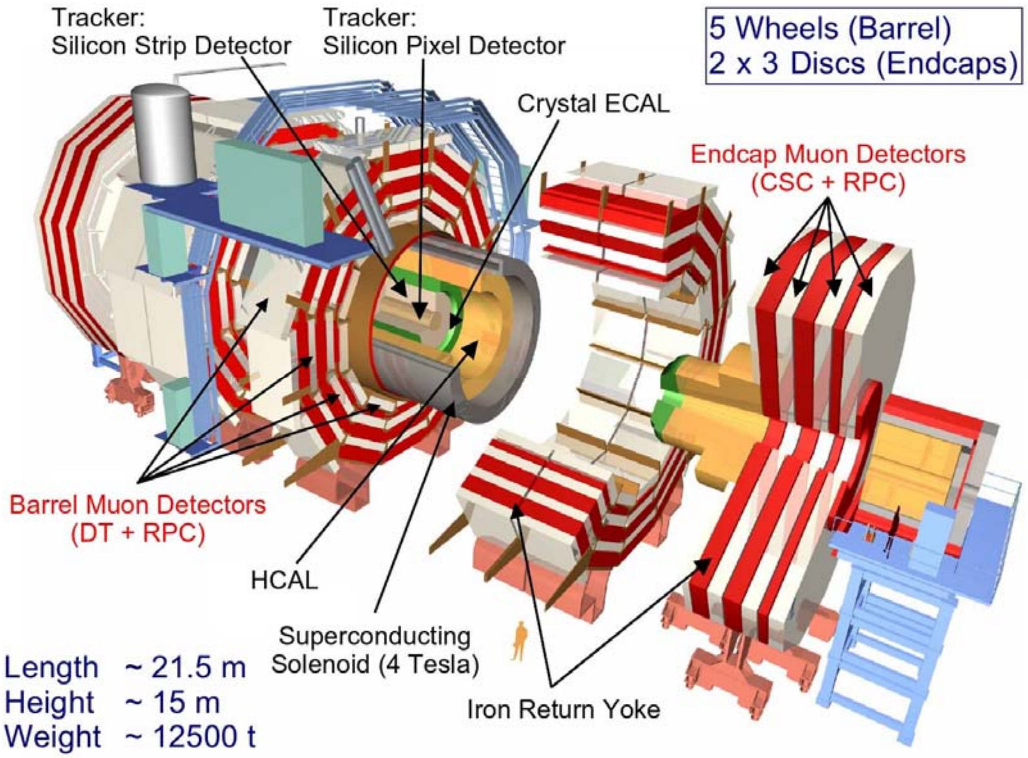
Radiation Hard Sensor Materials for the CMS Tracker Upgrade

M. Bergholz

On behalf of the
CMS Tracker Collaboration

Introduction: CMS @ LHC



- The **C**ompact **M**uon **S**olenoid is one of the 4 main experiments at the **L**arge **H**adron **C**ollider
- To improve sensitivity to rare processes the luminosity will further be increased by a factor of five in the year 2020

=> Sensors with higher radiation hardness and granularity are needed

This talk will only cover planar silicon sensors for the tracker investigated in the HPK-Campaign. *With in CMS also other options like 3D silicon are investigated.*

1. HPK# Campaign (1)

- The goal is to find the best material and geometry choice for the upgrade of the CMS (silicon) tracker
- To achieve this goal **one wafer layout** was designed and produced with different substrates, thicknesses and different production technologies *but* with same production process from **one manufacturer**! **(Hamamatsu)**

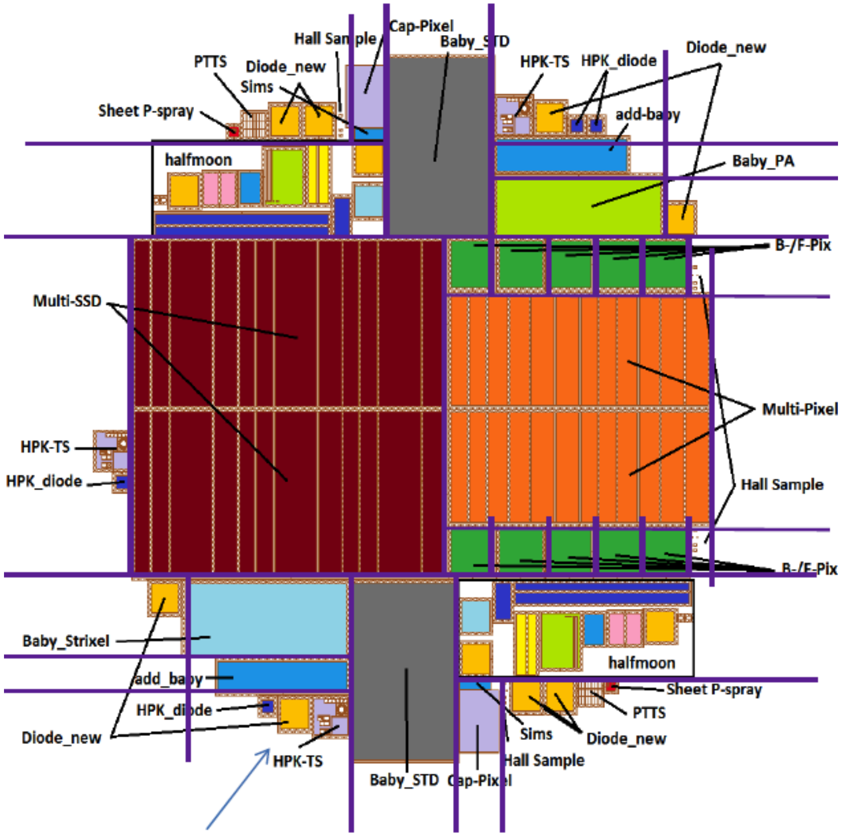
technology / material	FZ-320µm	FZ-200µm	FZ-200µm*	FZ-120µm	FZ-120µm*	MCz-200µm	Epi-100µm	Epi-50µm
P-in-**N**	6	6	6	6	6	6	6	6
N-in-**P** pstop	6	6	6	6	6	6	6	6
N-in-**P** pspray	6	4	6	4	6	6	6	6
2'nd metal **P**-in-**N**			6					
2'nd metal **N**-in-**P** pstop			6					
2'nd metal **N**-in-**P** pspray			6					

FZ – **F**loating **Z**one silicon
MCz – **M**agnetic **Cz**ochralski silicon
Epi – **EPI**taxial silicon

* Physical thickness is 320µm, active thickness is reduced by a "*Deep Diffusion*" process
Hamamatsu **P**hotonics **K**K

In total 158 wafers have to be qualified, irradiated and re-qualified.

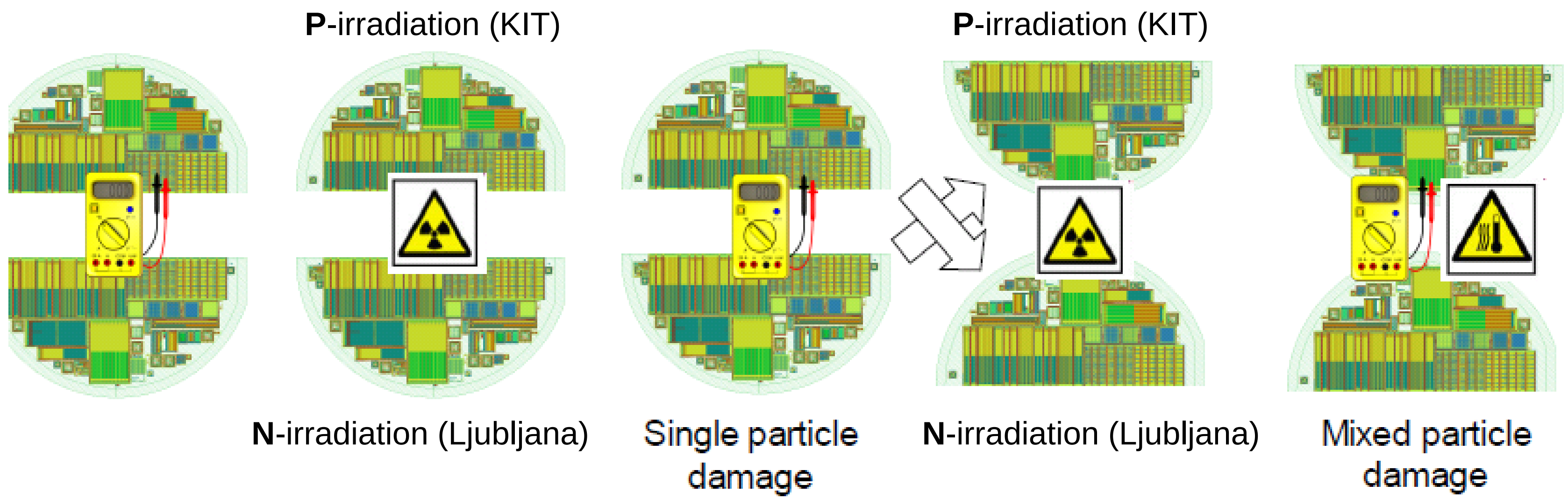
1. HPK Campaign (2)



Wafer is cut into 30 pieces e.g.:

- Test-Structures **Process/surface**
- Diodes **Irradiation/annealing/material**
- Multi geometry pixels **Geometry**
- Multi geometry strips
- Baby_std sensor **Irradiation/annealing**
- Baby_PA sensor **Routing/design**
- Baby_Strixel sensor
- Add_Baby **Lorentz angle**

1. HPK Campaign (3)

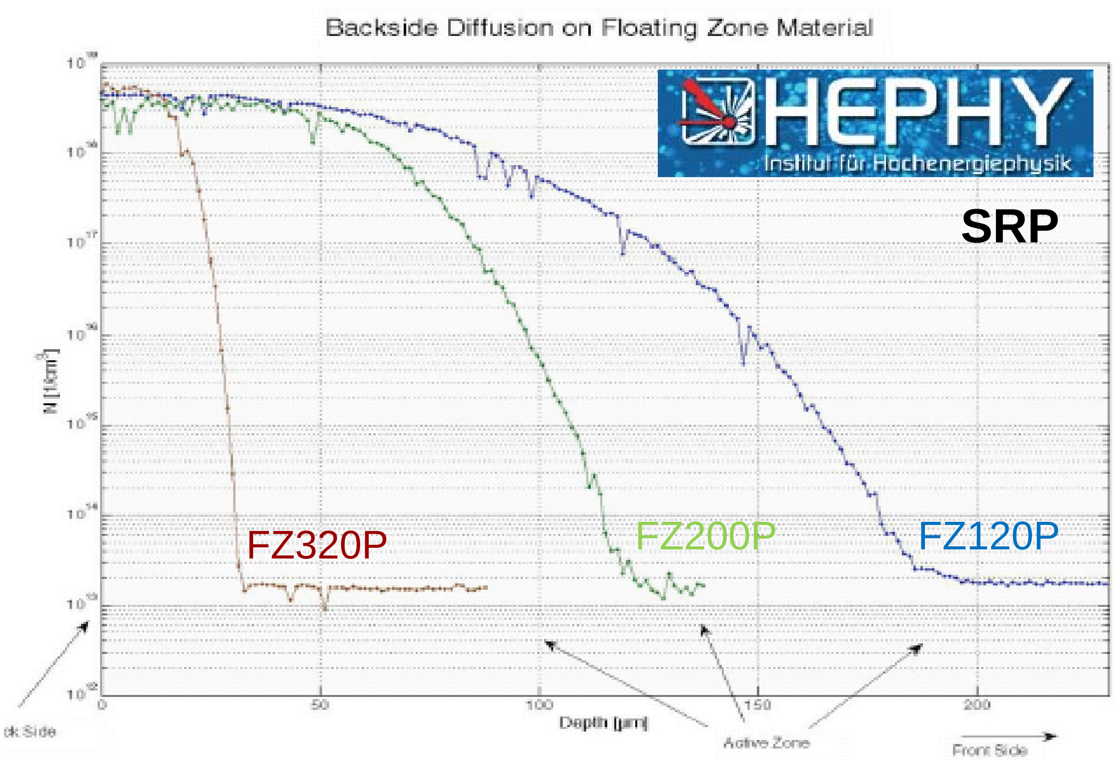


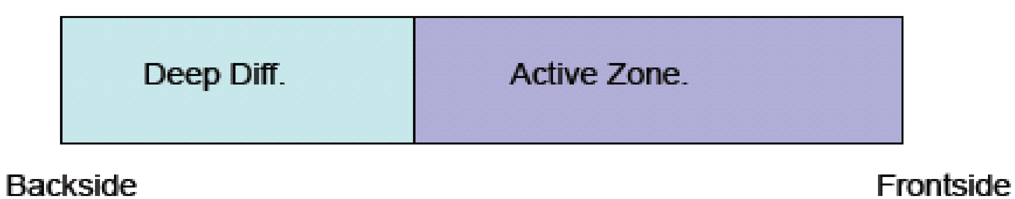
Expected fluences at $3000fb^{-1}$ for CMS

Radius [cm]	Protons [10^{14} n_{eq}/cm^2]	Neutons [10^{14} n_{eq}/cm^2]	Sum [$10^{14} n_{eq}/cm^2$]	Ratio P/N
5	**130**	**10**	**140**	**13**
10	30	7	37	4.3
15	15	6	21	2.5
20	10	5	15	2
40	3	4	7	0.75

Corresponding to simulated fluences
- Single and mixed particle irradiation for 5 radii
- Electrical measurements after each irradiation
- Several beam tests
- Annealing studies after irradiation

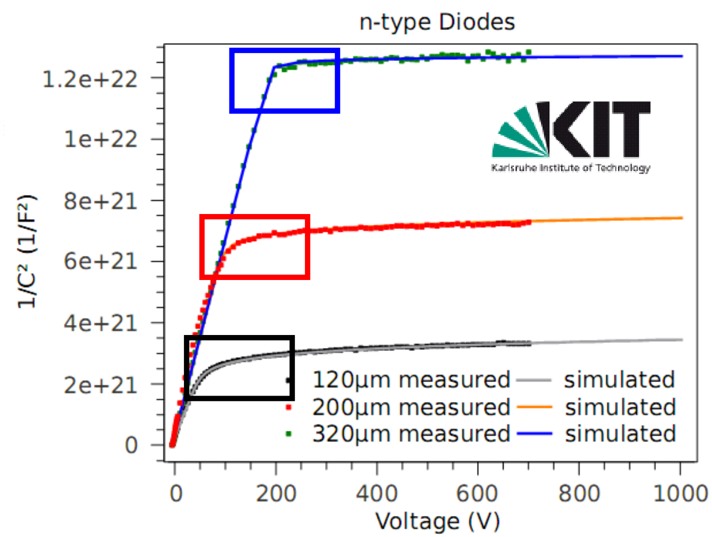
2. First results: Production Process Analysis



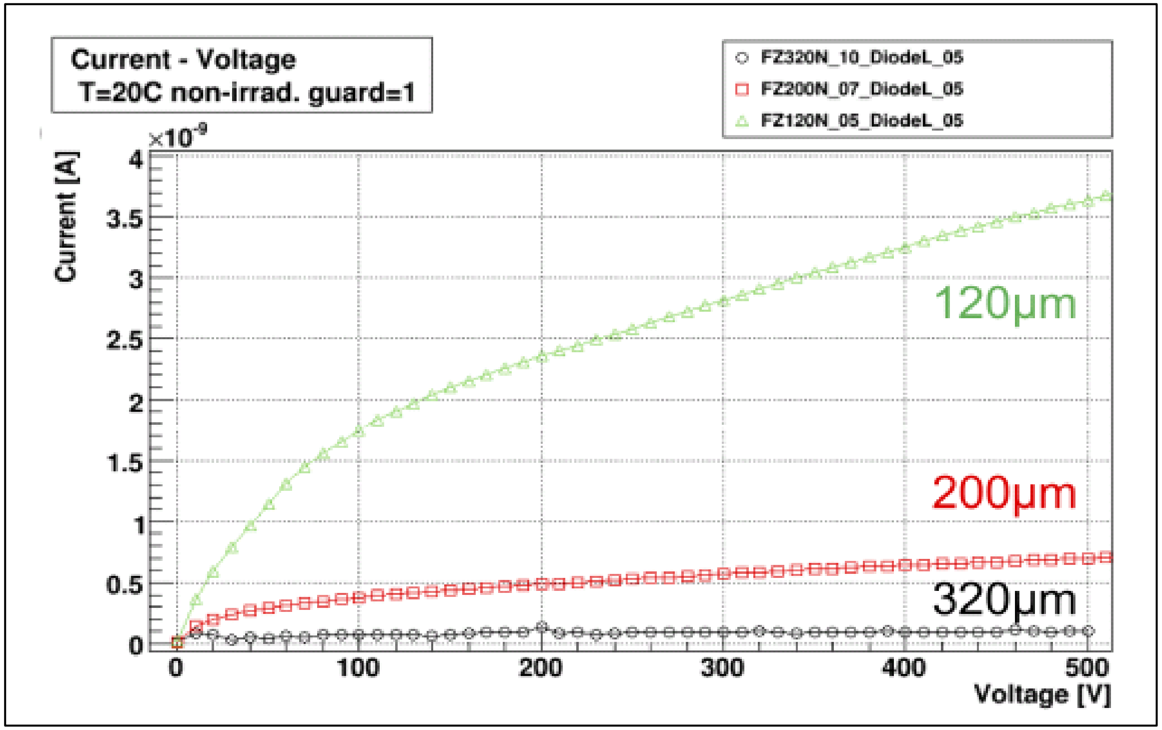


Spreading **R**esistance **P**rofiling measurements show the back side doping profile for different sensor thicknesses

Such profiles are used to compare simulations with measured curves

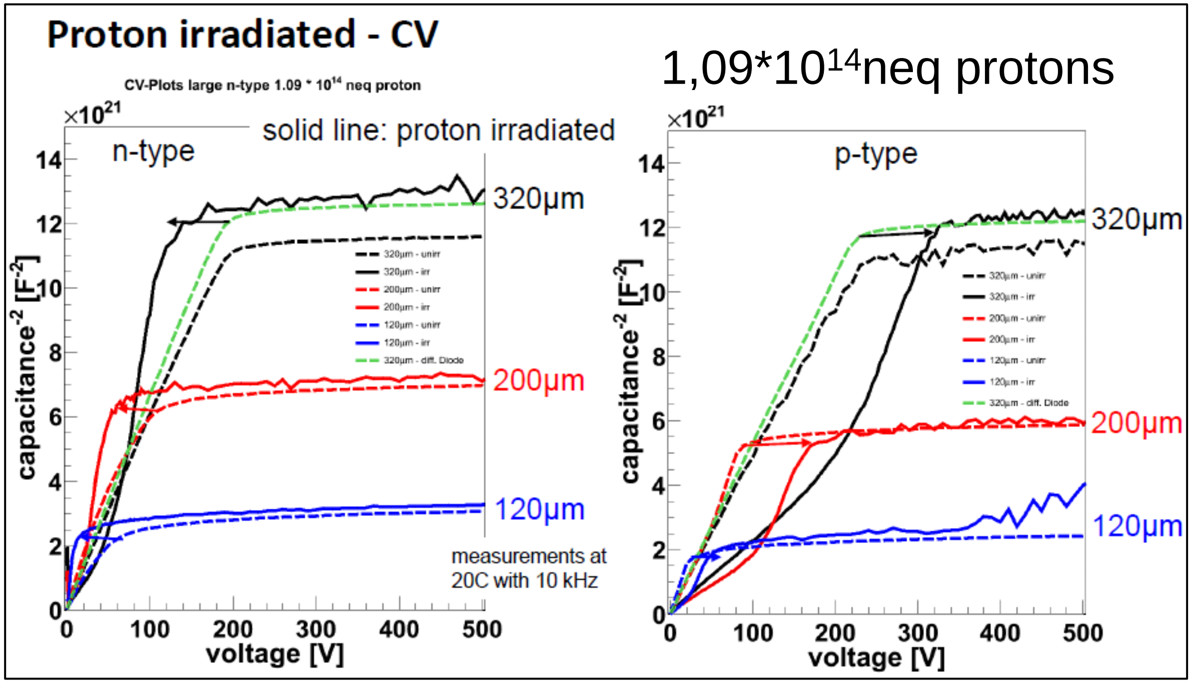


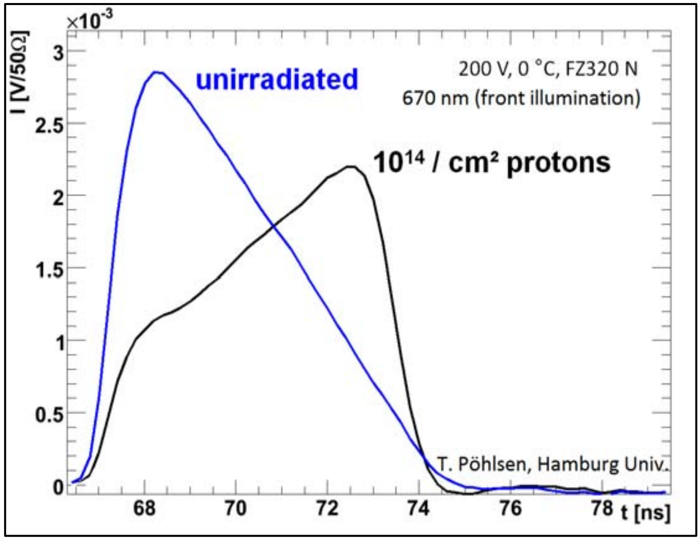
2. First results: Diodes (1)



- Currents for thin diodes are higher than for thick diodes; that indicates that the deep diffusion process produces defects acting as current generators
- This could be confirmed with additional Deep Level Transient Spectroscopy (DLTS) where a so called H220K defect was identify as current generator

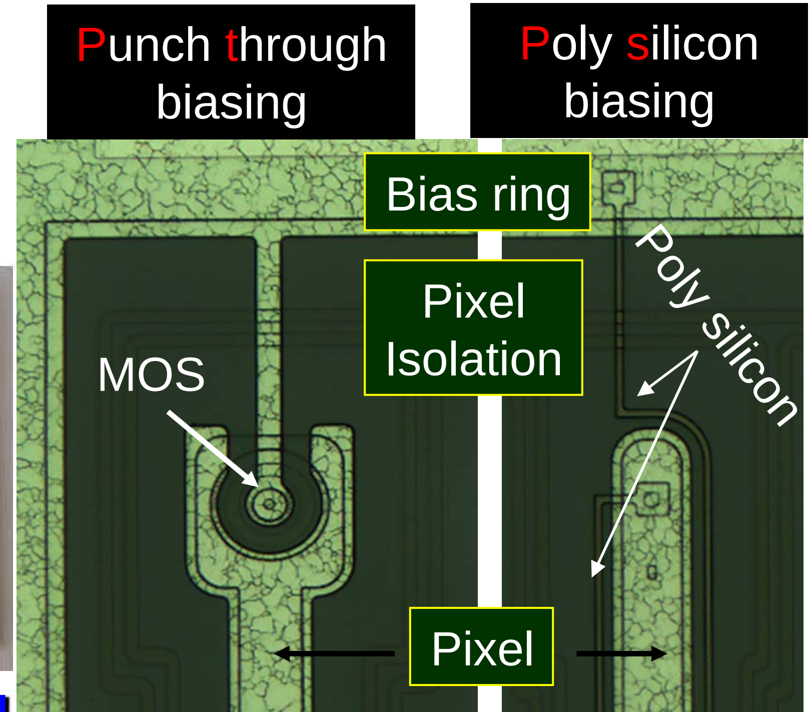
2. First results: Diodes (2)

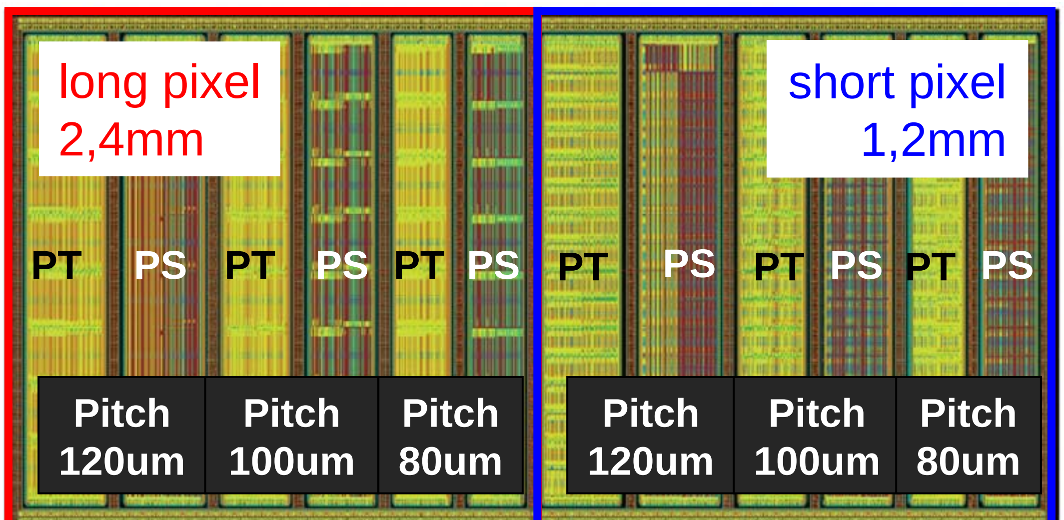


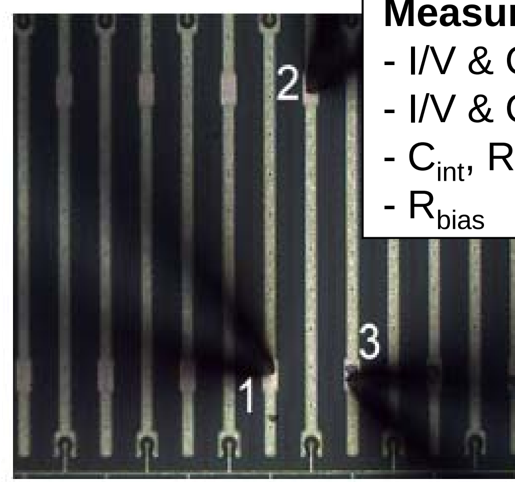


- For n-type sensors the depletion voltage decreases with fluence
- contrary: it increases for p-type sensors
- reason: type inversion of the n-type sensors (could be confirmed with TCT measurements)

MPIX sensors



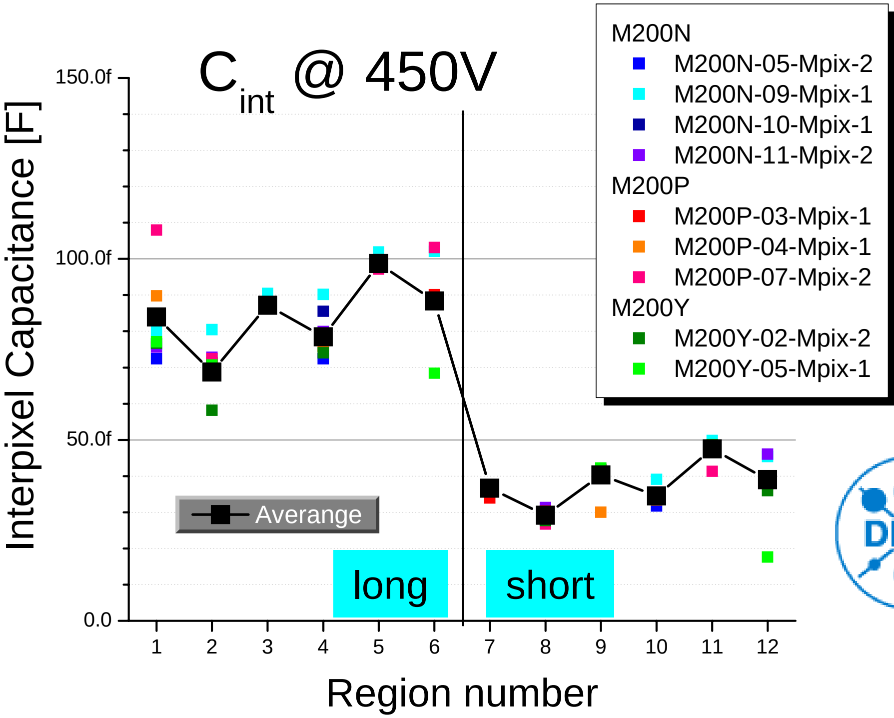


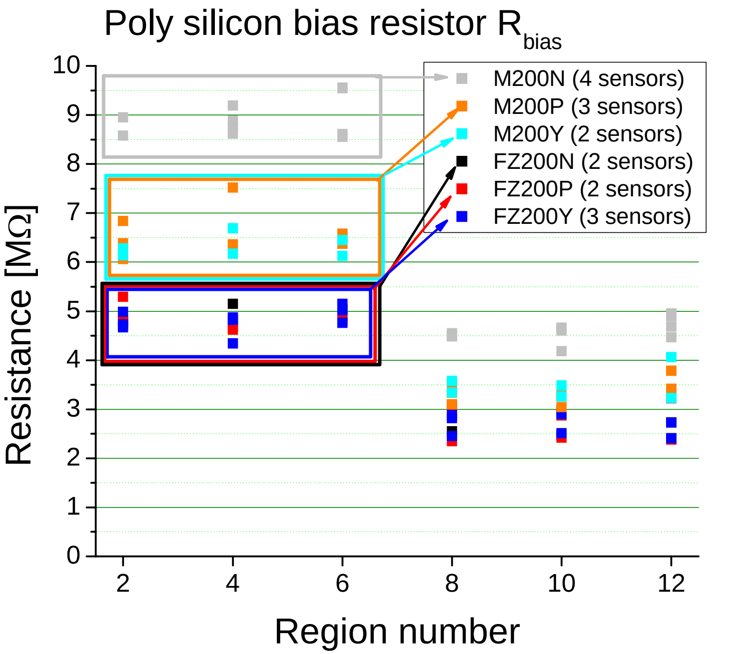


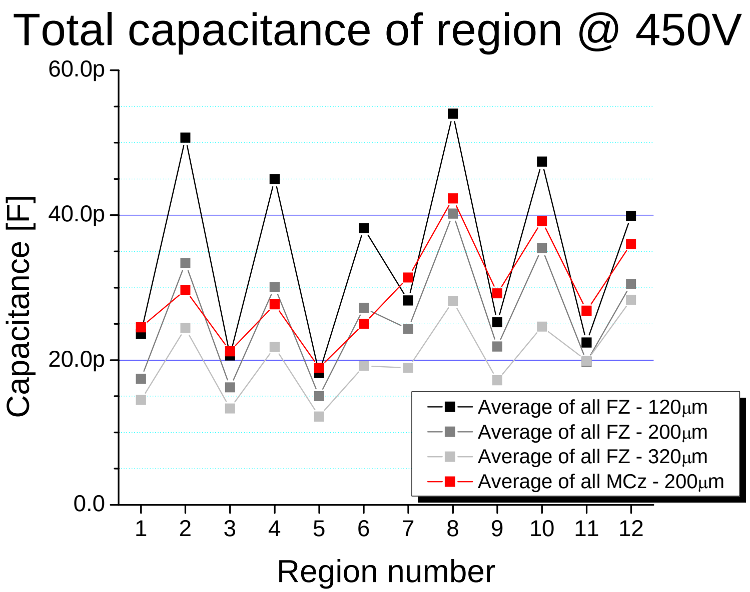
Measurements
- I/V & C/V bias ring
- I/V & C/V single pixel
- C_{int}, R_{int}
- R_{bias}

→ inner layers, P_t-module *(N41-5, N24-2)*

First results: MPIX







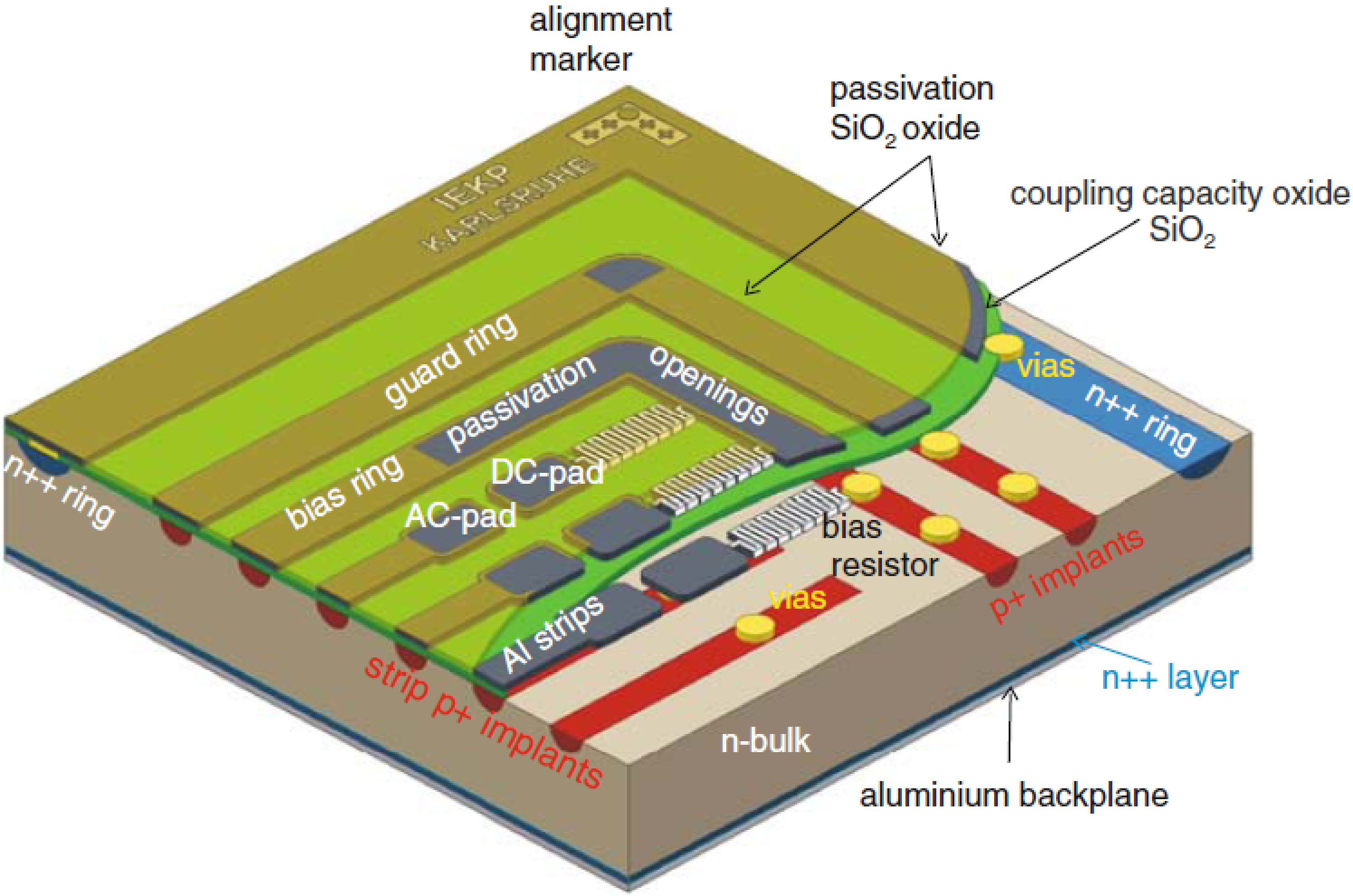
- C_{int} is lower for PT biased structures,
  (no significant difference between isolation technologies)
- Bias resistor is higher for MCz sensors
- The total capacitance at 450V is higher for PS biased regions

3. Summary / Outlook

- Most of the materials and structures have been characterized
- Sensor quality is in general very good
- First irradiations were done and irradiated sensors are now being investigated
- Test beam data now being analyzed
- End of 2012 final conclusions for material choice of future CMS tracker are planned

Backup

Silicon sensor



F. Hartmann, *Evolution of Silicon Sensor Technology in Particle Physics*, STMP 231 (Springer, Berlin Heidelberg 2009), DOI 10.1007/ 978-3-540-44774-0

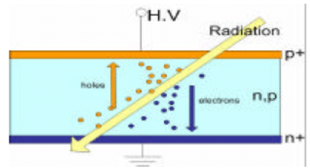
Transient Current Technique

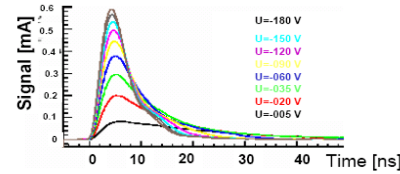
Alison Bates, Michael Moll

TCT Analysis provides information on:

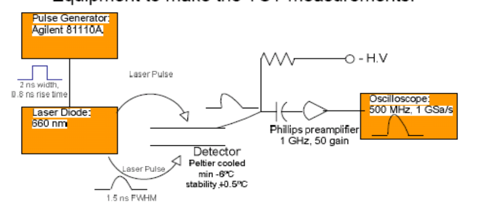
- Electric field formation
- Effective trapping time
- Charge collection efficiency
- Full depletion voltage

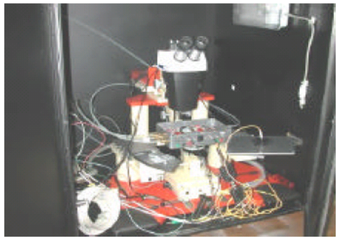
• Normal detector operation:



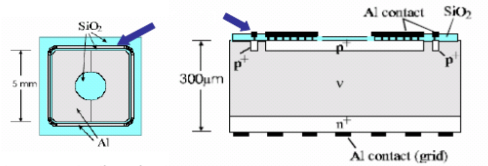


Equipment to make the TCT measurements:



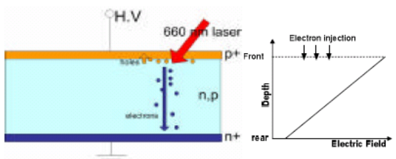


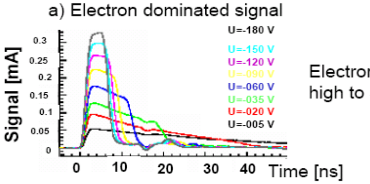
Test structures used to characterise the material:



• 660 nm Red laser illuminates the front of the detector, penetration depth ~few µm

a) Electron dominated signal

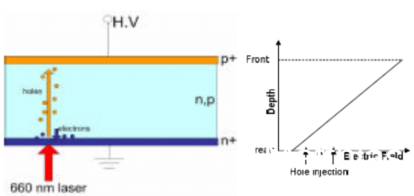


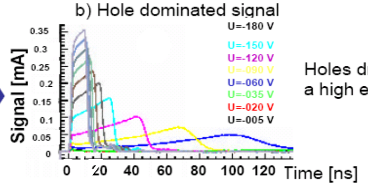


Electrons drift from a high to a low electric field

• 660 nm Red laser illuminates the rear of the detector

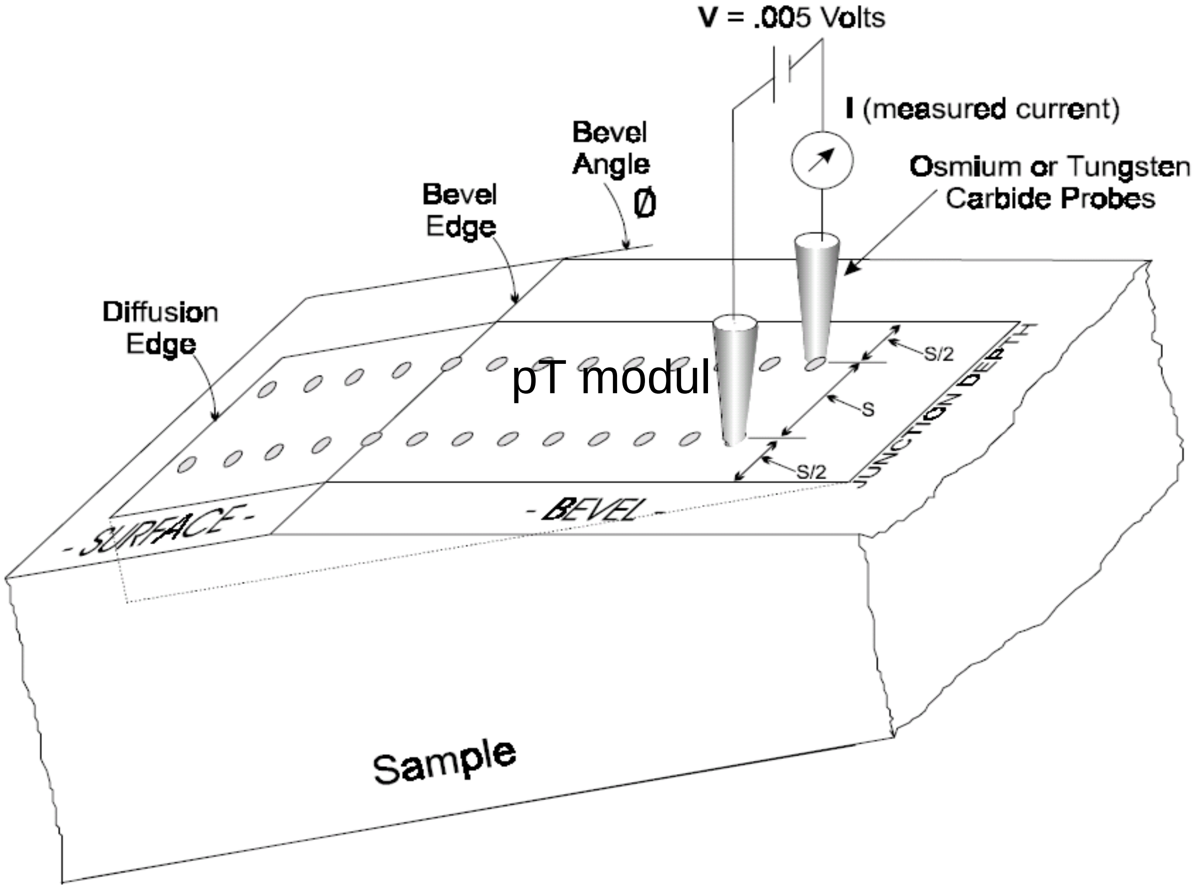
b) Hole dominated signal





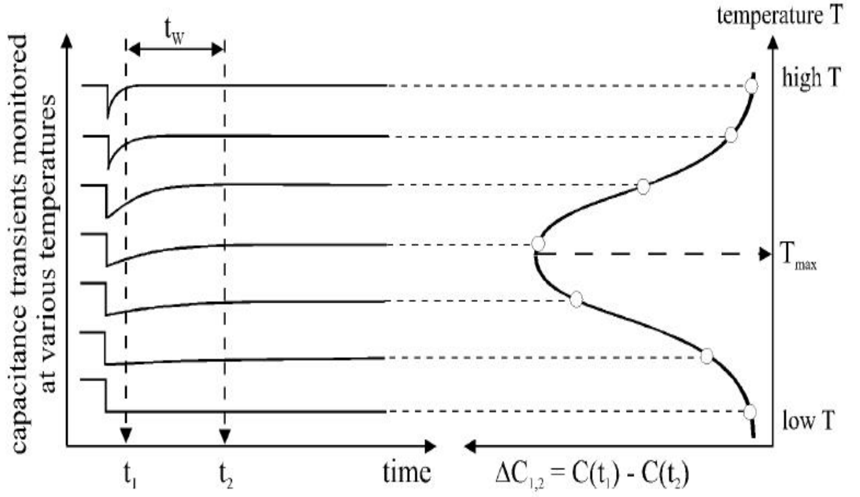
Holes drift from a low to a high electric field

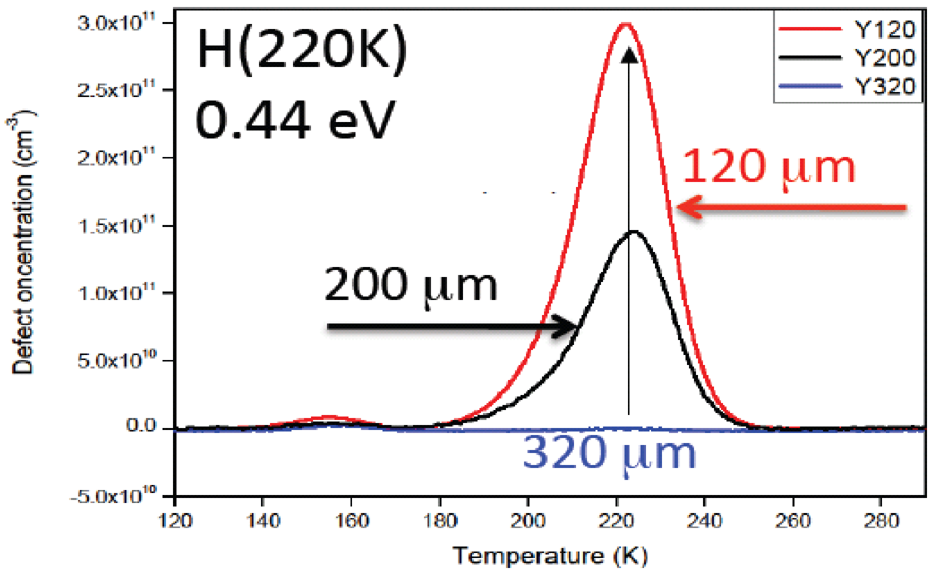
Spreading **R**esistance **P**rofiling



Source: SOLECON LABS TECHNICAL NOTE

DLTS





- Traps are filled by a voltage ramp
- After 'capacitance vs. time' was measured, τ de-trapping constant
- DLTS Signal is difference for two different times t_1 and t_2

$$C(t) \propto \exp\left(-\frac{t}{\tau}\right)$$

$$\Delta C(T) = C(t_1) - C(t_2)$$

Source: PhD thesis of Alexandra Junkes University Hamburg, 2011

Biasing and isolation technics

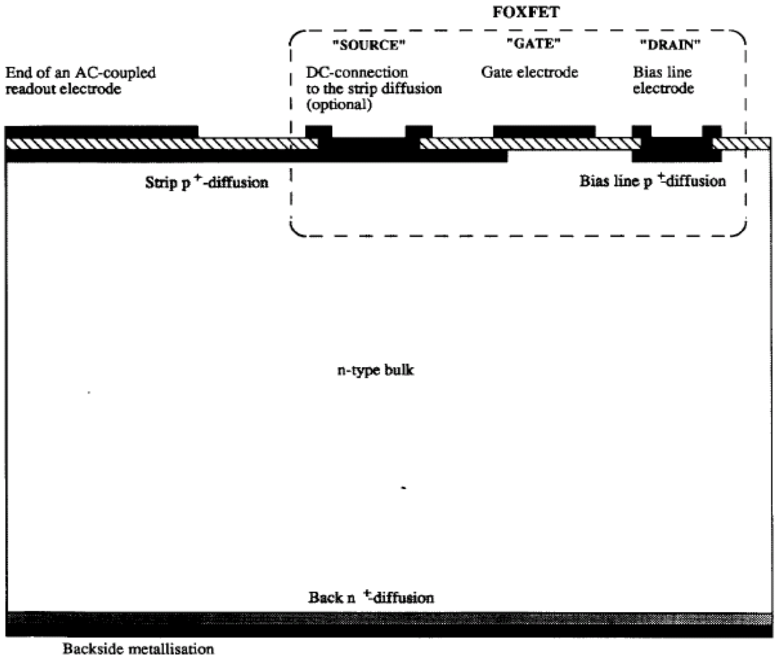
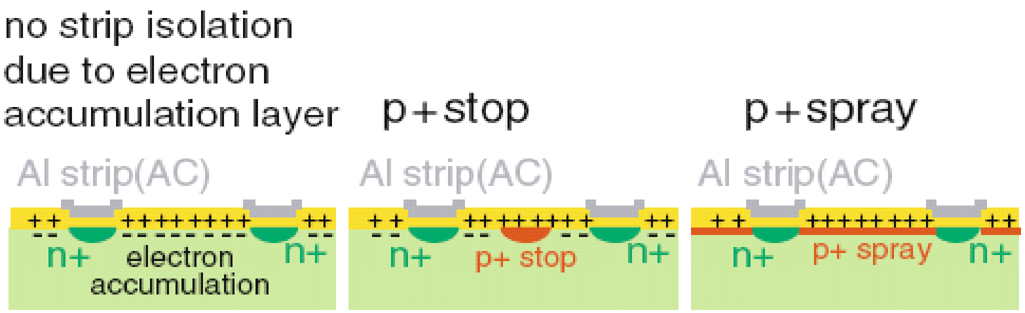


Fig. 1. A cross section along the direction of the strips of the FOXFET structure.



Operation and radiation resistance of a FOXFET biasing structure for silicon strip detectors

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F. Hartmann, *Evolution of Silicon Sensor Technology in Particle Physics*, STMP 231 (Springer, Berlin Heidelberg 2009), DOI 10.1007/ 978-3-540-44774-0