Front-side biasing of n-in-p silicon strip detectors

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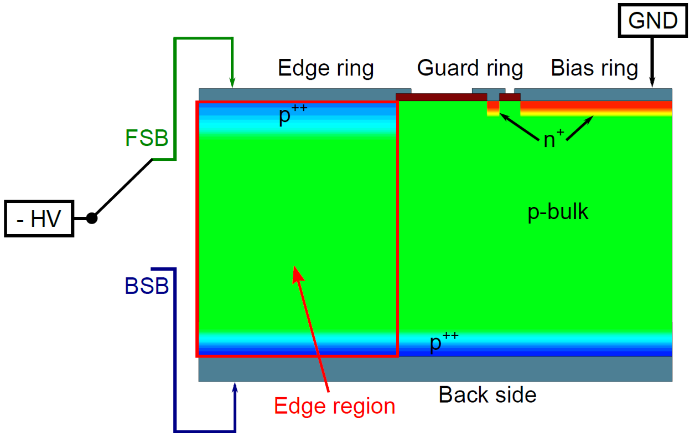
INSTITUT FÜR EXPERIMENTELLE TEILCHENPHYSIK

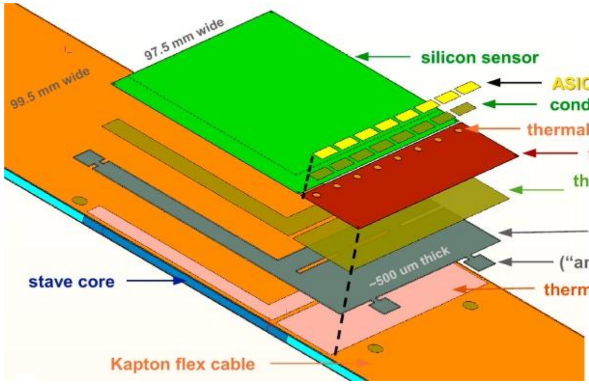
32nd RD50 Workshop in Hamburg

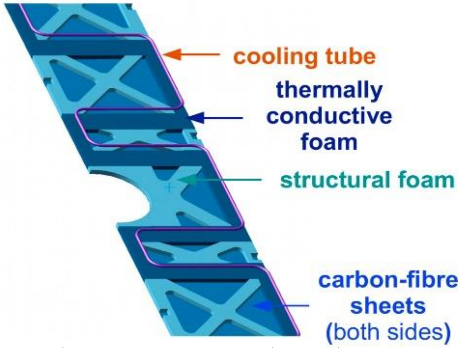


Why front-side biasing?

- Module assembly could be simplified by accessing front-side only
  - connecting back-side for biasing sometimes tricky

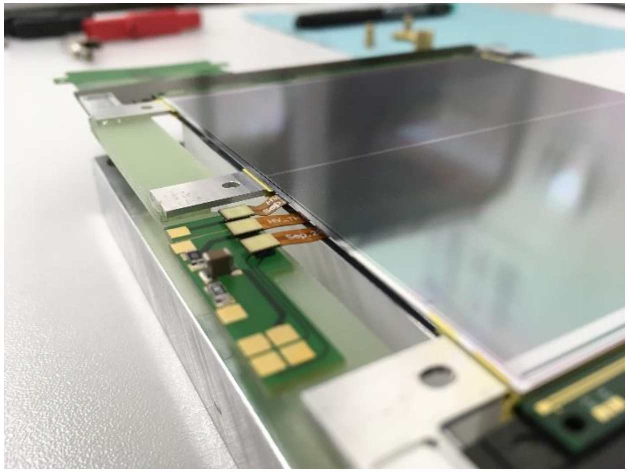
Passivated back-side





LHCb Upstream Tracker, *NIM A831 (2016) 367–369*

Sandwich structures



CMS OT proto. module

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Disclaimer

- This study focuses on the applicability in large scale systems, for which also a simplified assembly is required
- Most of the previous studies on this subject concentrated on n-type silicon; here we investigate p-type material!
- Study how FSB is influenced by:
  - operation temperature
  - irradiation
  - annealing

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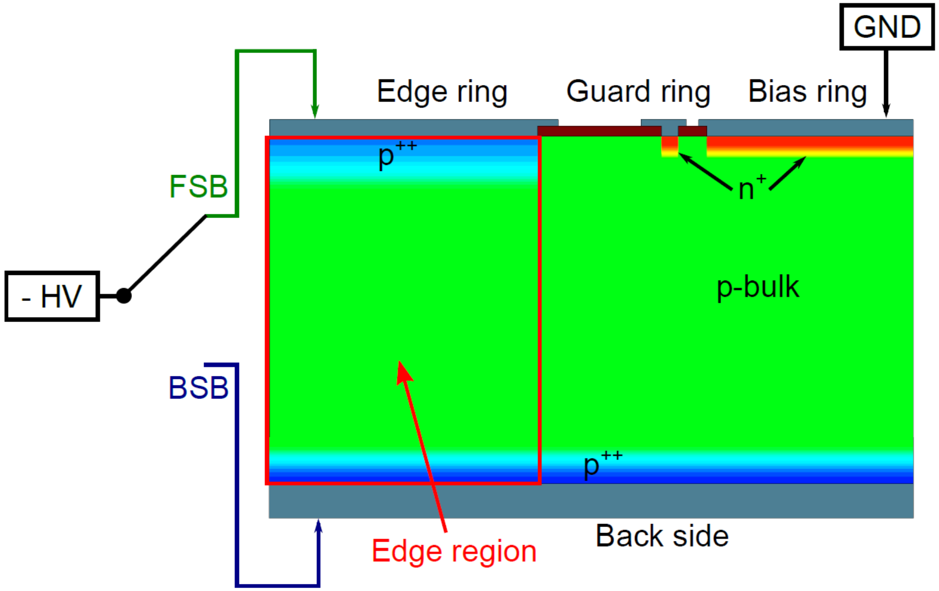
Edge view

- While bias ring is on ground either back-side (BSB) or front-side (FSB) could be connected to HV
- Edge region forms a p^{++}-p-p^{++} contact and is initially conductive
  - resistivity is defined by the bulk and the resistance of the contact to the back-side is defined by the geometry

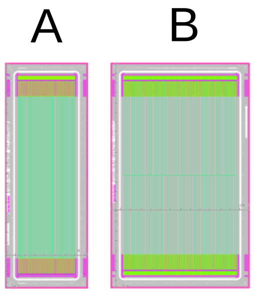
$$R_{edge} = \rho_{edge} \cdot D / A_{edge}$$

  - problems arise when bulk resistivity increases...

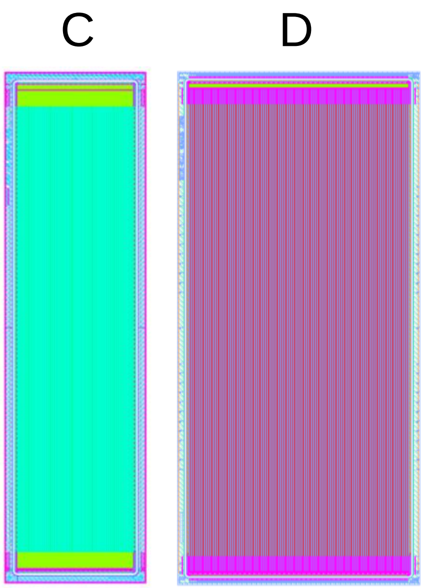


Samples

- n^{++}-p mini-sensors of two vendors (HPK, IFX)
  - most of earlier studies concentrated on n-type material
- Different thicknesses (mainly ddFZ indicated in name)
- Different sensor geometries



Sensor name	A_{sensor} (cm^2)	A_{edge} (cm^2)
A200	1.83	0.38
A240	1.83	0.38
B200	3.10	0.46
B240	3.10	0.46
C240	6.96	0.81
X240	96.66	2.54
D200*	13.49	1.01



*IFX, thinned

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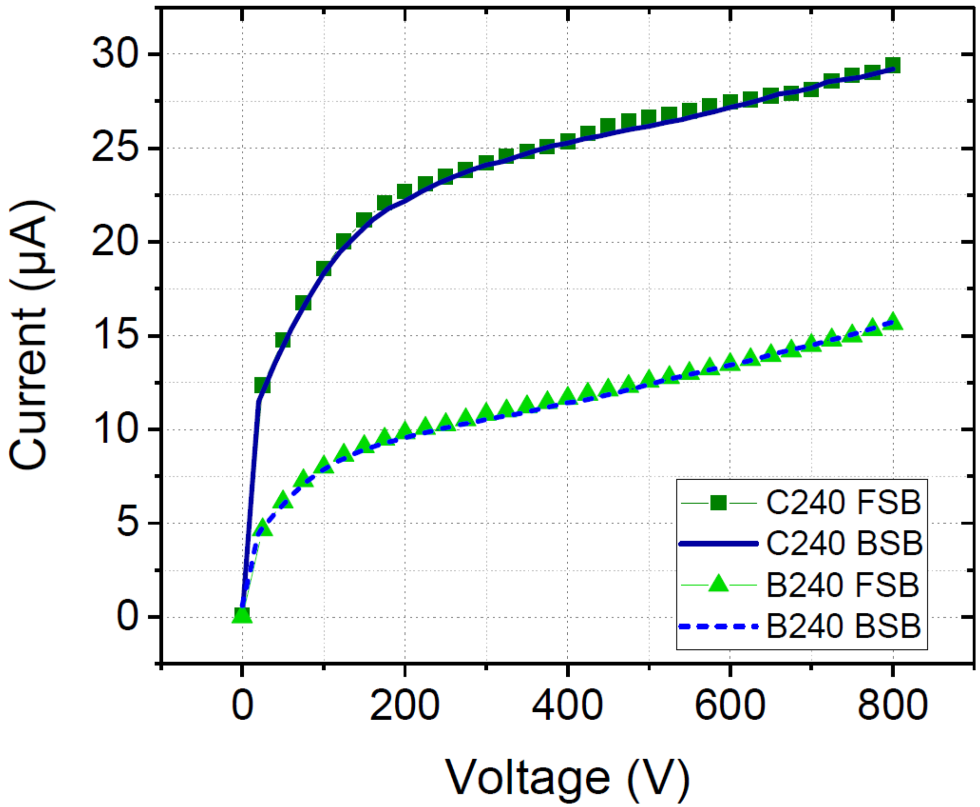
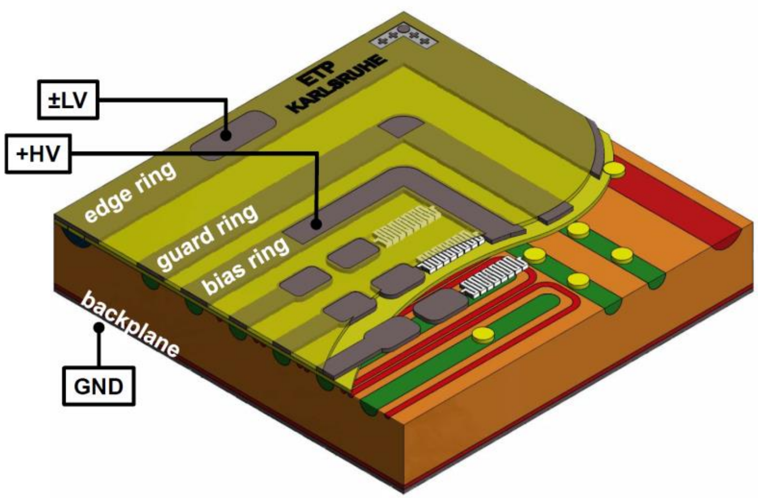
Example before irradiation

- Comparison of IV curves in FSB and BSB configuration can reveal voltage drops if they divert
  - typically they lie on top of each other

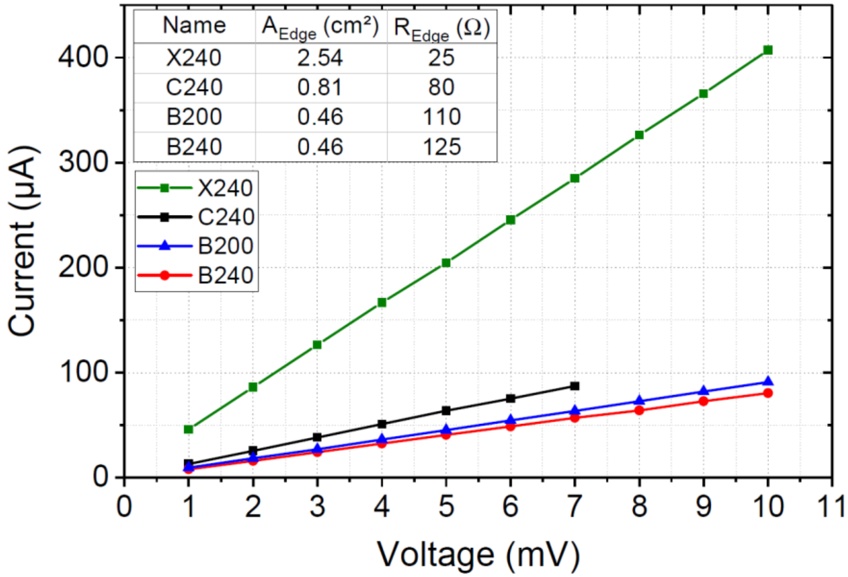


Edge resistivity

- The resistivity can be extracted by an IV curve over the edge, while the sensor is reverse biased
  - need to change potentials of applied bias on the probe station to get a common ground
- Edge resistivity and bulk resistivity are very similar

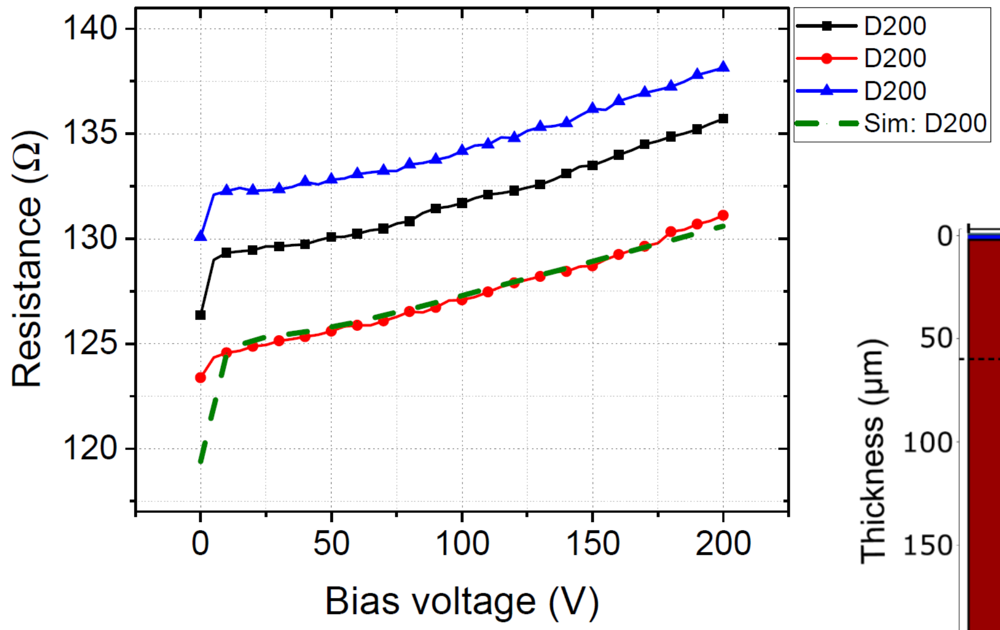


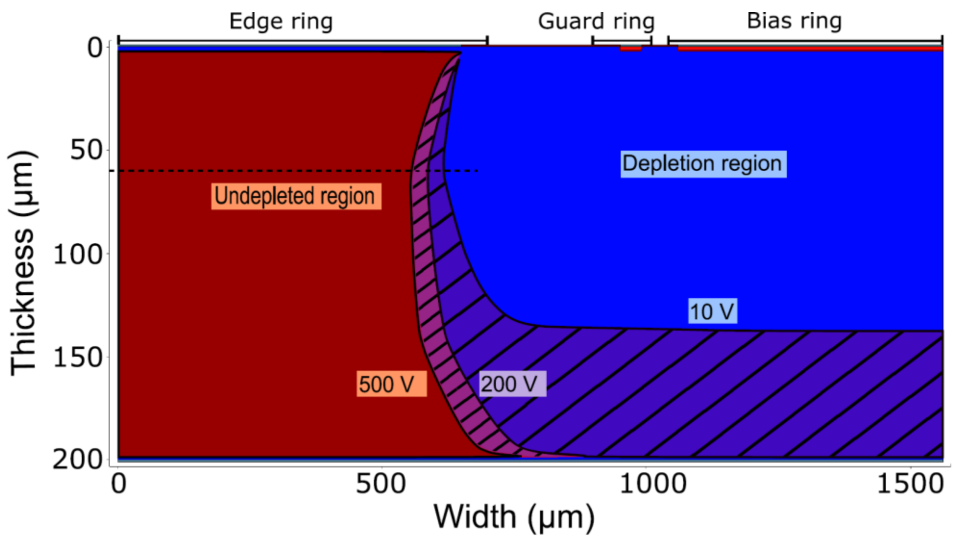
Material	ρ_{ER} (kΩcm)	ρ_{CV} (kΩcm)
240 μm, ddFZ (HPK)	2.7 ± 0.2	3.0 ± 0.1
200 μm, ddFZ (HPK)	2.6 ± 0.4	3.3 ± 0.1
200 μm, FZ (IFX)	6.3 ± 0.6	6.5 ± 0.3



Bias voltage dependence

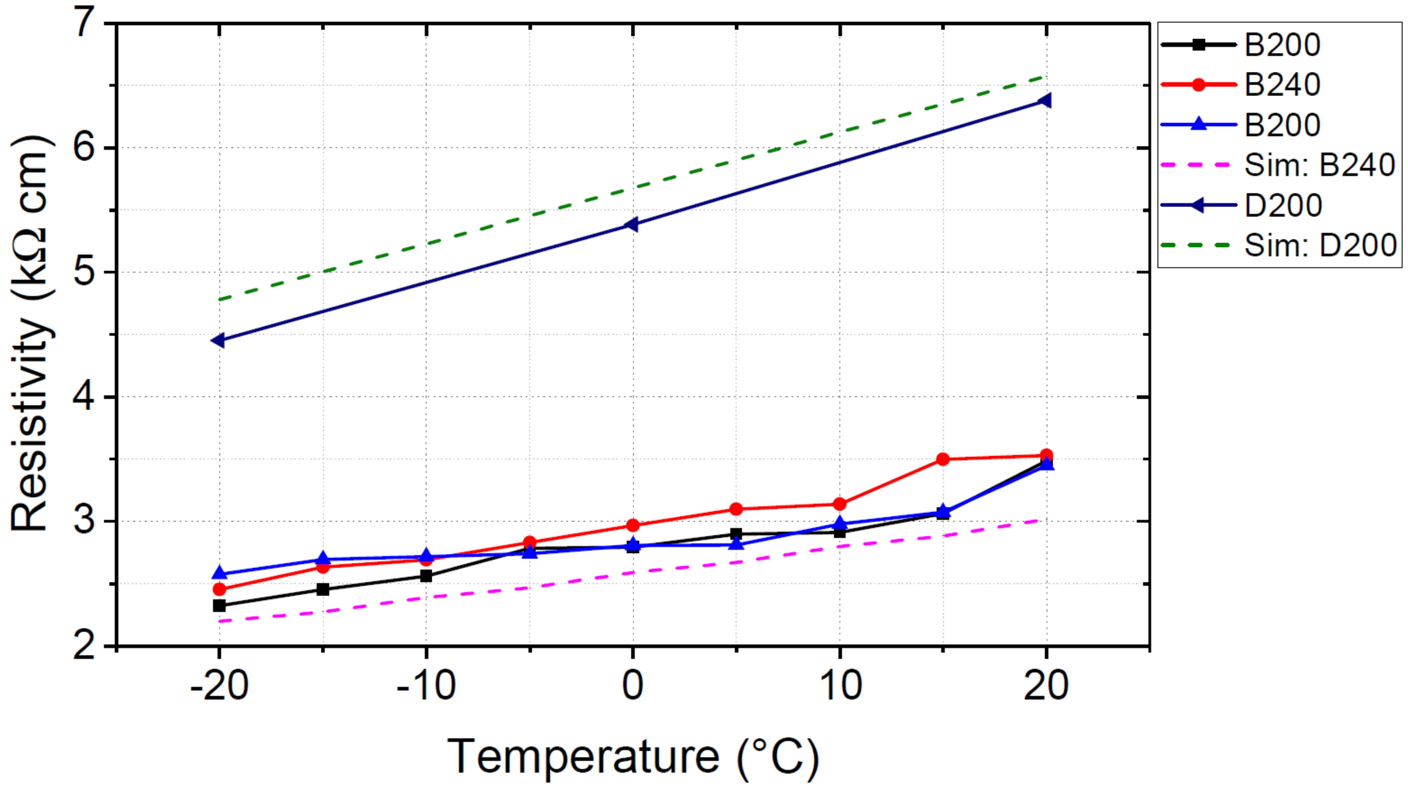
- Edge resistance increases with increasing bias and extending depletion zone
  - shrinkage of edge zone causes reduction of A_{edge}
  - increase supported by TCAD simulations





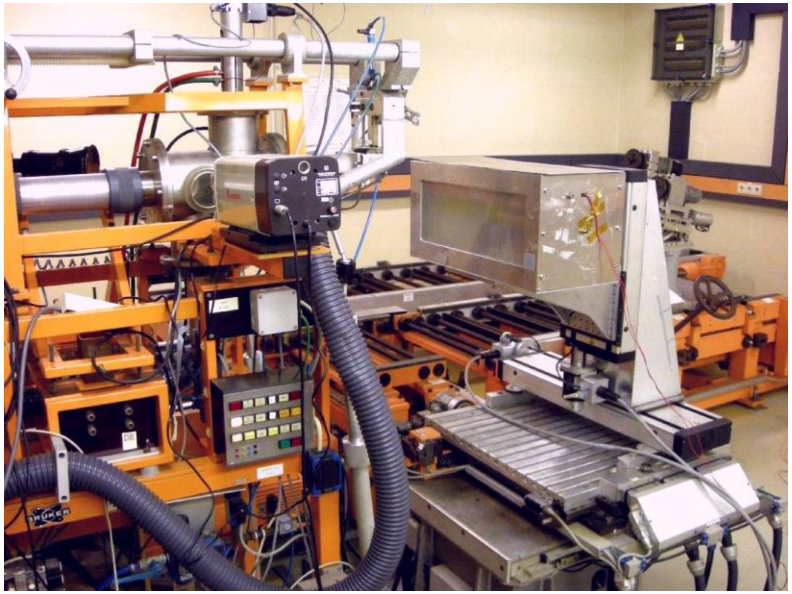
Temperature dependence

- The edge resistivity increases with increasing temperature
  - $\rho \sim T^{3/2}$ (phonon scattering)
  - increase supported by TCAD simulations



Irradiation

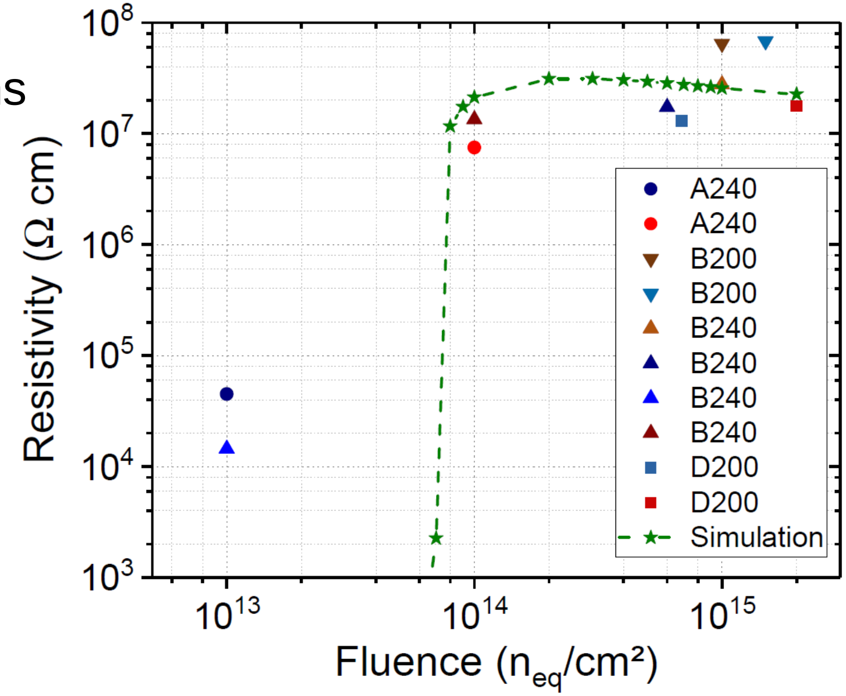
- 23MeV proton irradiation at KIT
- Fluences: $1x10^{13} n_{eq}/cm^2$ to $2x10^{15} n_{eq}/cm^2$
  - (dose: 15kGy – 3MGy)
- Performed cold (flushed with cold nitrogen gas of ~-30°C)
- Irradiating one sensor of 10mm x 20mm to $2x10^{15}$ n_{eq}/cm^2 takes about 20 minutes



http://www.etp.kit.edu/english/irradiation_center.php

Resistivity vs. fluence

- We observe a severe increase of the edge resistivity with fluence
- At $1x10^{14} n_{eq}/cm^2$ of 23MeV protons the edge resistivity reach 10GΩcm
- We also observe a kind of saturation
  - this is supported by TCAD simulations



Extracted resistivity from edge resistivity measurements on irradiated mini sensors for different fluences at a temperature of -20°C.

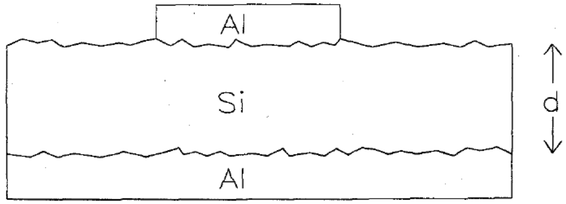
- Extrapolation to large sensors:
  - 10cm x 10cm sensor
  - fluence > $10^{14} n_{eq}/cm^2$
  - resistance to backplane: ~150kΩ
  - voltage drop: ~150V
    - unacceptable additional load on power system and cooling

  → no FSB at high fluence and large sensors

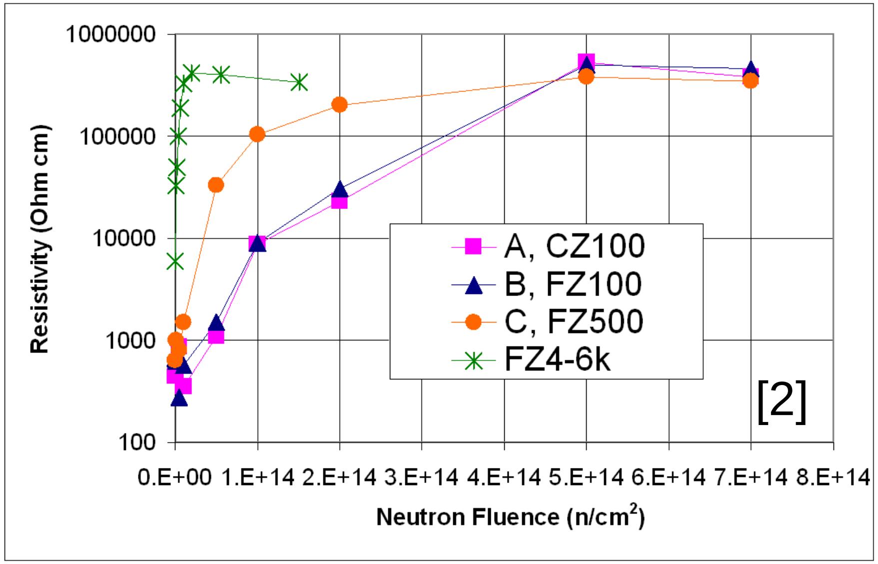
Influence of defects on resistivity

Interpretation?

- The resistivity increases due to the process of "space charge limited currents" already known since long (e.g. [1])
  - Current through the edge is increased (bulk damage effect)
  - Large concentration of charge carriers in edge region occupy defects
  - Resulting E-field opposes current flow
  - Effective resistivity increases
- The fast increase of resistivity with fluence was also shown in [2]



IEEE Trans. Nucl. Sci. **46** (1999) 221.



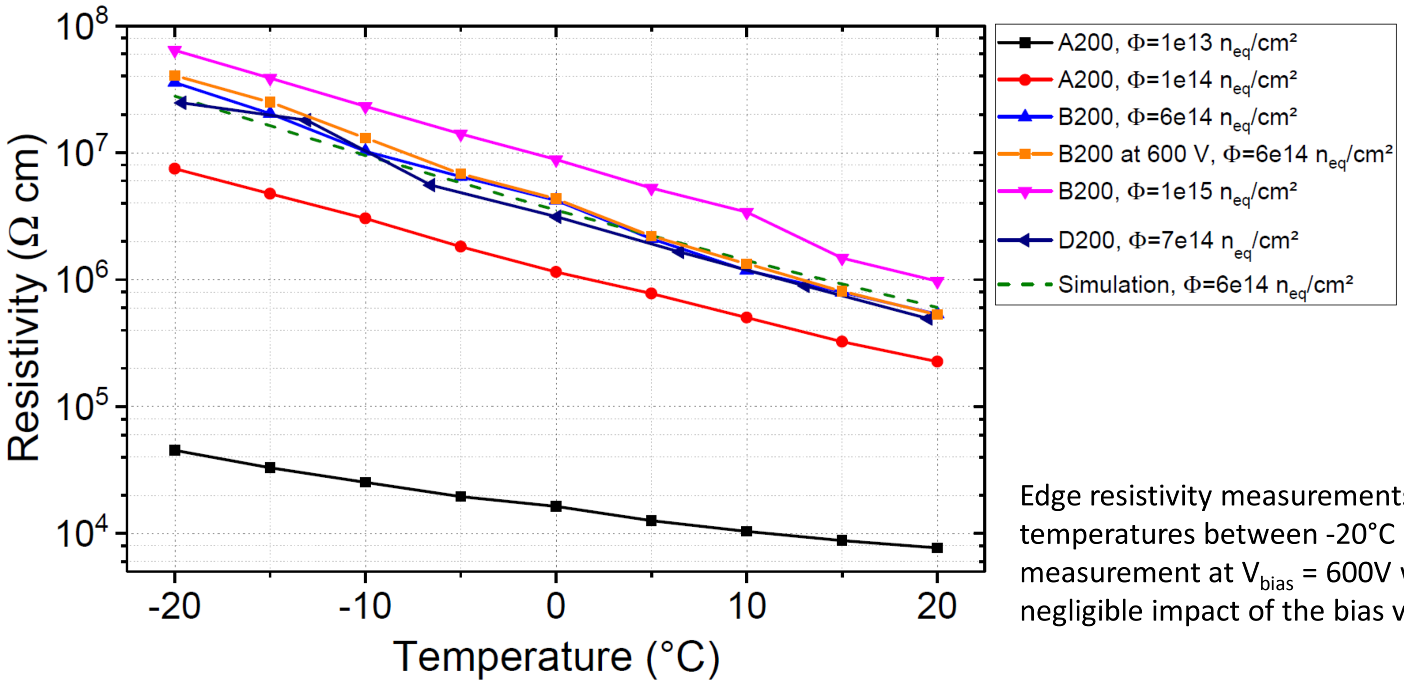
ENB resistivity, obtained from a direct resistor measurement, as a function of neutron fluence for n-type Si materials with different resistivity

[1] A. Taroni and G. Zanarini, "Space charge limited currents in P-N junctions", J. Phys. Chem. Solids 30 (1969) 1861 – 1871.

[2] Z. Li, "Radiation damage effects in Si materials and detectors and rad-hard Si detectors for SLHC", JINST 4 (2009) P03011.

Resistivity vs. temperature (irrad.)

- After irradiation we also observe a reversed and more pronounced temperature dependence
  - non-irrad: ΔT of -40°C → ρ ~**-40%**
  - irrad.: ΔT of -40°C → ρ from **+600%** to +6600%

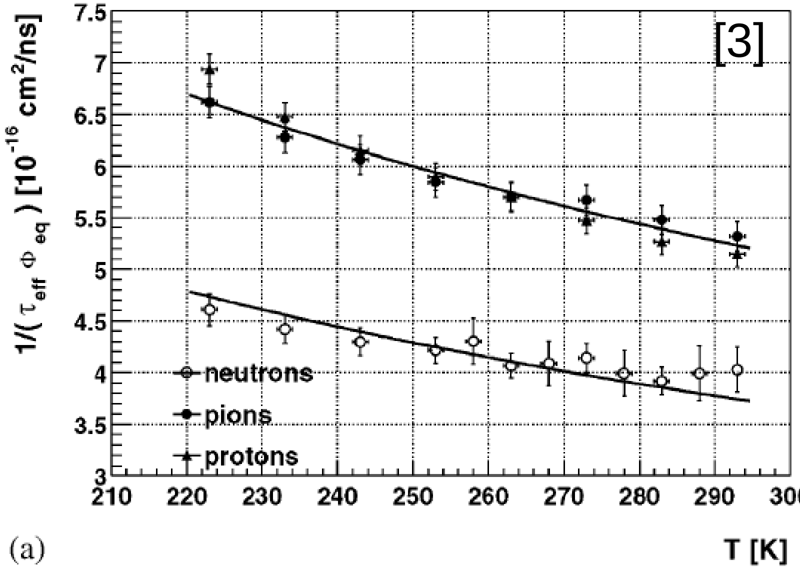


Edge resistivity measurements of irradiated sensors for temperatures between -20°C and +20°C at V_{bias} = 0 V. A measurement at V_{bias} = 600V was added to confirm the negligible impact of the bias voltage after irradiation.

Interpretation?

Influence of trapping on resistivity

- Gregor showed in [3] that trapping probability decreases with increasing temperature
- Therefore less traps are occupied at higher temperature and resistivity is reduced
  - not clear if this explains the increase of resistivity to full extend...



(a)

Fig. 3. Temperature dependence of β for: (a) electrons and (b) holes. The measured points are the average of β's for all measured samples.

[3] G. Kramberger et al., "Effective trapping time of electrons and holes in different silicon materials irradiated with neutrons, protons and pions", Nucl. Instr. and Meth. 481 (2002) 297 – 305.

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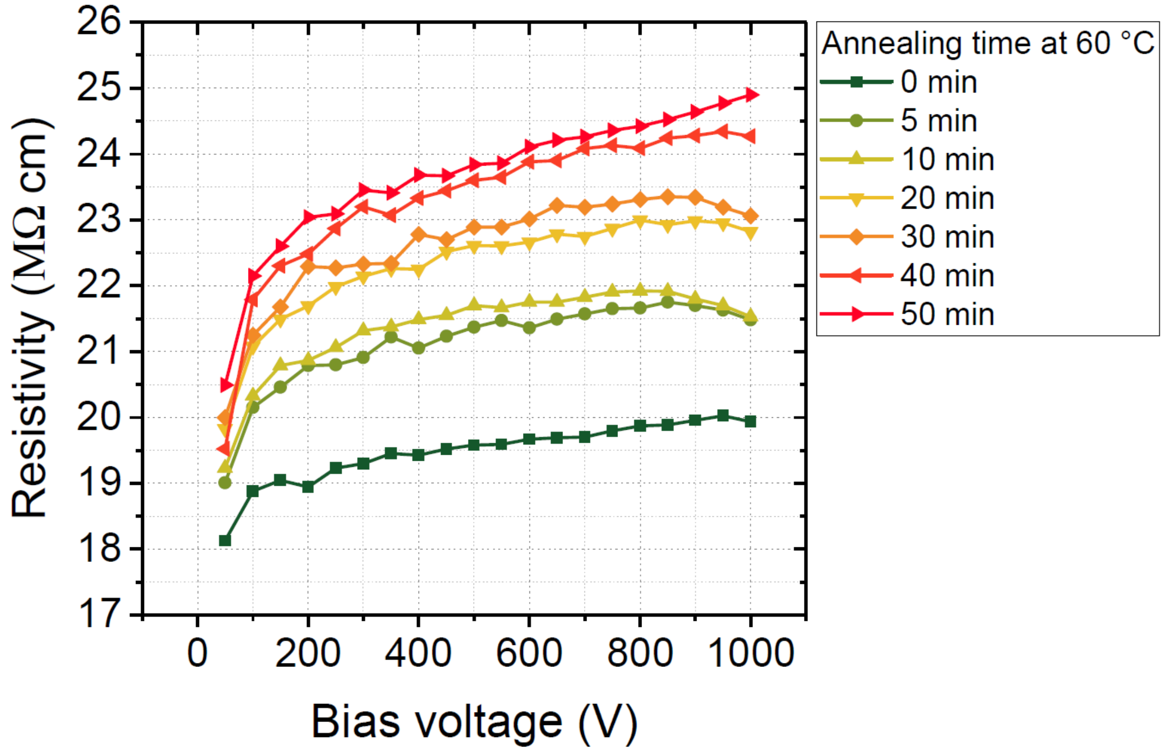
Resistivity vs. annealing

- Resistivity further increases with annealing

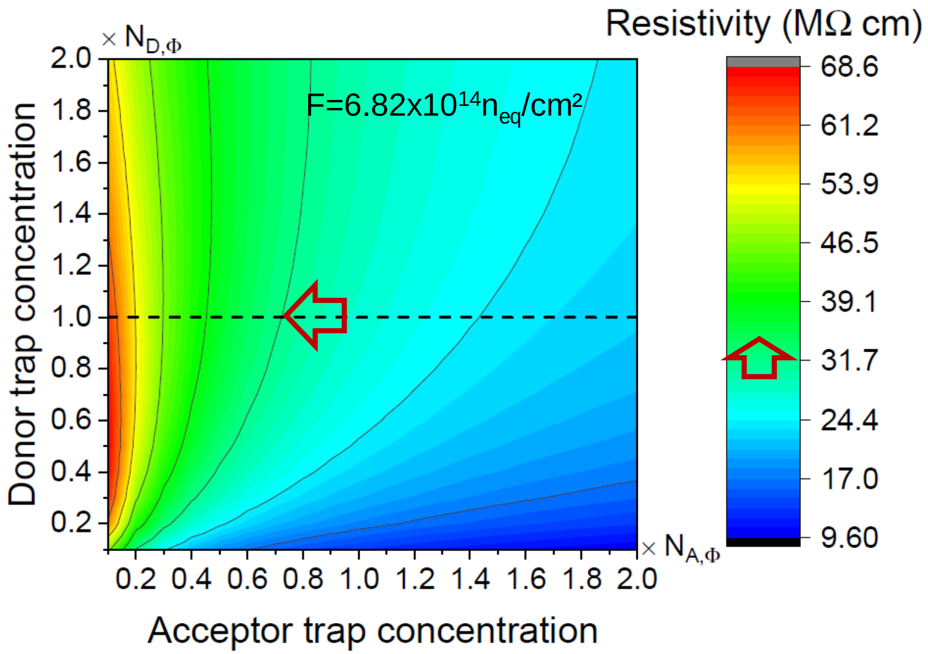


Measured resistivity of a D200 sensor irradiated to a fluence of 6.82x10^{14} n_{eq}cm² with 23 MeV protons, as a function of the bias voltage and different annealing times.

Annealing of traps

Interpretation?

- TCAD simulations were performed with varying trap concentrations
  - A decrease of the acceptor trap increases the resistivity at high fluence
- Several studies indicate that (at least) during beneficial annealing the defect concentration is reduced
  - Decrease of N_{eff} , i.e. shallow defects, was studied, but what about annealing of deeper defects responsible for trapping?
  - Deep acceptors like H(116K), H(140K), H(151K) would increase at least after beneficial annealing though...



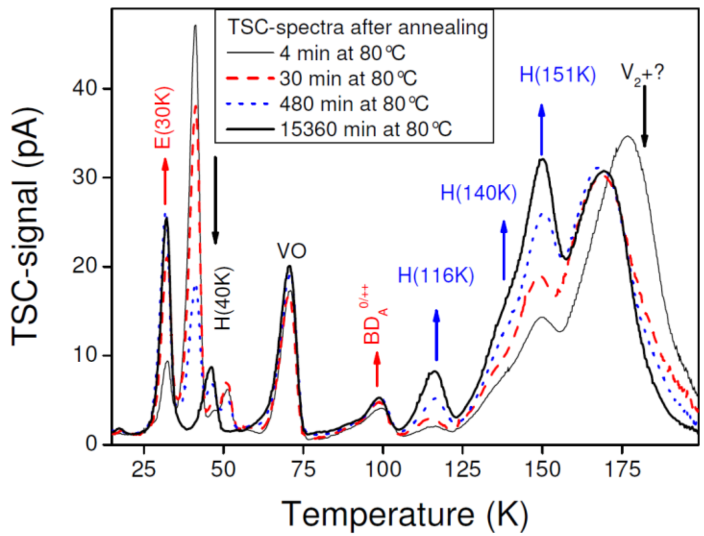
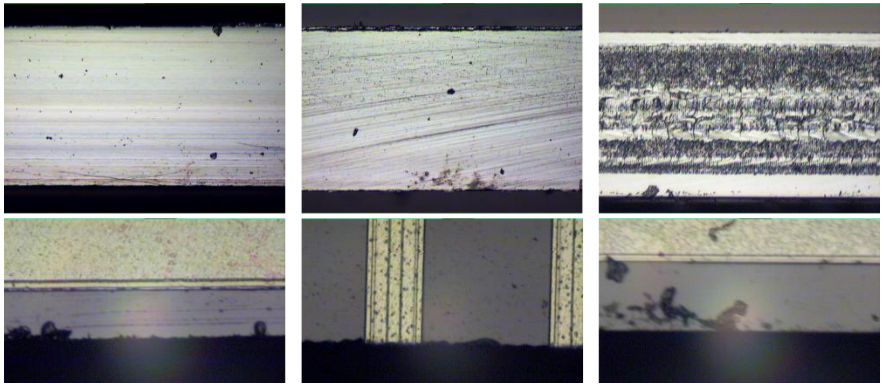


Figure 9.1.5.: TSC spectra illustrating the shallow donors during annealing at 80 °C. Material: Epi-Do, fluence: $\Phi = 2 \times 10^{14}$ n cm^{-2}, measurement at $V_{bias} = 100$ V.

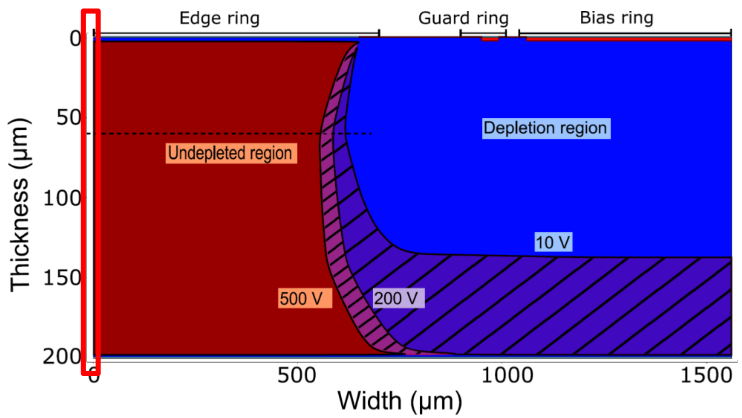
A. Junkes, PhD, 2011

Intrinsic vs. practical case

- These studies focused on the intrinsic properties of the silicon bulk
- In practice there could be severe distortions of the lattice at the diced edge
  - low ohmic path is possible at the cut edges
  - large scale detectors with long edge are more likely to be affected
  - not wise to rely mass production on such a mechanism
- Probability not too big since all mini-sensors in this study showed high resistance after irradiation without a short-circuit at the edge



Industrial saw | In-house saw | Laser dicing



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Summary

- FSB would simplify module assembly in some cases
- Edge resistivity and dimensions influence parasitic bias resistance
- Very high edge resistivity starting from around $1x10^{14} n_{eq}/cm^2$
  - not to be recommended for highly irrad. sensors with large leakage current
- Further findings:
  - Dependence of edge resistivity on T is reversed after irradiation
  - Resistivity further increases with short term annealing

- Further details in CMS NOTE-2018/002 and soon in JINST

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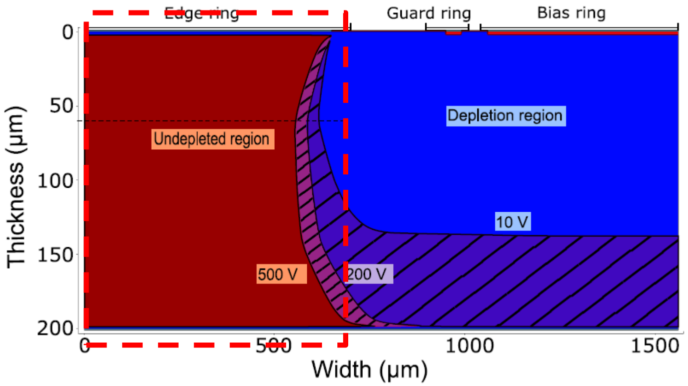
BACKUP

TCAD details

- Product: Synopsys Sentaurus
- Only oxide charge N_{ox} used; no interface traps or charge
- Simulated geometry:
  mainly the p^{++}-p-p^{++} region
- Physics models:
  - Fermi
  - Hydrodynamic(hTemperature)
  - Mobility (DopingDependence eHighFieldSaturation hHighFieldSaturation CarrierCarrierScattering (ConwellWeisskopf) Enormal)
  - Recombination (SRH (DopingDependence TempDependence ElectricField (Lifetime=Hurkx DensityCorrection=none)) Auger eAvalanche (vanOverstraeten Eparallel) hAvalanche (vanOverstraeten Eparallel) Band2Band (Hurkx))
  - EffectiveIntrinsicDensity(Slotboom)
  - Recombination (CDL(TempDependence DopingDependence))
- Defect parameters:



Parameter	Donor	Acceptor
Energy (eV)	$E_V + 0.48$	$E_C - 0.525$
Conc. (cm^{-3})	$5.598\ cm^{-1} \times \Phi - 3.949 \cdot 10^{14}$	$1.189\ cm^{-1} \times \Phi + 6.454 \cdot 10^{13}$
$\sigma(e)$ (cm^2)	$1.0 \cdot 10^{-14}$	$1.0 \cdot 10^{-14}$
$\sigma(h)$ (cm^2)	$1.0 \cdot 10^{-14}$	$1.0 \cdot 10^{-14}$