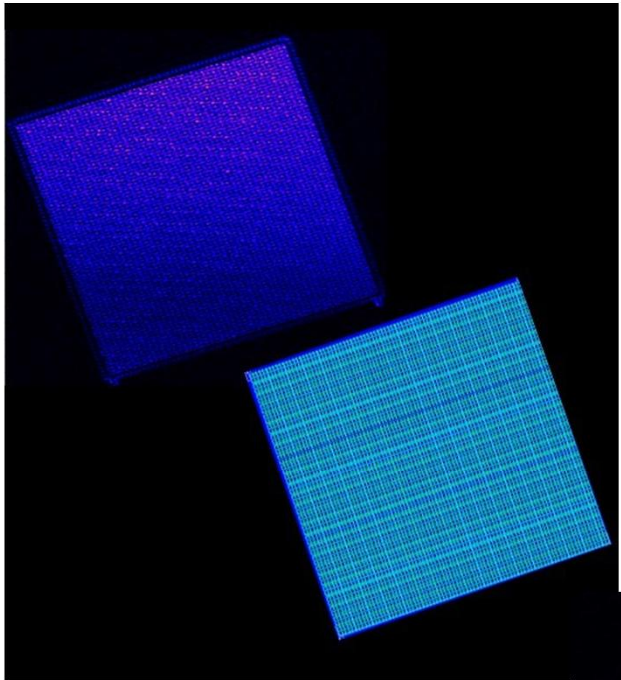
1. Sami Franssila, John Wiley & Sons, Incorporated 2010, Introduction to Microfabrication Second Edition
2. J. Ott et al., Presented at 33rd RD50 Workshop, CERN, Geneva, Switzerland, November 28th 2018, Processing of pixel detectors on p-type MCz silicon using atomic layer deposition (ALD) grown aluminium oxide https://indico.cern.ch/event/754063/contributions/3222806/attachments/1760772/2865963/JOtt_RD50_Nov18_3.pdf
3. Jaakko Härkönen, Presented at Croatian Particle Physics Days, Dec 09 2019
4. Esa Tuovinen, PROCESSING OF RADIATION HARD PARTICLE DETECTORS ON CZOCHRALSKI SILICON (Doctoral dissertation), 2008

http://paradesec.irb.hr/
http://research.hip.fi/hwp/cmsupg/
http://research.hip.fi/detlab/index.htm
http://www.micronova.fi/

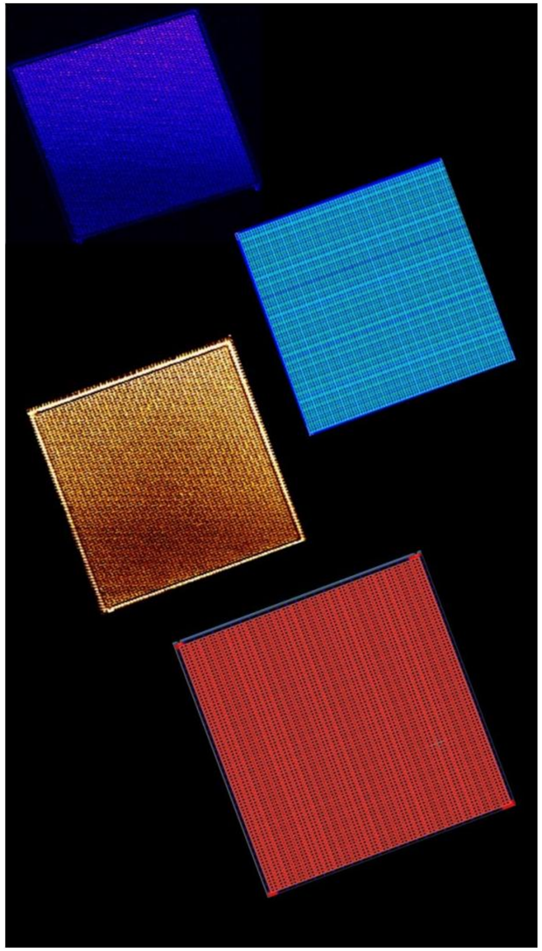
intentionally blank page

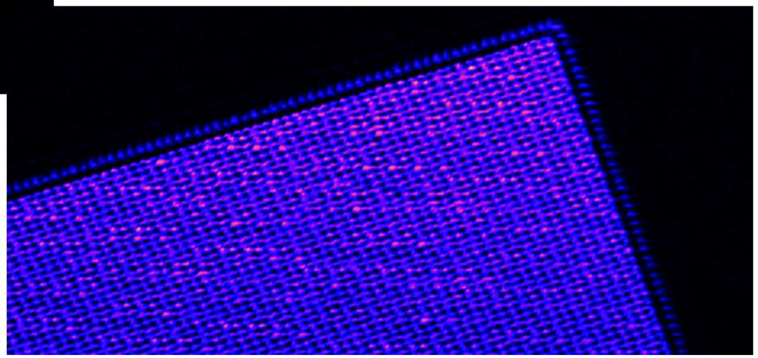
Backup slides: from Dr. Jaakko H.

"When pixel technology meets Arts...." by Jaako Härkönen

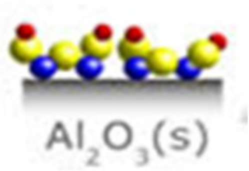


Each square is TCT xy-scan of about 60 000 data points.
The amplitude of the signal is converted
into color scale.





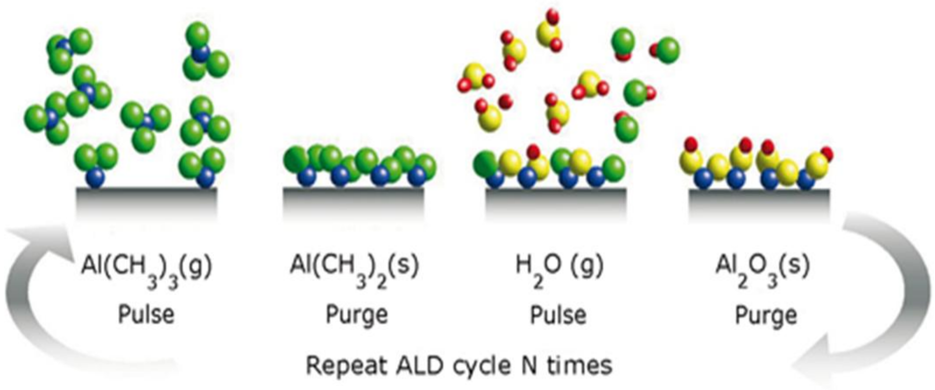
Backup slides: ALD process for metal oxide deposition



(A) $Al\text{-}OH^* + Al(CH_3)_3 \quad Al\text{-}O\text{-}Al\text{-}(CH_3)_2^* + CH_4$

(B) $Al\text{-}CH_3^* + H2O \quad Al\text{-}OH^* + CH_4$

$$2Al(CH_3)_3 + 3H_2O \quad Al_2O_3 + 6CH_4$$



Ref. https://www.glassonweb.com/article/atomic-layer-deposition-glass-industry