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Radiation hardness studies of epitaxial diodes for the $\bar{P}$ANDA Micro-Vertex-Detector

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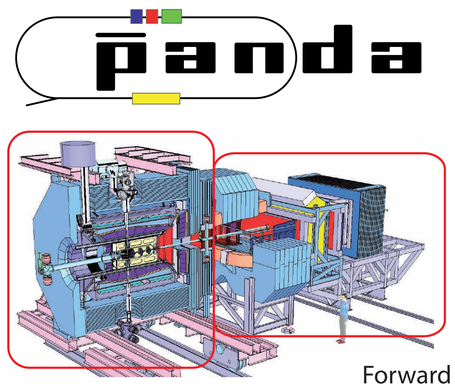
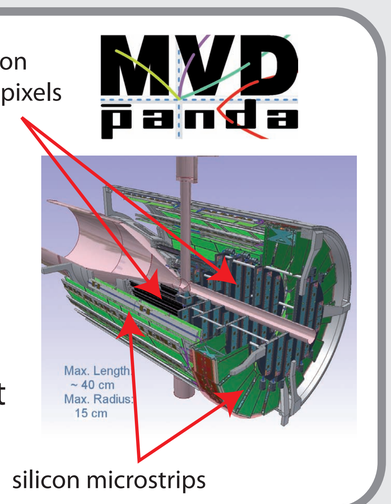
The $\bar{P}$ANDA Experiment

- Fixed target experiment
- 4π acceptance charged and neutral
- Electron- and stochastic cooling of antiproton beam
- Hydrogen and heavy nuclear targets
- Momenta between 1.5 and 15 GeV/c
- Luminosity of $2 \cdot 10^{32}$ cm^{-2} s^{-1}



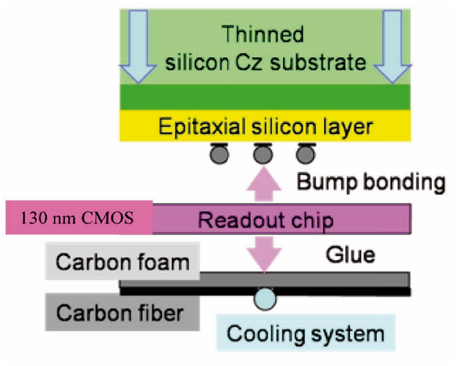
The Micro-Vertex-Detector

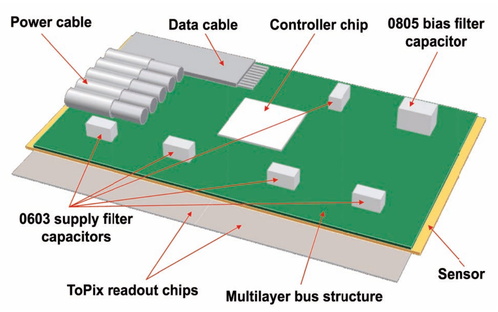
- 4 concentric barrels and 6 forward disks
- Reconstruction of primary and secondary vertices
- Improvement of momentum resolution and PID
- Requirements:
  - triggerless readout with high rate capability
  - good time resolution and low material budget
  - high radiation tolerance

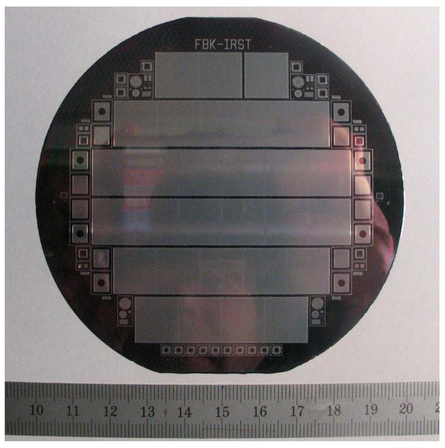


Hybrid Pixel Detectors

- Developed at INFN, Torino
- Sandwich of sensor, front-end chip and mechanical support (carbon fiber and carbon foam) with embedded cooling system
- Sensor: epitaxial 100 µm silicon layer on a thinned Czochralski (Cz) substrate
- Pixel size 100x100 µm^2
- Front-end connected via bump bonding



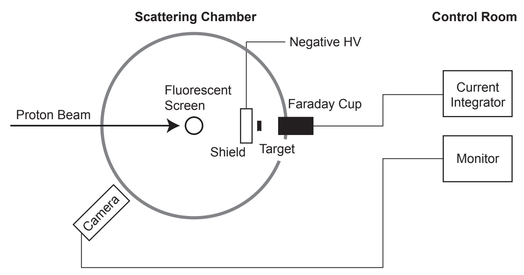




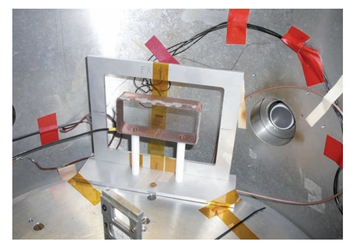
Pixel sensor wafer for the PANDA MVD

Irradiation Setup

- Irradiation of the diodes with a 14 MeV proton beam at the Bonn Isochronous Cyclotron, HISKP
- Also used for studies of $\bar{P}$ANDA strips: see H.-G. Zaunick, HK 34.2

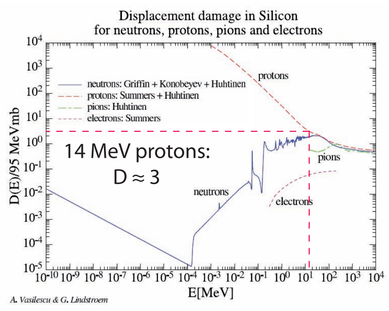


Schematic of the irradiation setup



Diode in the irradiation chamber at the cyclotron at HISKP in Bonn

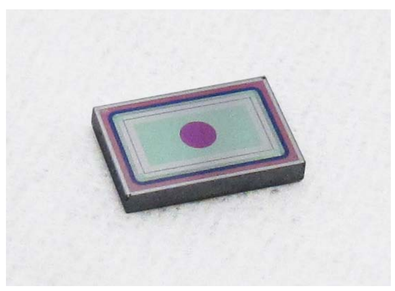
- Equivalent neutron fluence calculated with the NIEL hypothesis
- Two different fluences applied: $5 \cdot 10^{13}$ and 10^{14} $n_{1Mev\ eq}/cm^2$



Prototype Diodes and Measurement Setup

- Wafers substrate and epitaxial layer manufactured at ITME, Warsaw
- Diodes production and oxygenation process performed at FBK, Trento

- Oxygenation process (wafers 2 and 4):
  - 12 hours in O_2 at 1150 °C
  - ~53 hours in N_2 at 1150 °C



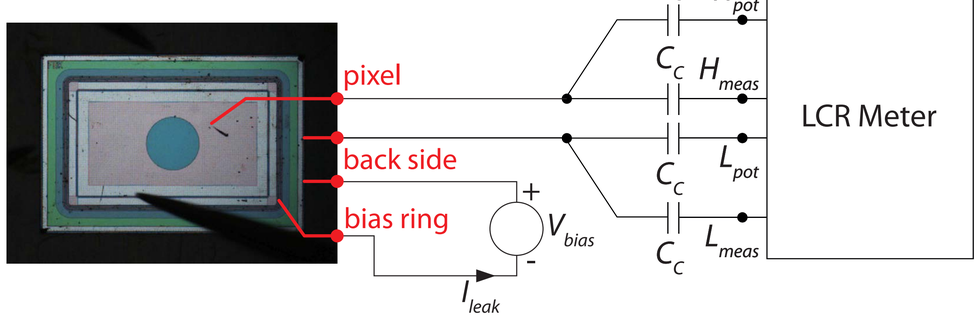
Diode General Properties

Substrate Thickness	525 ± 25 µm
Wafer diameter	100 ± 0.5 mm
Substrate resistivity	0.008 ÷ 0.02 Ω·cm
Orientation	<100>
Conductivity type/dopant (substrate)	n+/Sb
Conductivity type/dopant (epitaxial layer)	n/P
Diode size	3 x 5 mm^2

Epitaxial Layer Properties

	Wafers 2 and 14	Wafers 4 and 15
Thickness	99.34 ÷ 100.38 µm	149.70 ÷ 151.27 µm
Resistivity	3610 Ω·cm	3945 Ω·cm

- I-V and C-V curves of the diodes are measured with a PC-controlled LCR meter and a voltage source
- Diodes are connected with a probe station through a biasing box

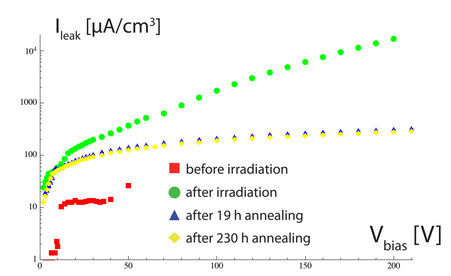


Experimental Results

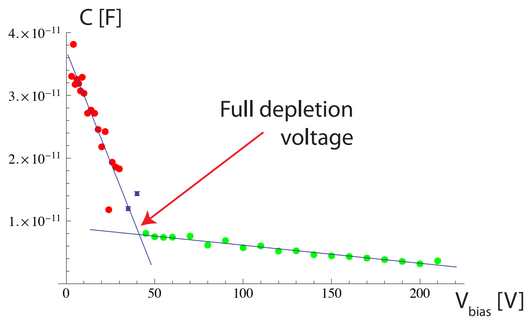
- Diode parameters measured:
  - before irradiation
  - immediately after irradiation
  - after ~19 hours and after ~230 hours of annealing at 60 °C

Pre-irradiation results

Wafer	Type	V_{dep} [V]	C [pF]
w14	100 µm	11 ± 5	4.3 ± 0.5
w2	100 µm, ox.	9 ± 2	5.2 ± 0.5
w15	150 µm	13 ± 4	2.1 ± 0.5
w4	150 µm, ox.	15 ± 5	2.1 ± 0.5

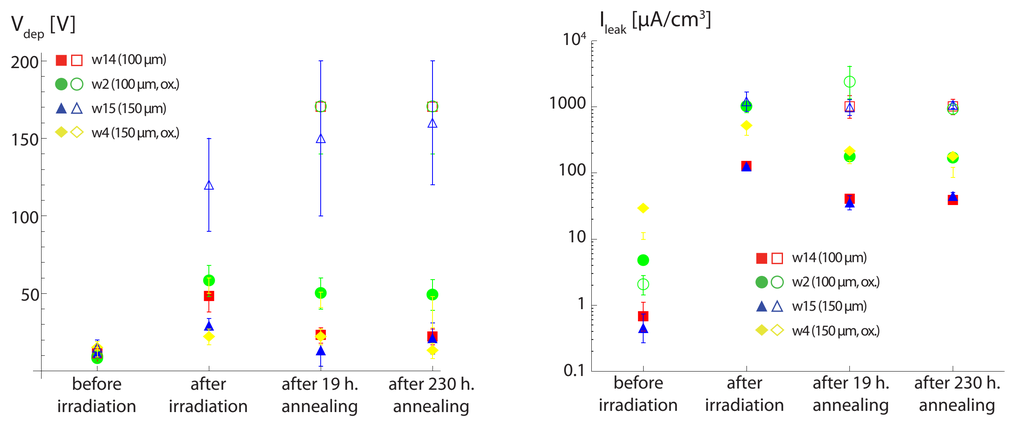


I-V curves of the same diode before and after the irradiation. A partial recovery can be observed after a thermal annealing phase



Determination of the full depletion voltage from the C-V curve of an irradiated diode

- C-V and I-V curves are used to determine the full depletion voltage and the leakage current, respectively



Annealing behavior of the full depletion voltage and of the leakage current. Filled and empty markers represent low and high fluences, respectively

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