Fabrication and characterization of wide area SiC detectors for neutron monitoring

Solid State Physics Group

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Y. Garino (PhD Student)

Projects and collaboration

GAMMA-NEU, INFN

G. Wagner, IKZ, Berlin, Germany

C. Lanzieri & S. Lavanga, AMSJV, Rome, Italy

G. Amato & L. Boarino, IEN, Turin, Italy

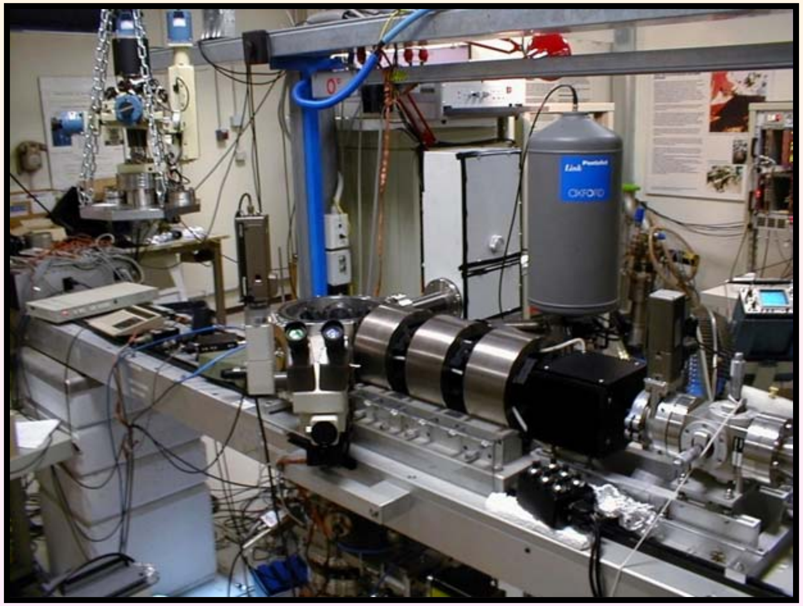
ENEA (TAPIRO), Casaccia, Rome, Italy

Ion Beam Analysis

AN2000 microbeam facility @
INFN National Laboratories (Legnaro, I)
Dr. Valentino Rigato

2.5 MV Van de Graaff accelerator

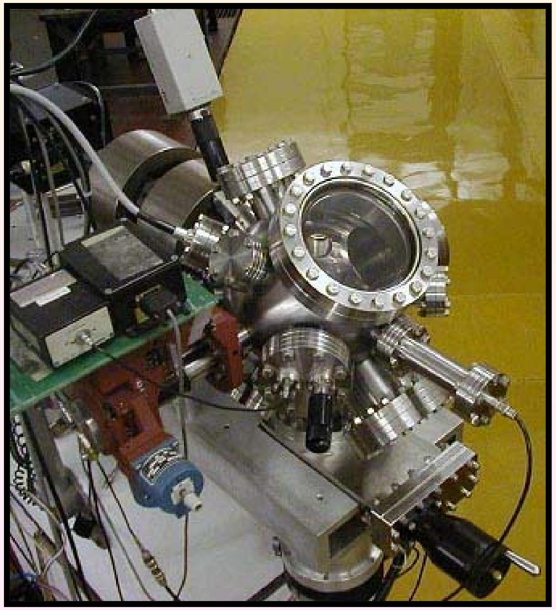
available ions: H, He
micrometric spot size
PIXE, IBICC and IBIL measurements
recently developed cryogenic apparatus



Nuclear microprobe facility @
Ruđer Bošković Institute (Zagreb, Croatia)
Dr. Milko Jaksic

6 MV Tandem accelerator

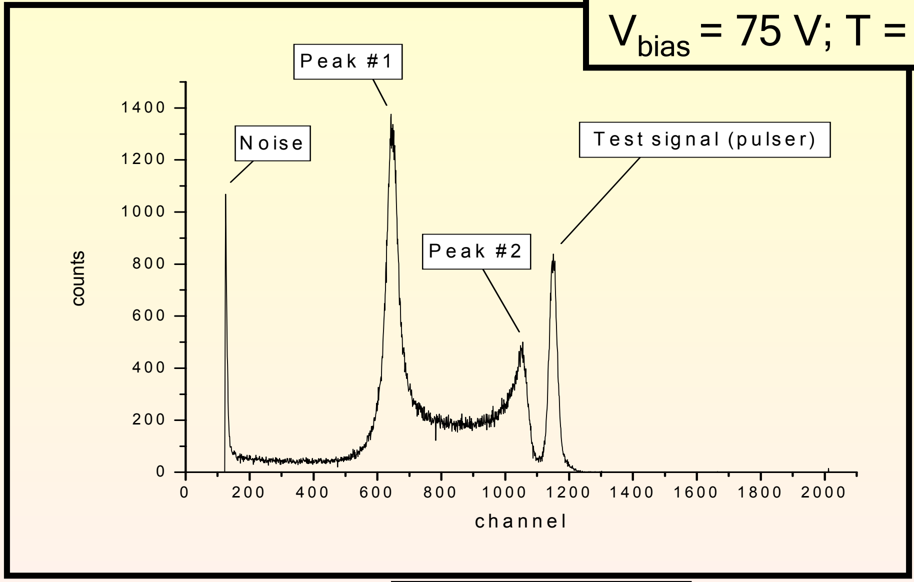
available ions: H, C, Li, O, …
micrometric spot size
PIXE, IBICC measurements



Ion Beam Analysis

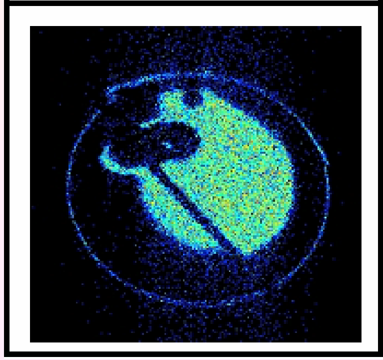
4H-SiC IKZ sample; 1.5 MeV protons (Legnaro 2003)

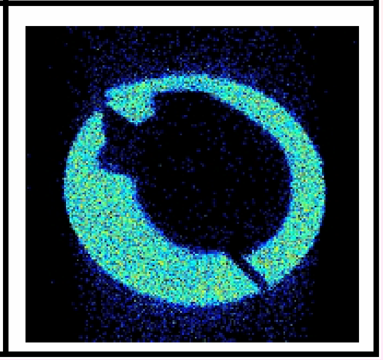
V_{bias} = 75 V; T = 77 K



Peak #1 map

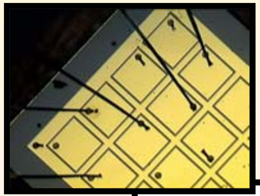
Peak #2 map

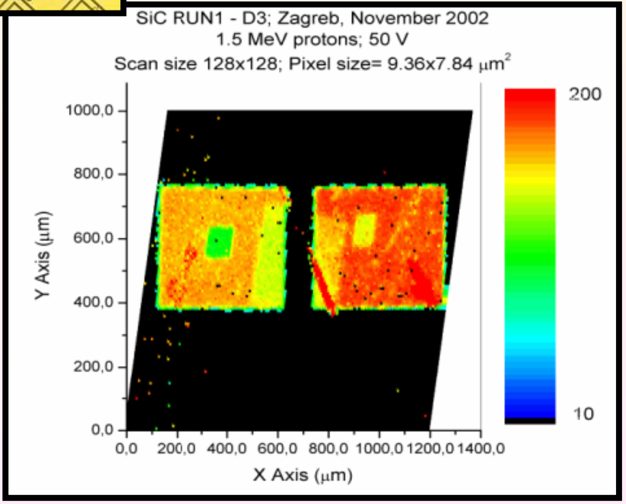




"Silicon Carbide Radiation Detectors for Room and High temperature Spectrometry", COFIN-MIUR

- G. Bertuccio: Dept Elect Engn & Informat Sci, Politecnico of Milano
- A.Cavallini: Physics Dept., University of Bologna
- F.Nava: Physics Dept., University of Modena
- C.Lanzieri: Alenia Marconi Systems, Roma (I)



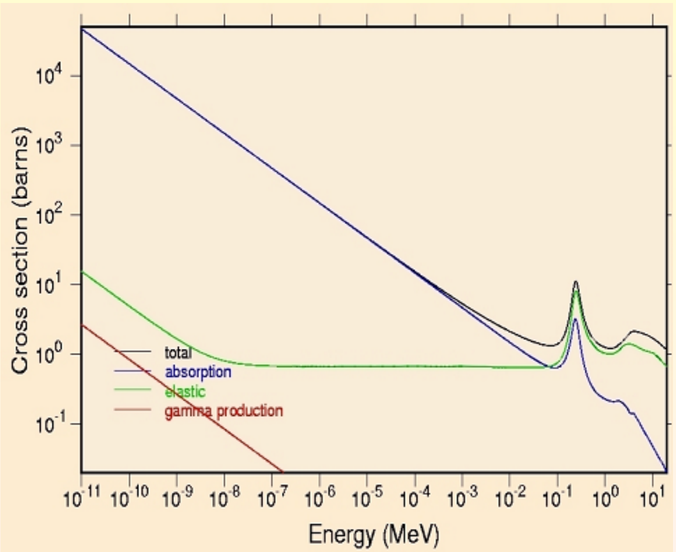


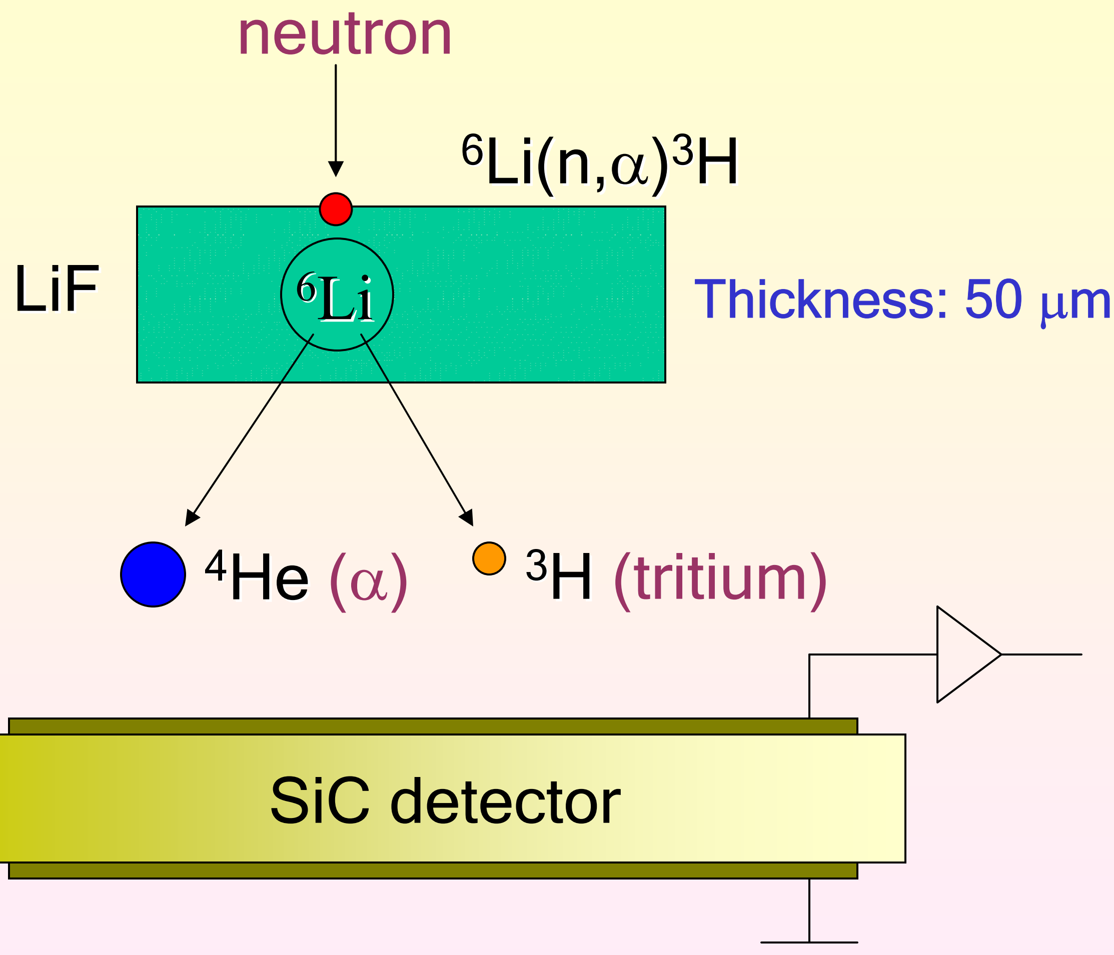
Vittone et al., 2003

Outline

- About Neutron detector.
- Samples description.
- CV and IV electrical characterization.
- Characterization under exposure to alpha sources.
- Neutron monitoring.
- Conclusions.

Neutron detectors





Detector
Depletion layer > 30 μm

Neutron detectors

Conversion reaction: $^{6}Li(n,\alpha)^{3}H$

Q-value = 4.78 MeV

For a neutron spectrometer:

mean free path of reaction products within the active volume of the detector

		Neutron Energy [MeV]			
		$2.5\ 10^{-8}$ MeV	0.1 MeV	2 MeV	10 MeV
Alpha	Ion Energy	2.05 MeV	2.35 MeV	4.29 MeV	10.86 MeV
	Penetration in SiC	4.8 μm	5.7 μm	12.6 μm	53.0 μm
Tritium	Ion Energy	2.73 MeV	2.53 MeV	2.49 MeV	3.92 MeV
	Penetration in SiC	27.4 μm	24.4 μm	23.8 μm	48.2 μm

Due to the low deposited energy, gamma background signals can be effectively distinguished from neutron signals, by choosing an appropriate cut-off.

Possible applications of SiC: intense neutron fields (included the case of mixed radiation fields):

1. Fast neutron fields (fusion reactors)
2. Epithermal neutron fields (BNCT facilities) 10^{9}-10^{13} n cm^{-2} s^{-1}

where a small obstruction, a great radiation hardness and a continuous radiation monitoring are required.

Samples

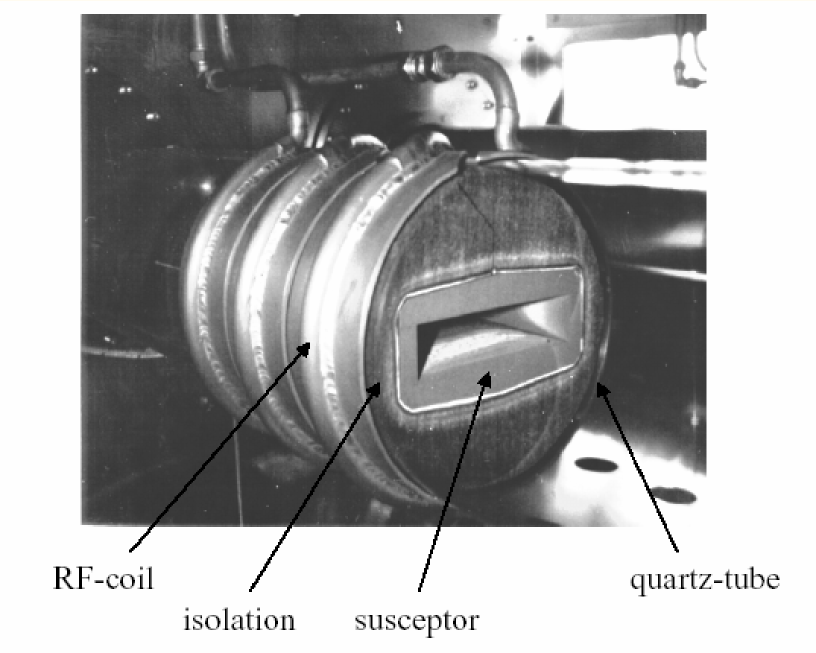
*Starting Material: 360 μm n-type 4H-SiC by **CREE** (USA)*

We processed two 2.0 inches wafers (a 3rd wafer is now under processing)

1st wafer: SMP quality: 16-30 micropipes/cm^2

2nd wafer: LMP quality: $\leq$ 15 micropipes/cm^2

*Epilayer by **G. Wagner**, Institute of Crystal Growth **(IKZ)**, Berlin, Germany*



Pre-treatment:

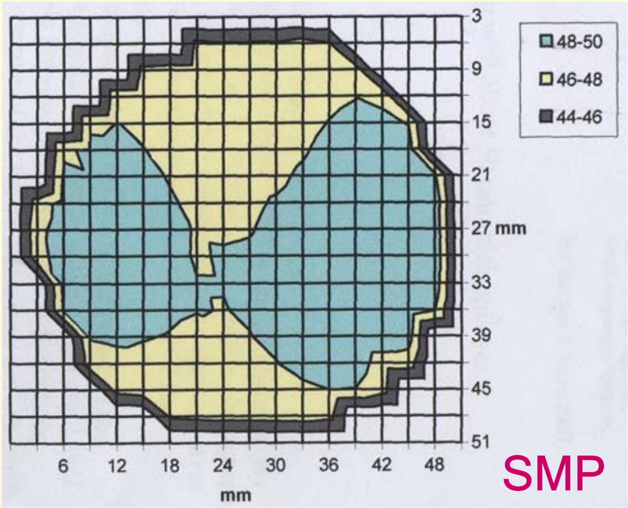
etching by hydrogen/propane gas for 4 minutes, in order to remove the damage layer (about 40 nm).

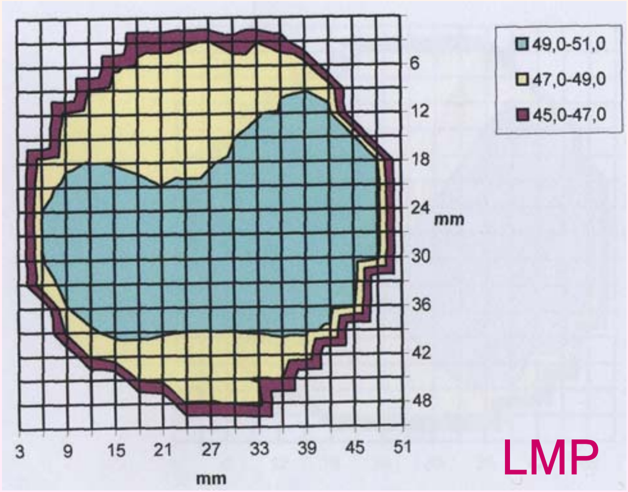
Growth conditions:

- hot-wall CVD reactor
- temperature: 1550 °C
- total pressure: 150 mbar
- C/Si ratio: 1.5
- growth rate: 9.5 μm/h
- nitrogen partial pressure: 2 x 10^{-4} mbar

Samples

Epilayer by G. Wagner, Institute of Crystal Growth (IKZ), Berlin, Germany



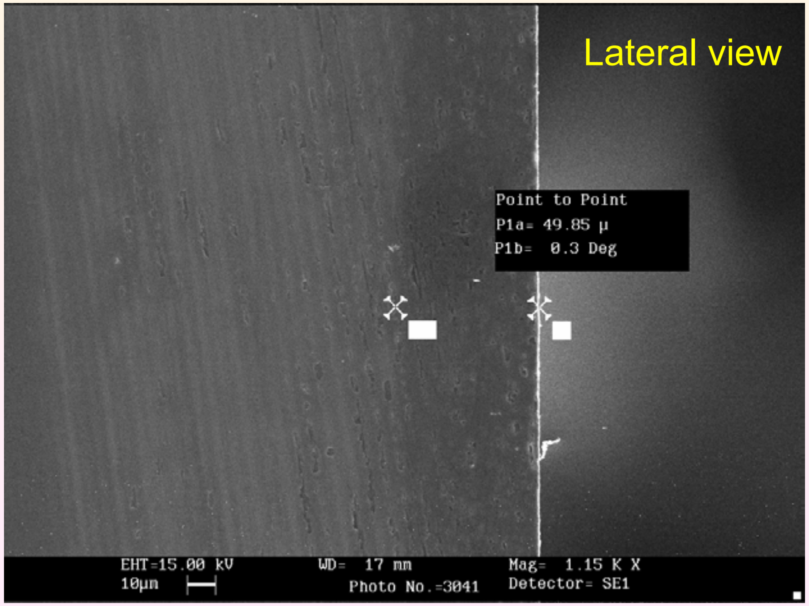


SMP wafer

Epilayer thickness: 48.0 ± 0.6 μm

LMP wafer

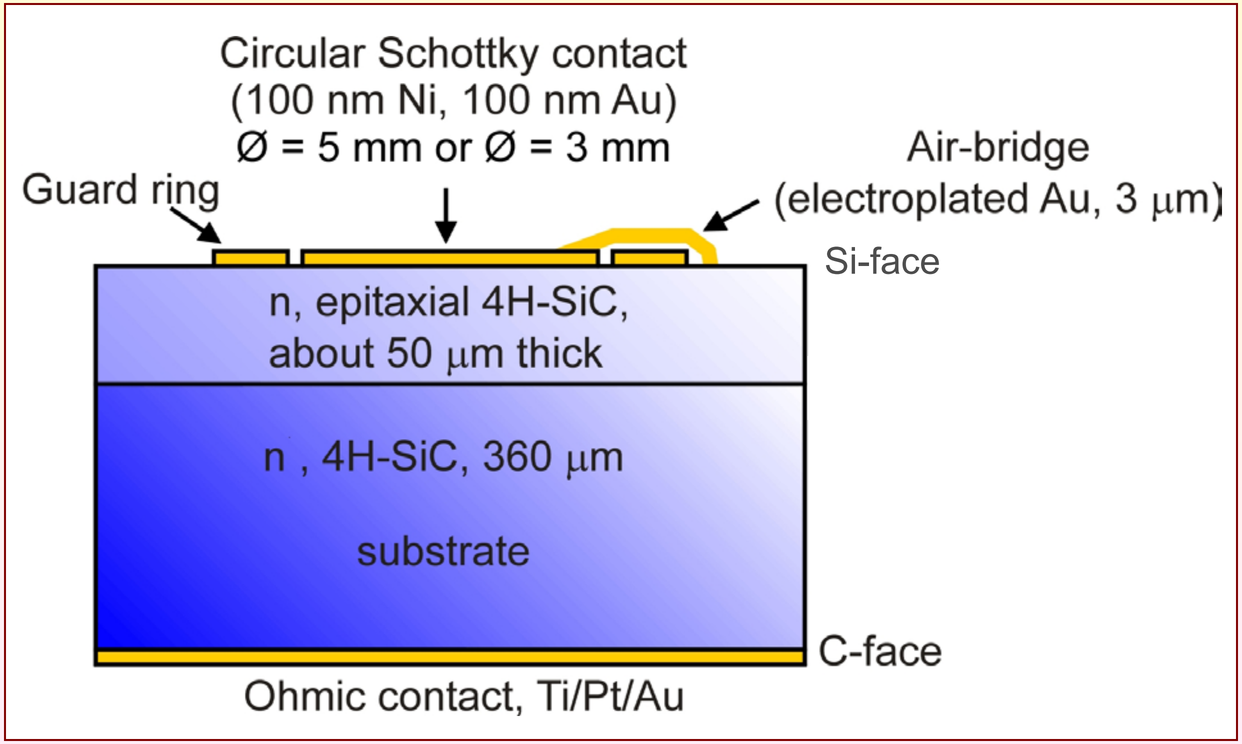
Epilayer thickness: 48.9 ± 0.8 μm

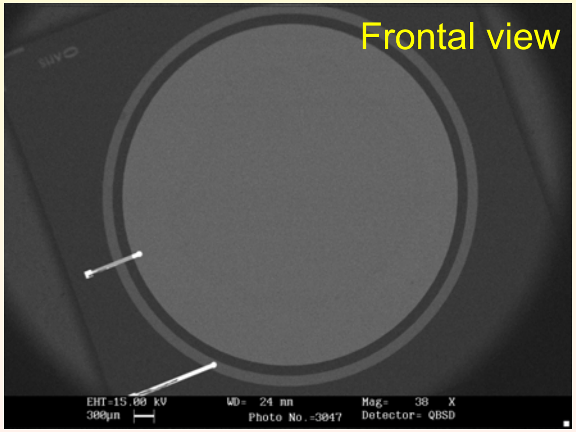


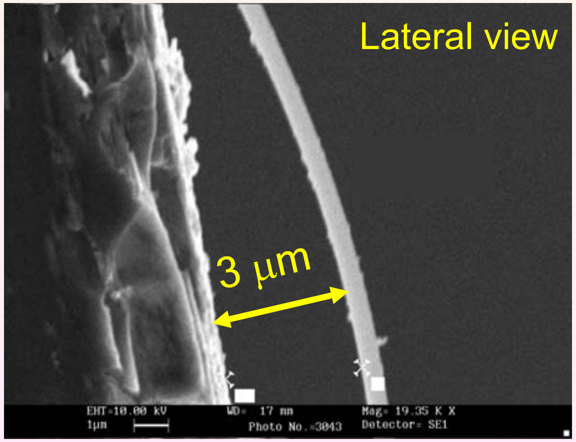
Samples

Devices by C. Lanzieri, Alenia Marconi System JV (AMSJV), Rome, Italy

Using a mask designed for our purposes, Alenia produced "small" (3 mm diameter) and large (5 mm diameter) Schottky SiC diodes. Up to now only 1.5 mm.

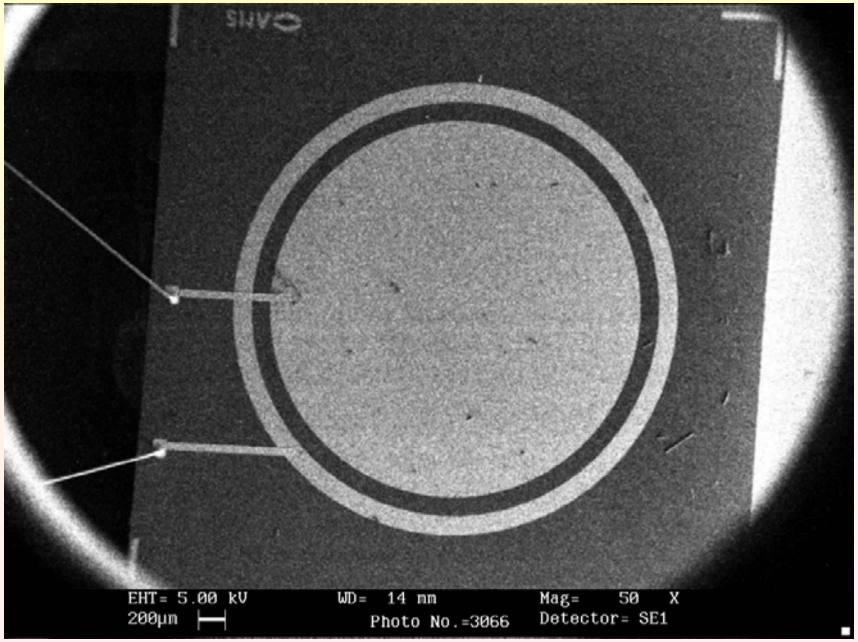


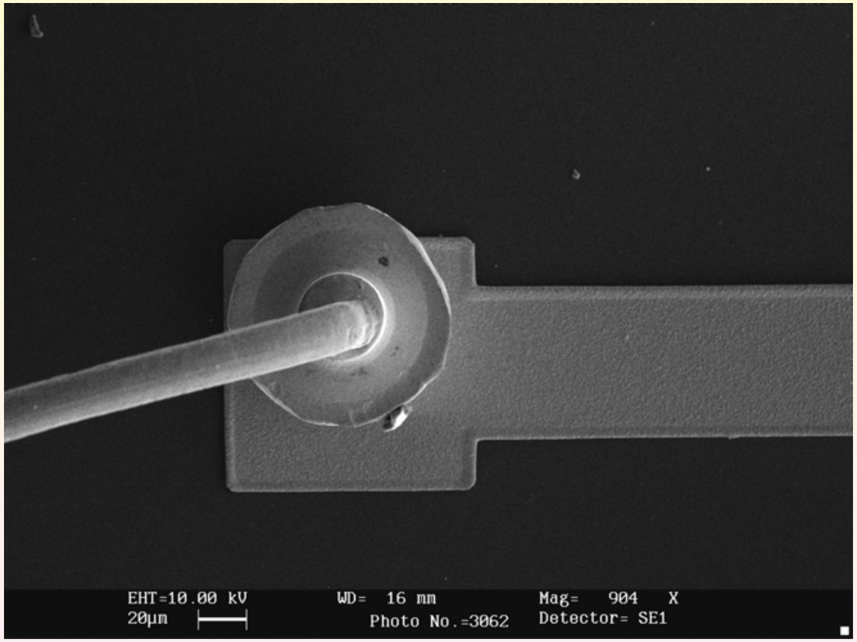


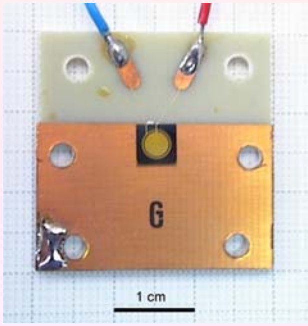


Samples

Microbonds by G. Amato, Istituto Elettrotecnico Nazionale Galileo Ferraris (IEN), Turin, Italy

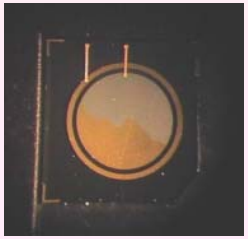






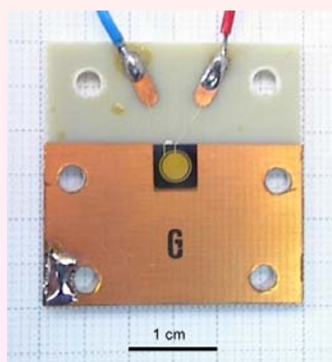
Devices were then ready for tests.

At now we have 20 small (∅ = 3 mm) diodes and 3 large diodes (∅ = 5 mm) from SMP wafer
20 small diodes (∅ = 3 mm) and 10 large diodes (∅ = 5 mm) from LMP wafer.



I-V and C-V characterization

Our set-up



Voltage Source	Keithley 617: -2 / +100 Volt Stanford PS350: +30 / +350 Volt
Picoamperometer	Keithley 617
Capacimeter	Bontoon BD52

When possible, to standardize measurements we used recommendation for Si diode measurements by A. Chilingarov.

“Measurements should be made between the backside and the central electrode with the guard ring kept at the same potential as the central part part (usually grounded)“.

Guard ring at ground, polarization on the backside

“Wherever possible measurements should be performed at a temperature around either 20°C or 0°C”.

Temperature: 19.1 - 21.6 °C

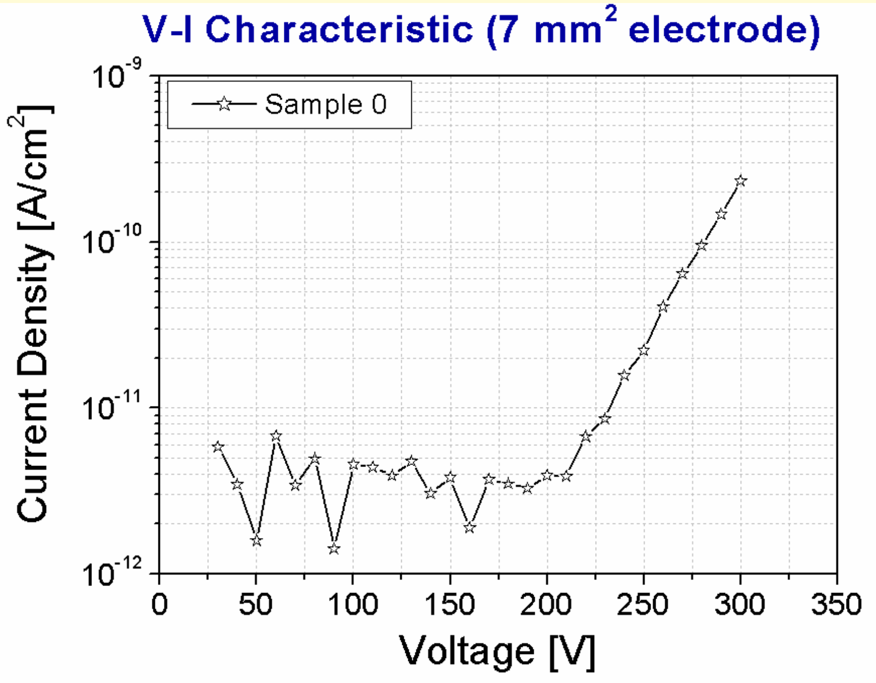
The IV and CV measurements between minimum and maximum bias values should be made both for increasing and decreasing voltages.

I-V characterization

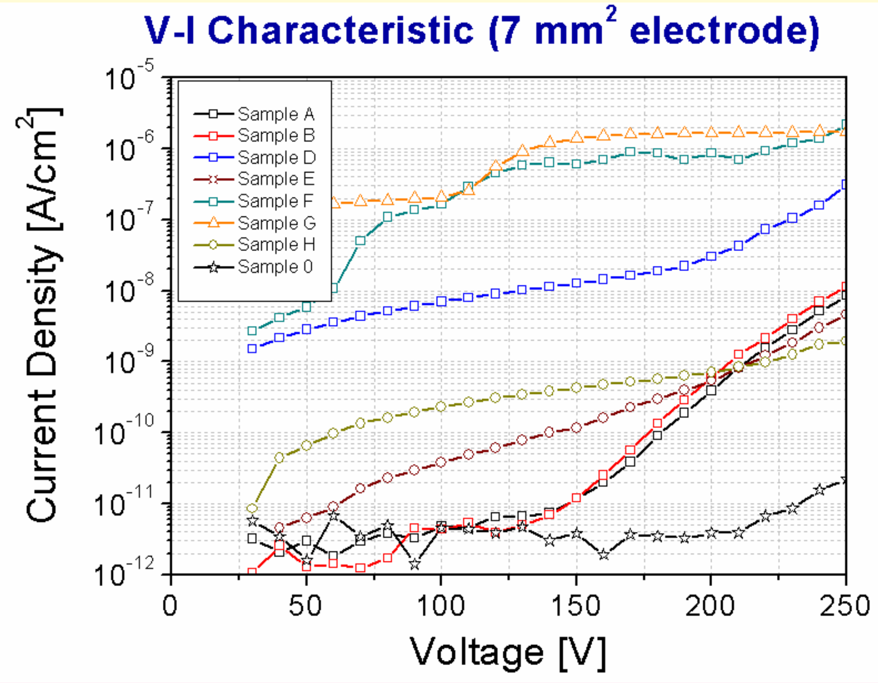
Reverse bias

For the moment we have characterized: 9 small diodes and 2 large diodes from SMP wafer.

Full depletion at about 200 V - 220 V (from C-V measurements)



Best result



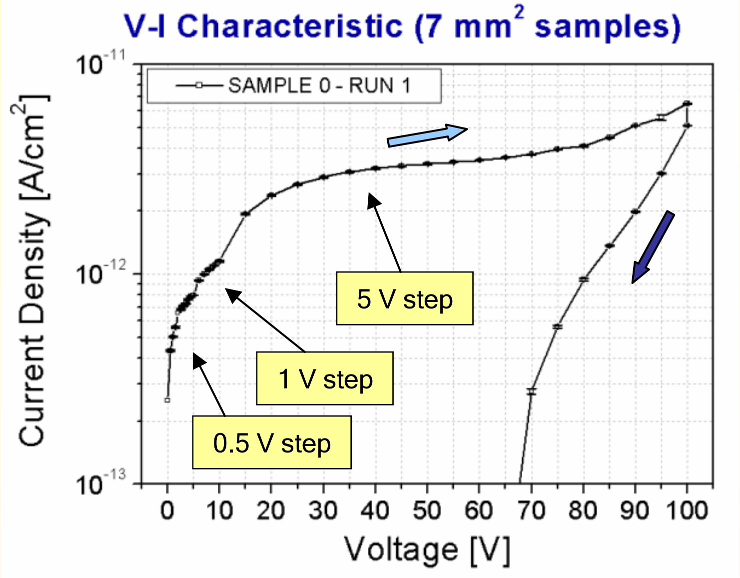
All 7 mm^2 diodes

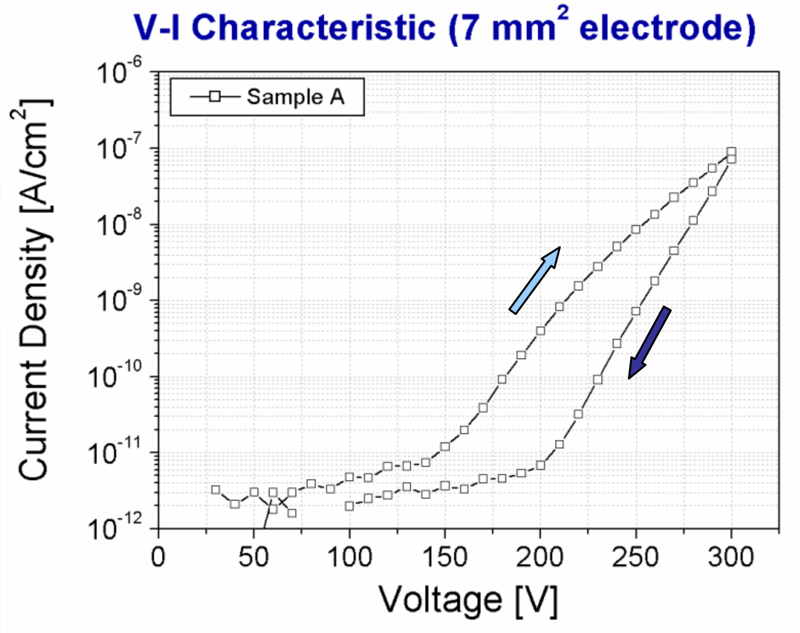
CONDITIONS: increasing voltages; 10 V steps; 10 seconds between two voltages; average on three measurements for every voltage (0.5 s time step).

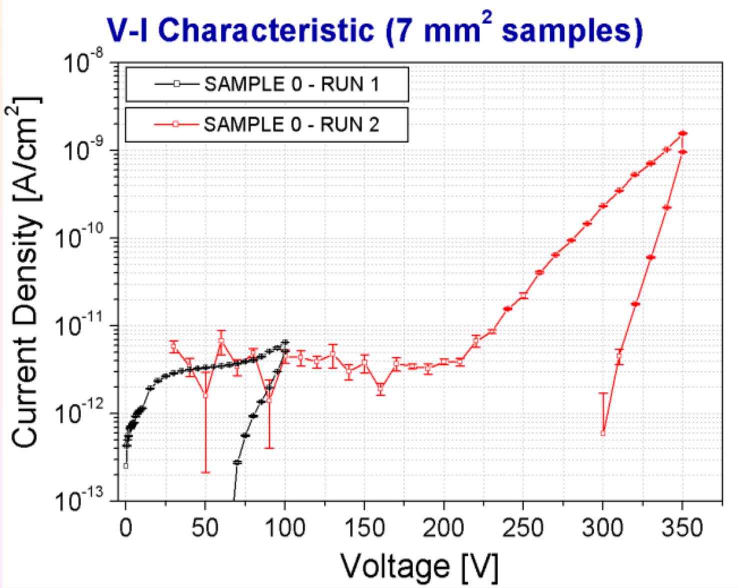
I-V characterization

Reverse bias

If the measurements can be made in one direction only (e.g. lack of time) the decreasing bias voltage mode should be preferred, wherever possible, as giving usually more repeatable results. However the measurements with two directions of voltage change are always strongly recommended. In all cases the time of the voltage ramp should be given in the measurement description.

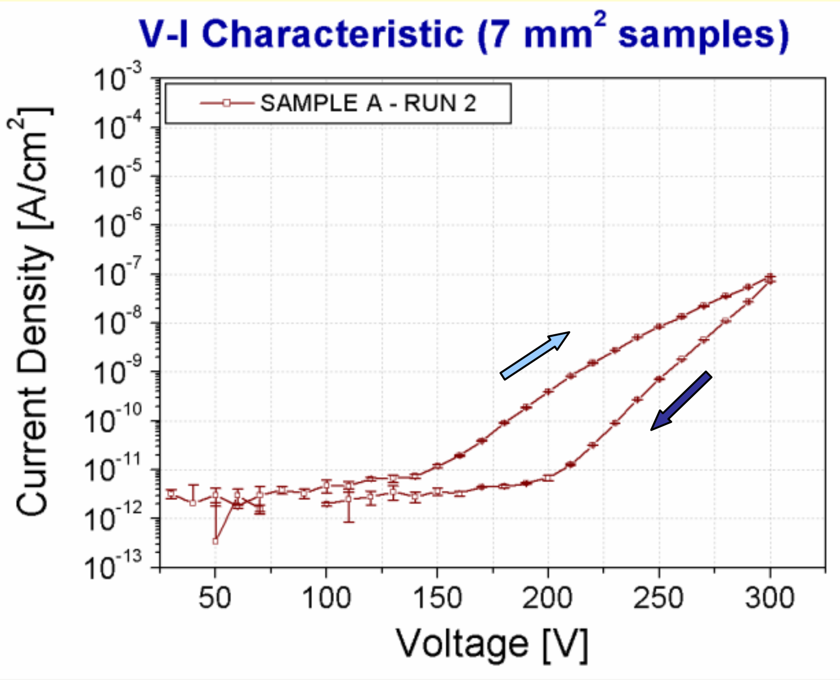


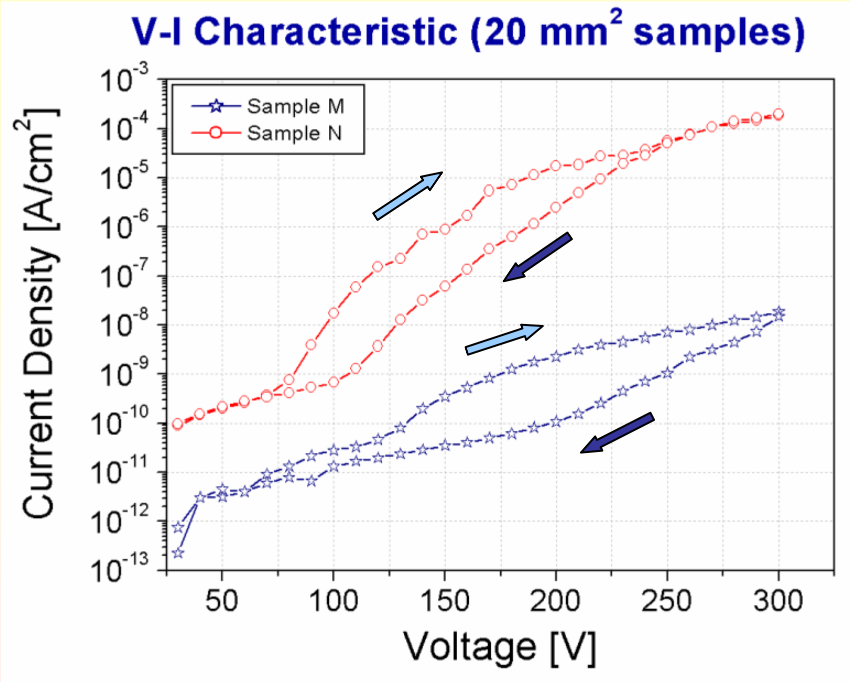




I-V characterization

Reverse bias



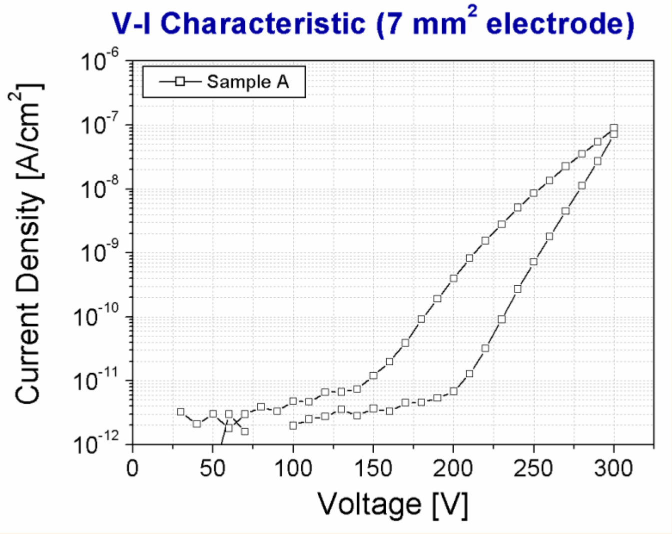


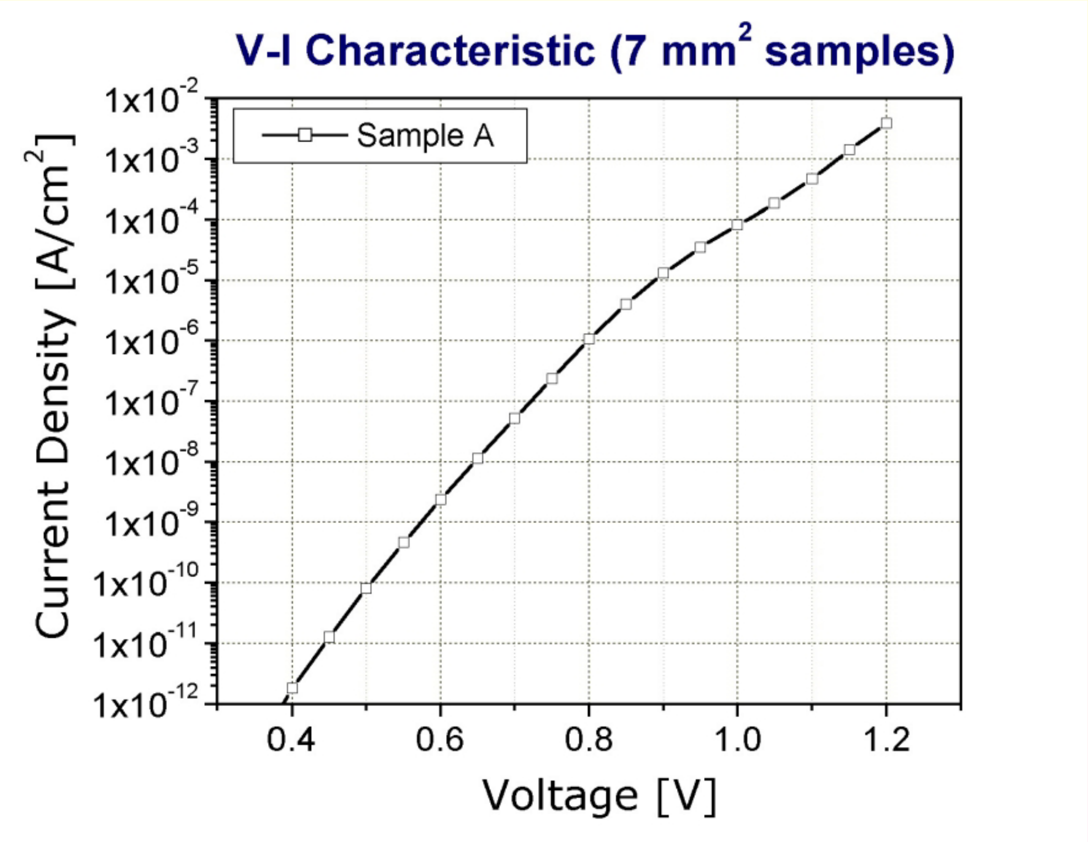
CONDITIONS: increasing voltages first and decreasing voltages after; 10 V steps; 10 seconds between two voltages;

average of three measurements for every voltage (0.5 s time step).

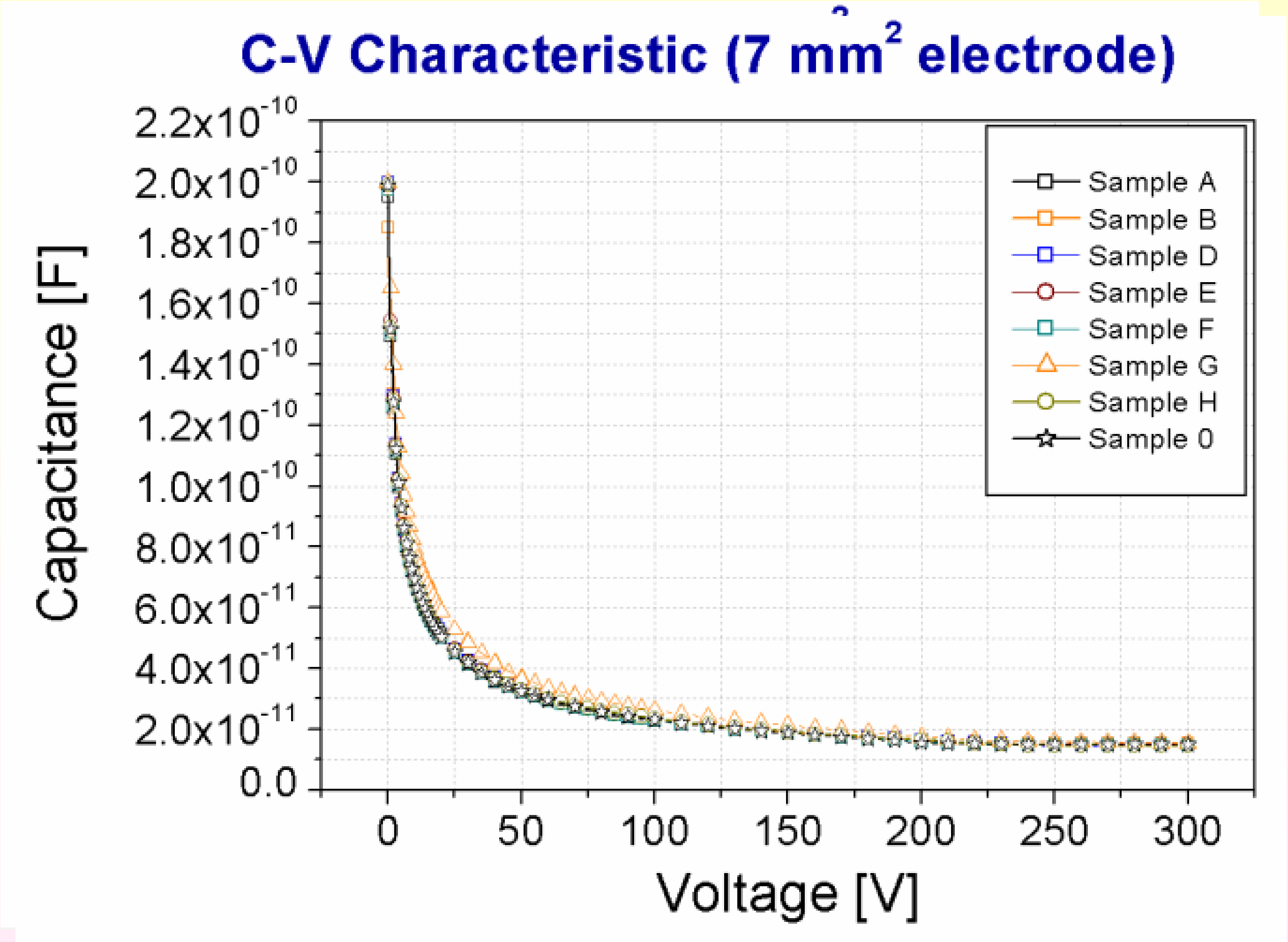
I-V characterization

Forward bias



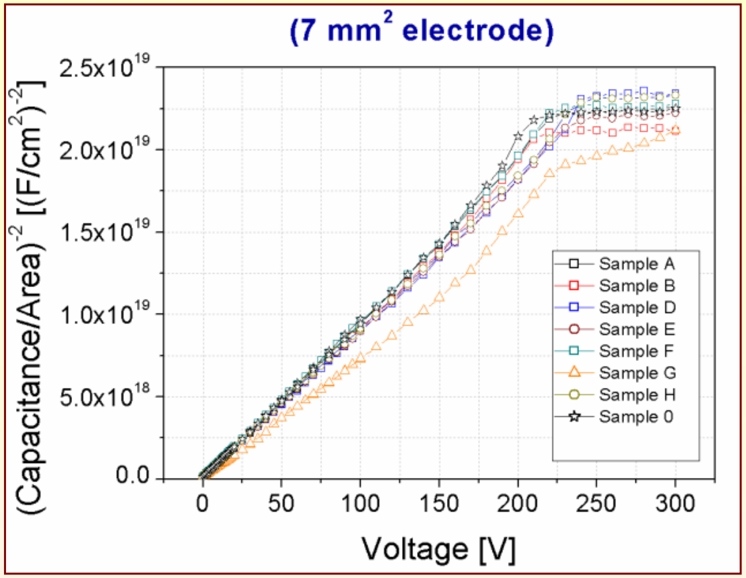


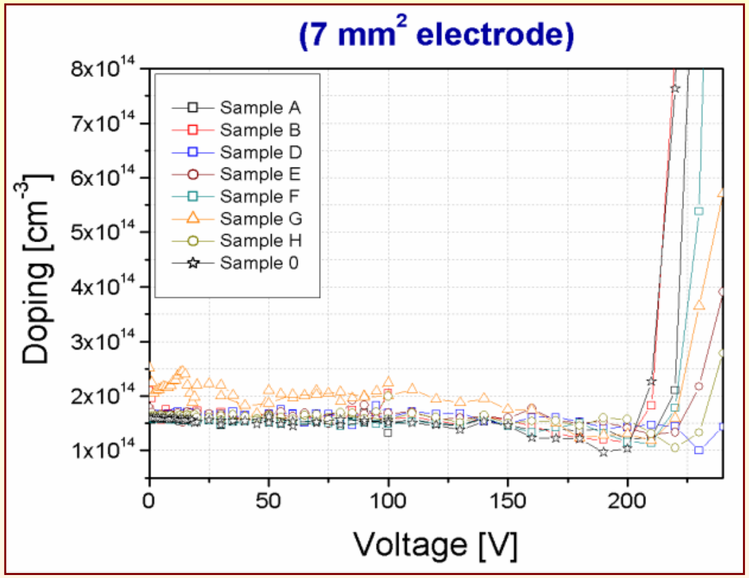
C-V characterization



About 15 pF at full depletion voltages

C-V characterization



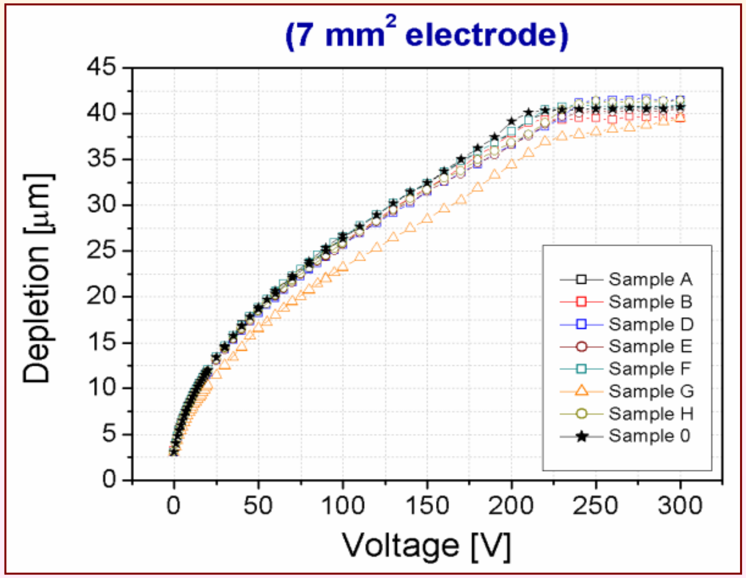


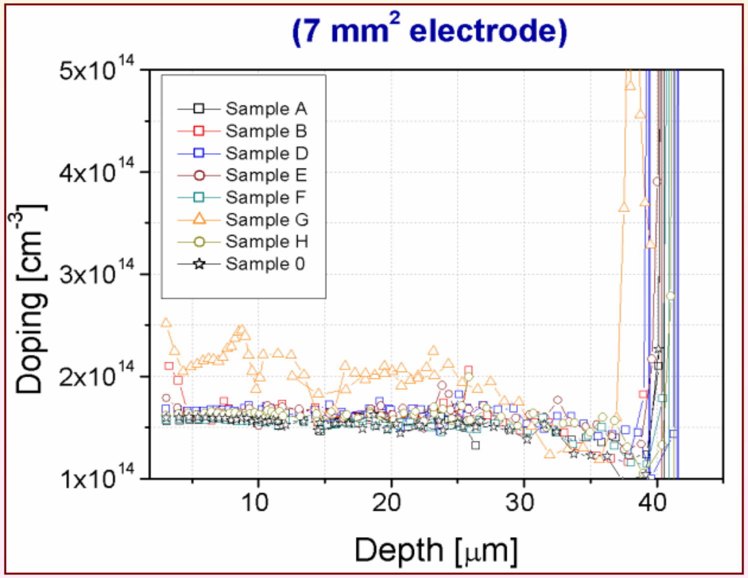
Full depletion

≈ 40 μm

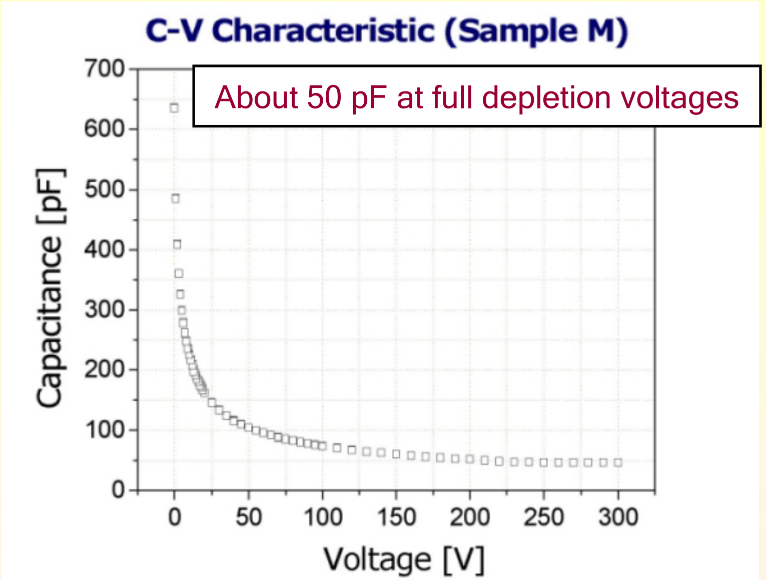
Doping

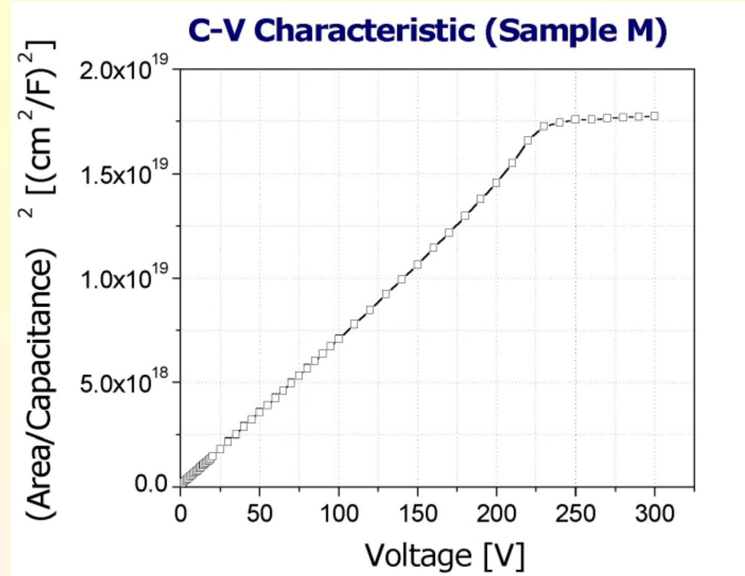
≈ 1.5 10^{14} cm^{-3}

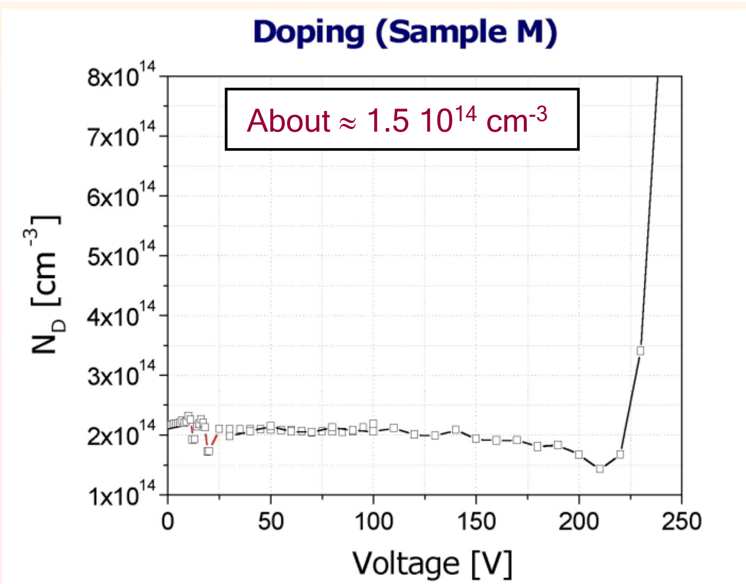


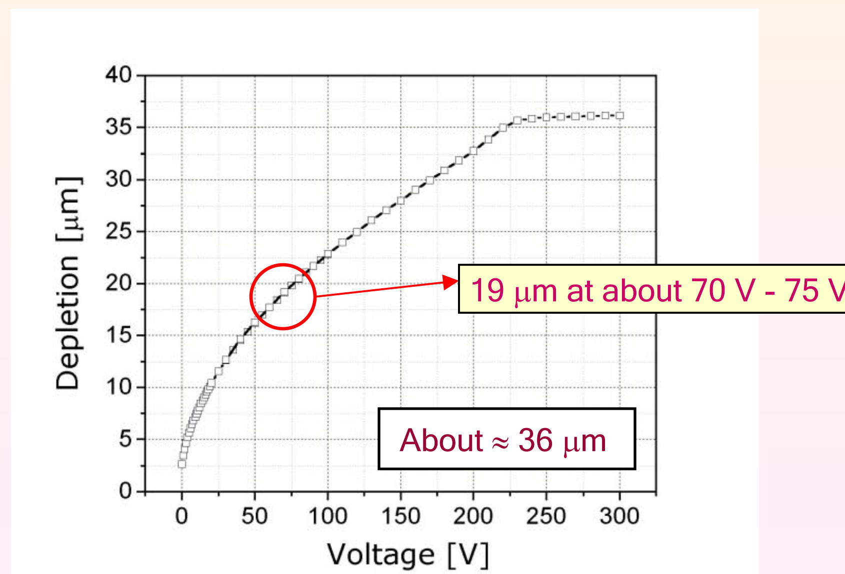


C-V characterization







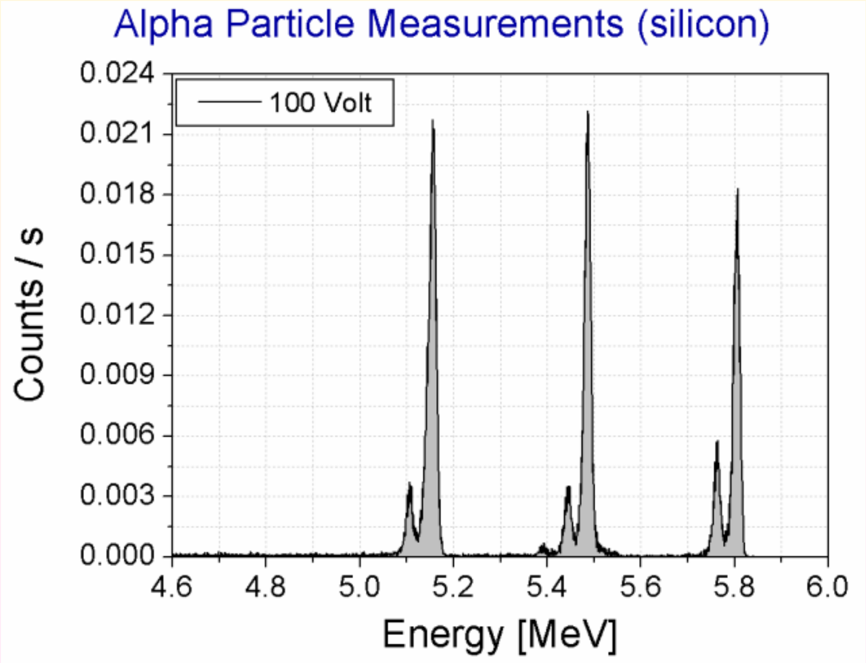


Alpha particle measurements

To perform alpha particle measurements we used a triple ultra-thin window Alpha Source.

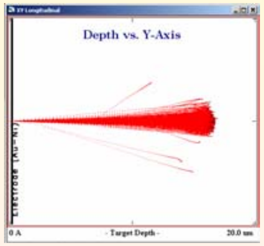
Plutonium (^{239}P):	Peaks: 5.16 MeV (73.1 %); 5.14 MeV (15.0%); 5.10 MeV (11.8 %); others
Americium (^{241}Am):	Peaks: 5,49 MeV (85.2 %); 5.44 MeV (12.8 %): 5.39 MeV (1.4 %); others
Curium (^{244}Cm):	Peaks: 5.80 MeV (77.4 %); 5.76 MeV (23.0 %); others

Spectrum obtained using a 25 mm^2 Si detector and our electronic set-up.



Energy Resolution = σ_E = 7 ± 1 keV
(Ortec calibration was 6.8 keV)

Penetration in SiC



5.16 MeV ➡ 16.2 μm

5.49 MeV ➡ 17.9 μm

5.80 MeV ➡ 19.4 μm

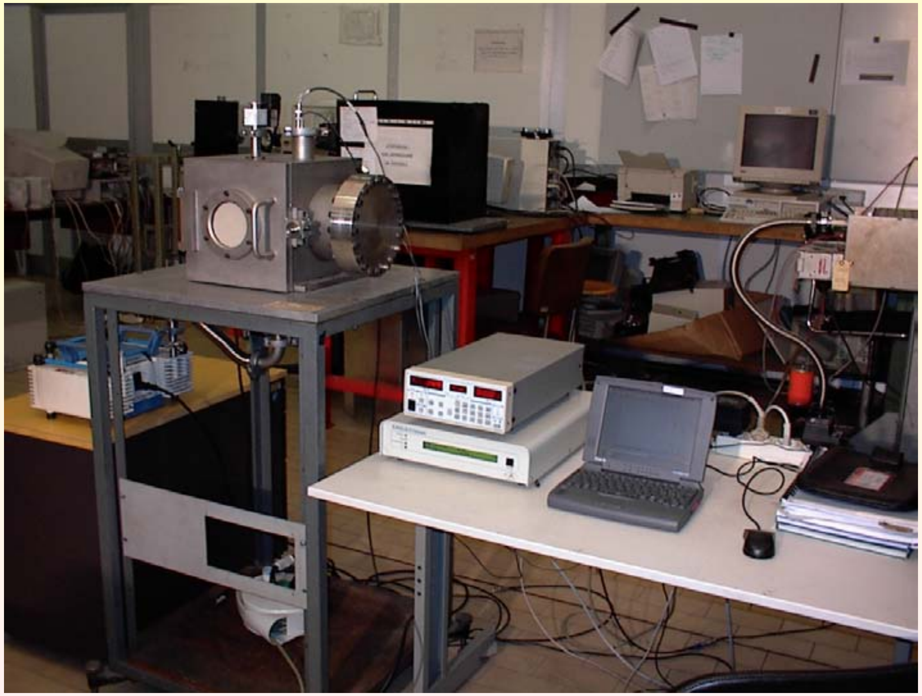
For the moment we have characterized:

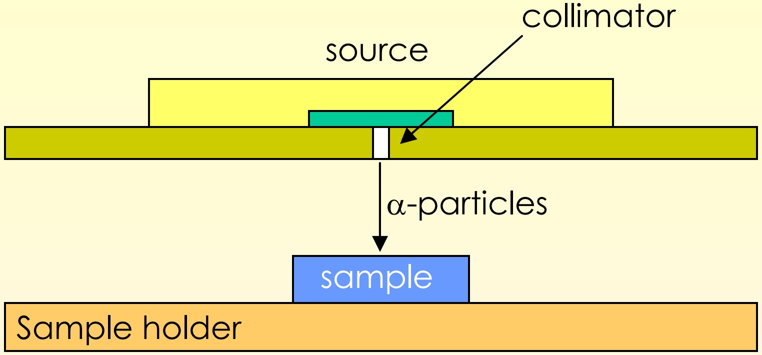
2 small diodes from SMP wafer
sample 0
sample B

1 large diode from SMP wafer
sample M

Alpha particle measurements

Our set-up

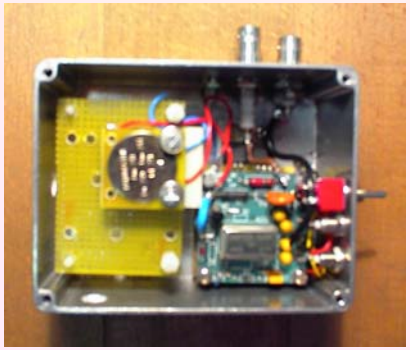


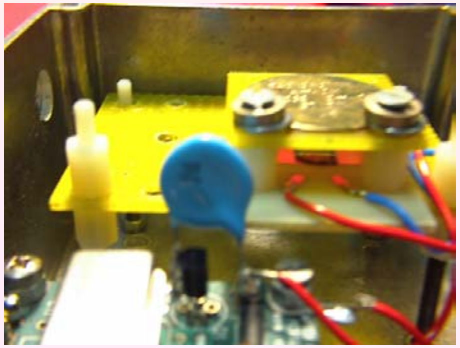


Preamplifier: Amptek A250

Amplifier & Multichannel: Eagle/Classic (APTEC-NRC)

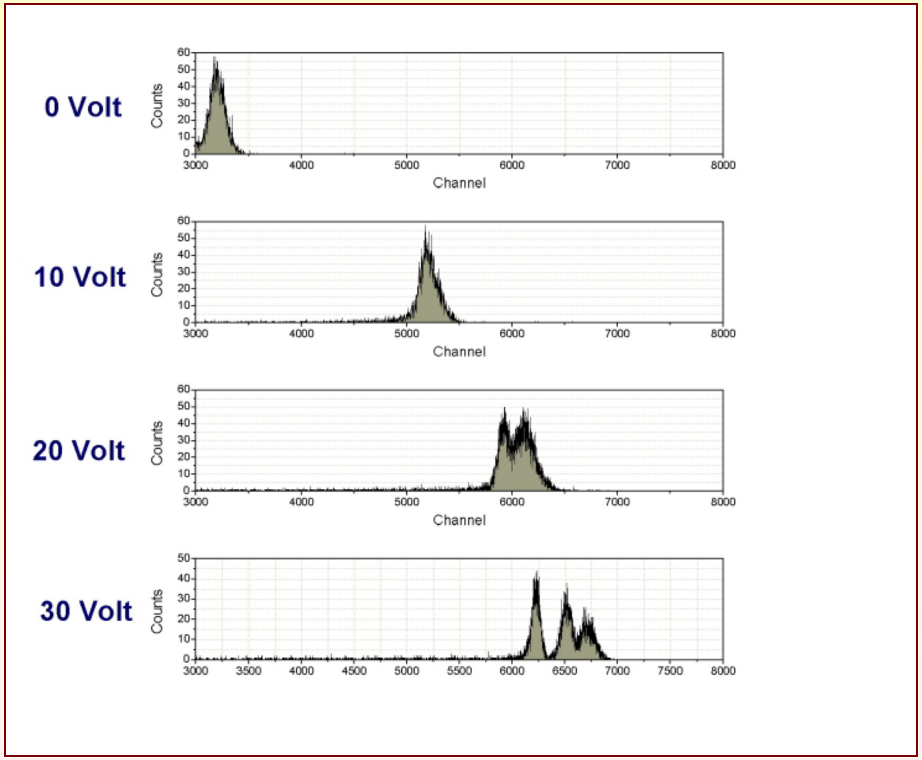
Voltage Source: Keithley 617: 0 / +100 Volt
Stanford PS350: +30 / +350 Volt

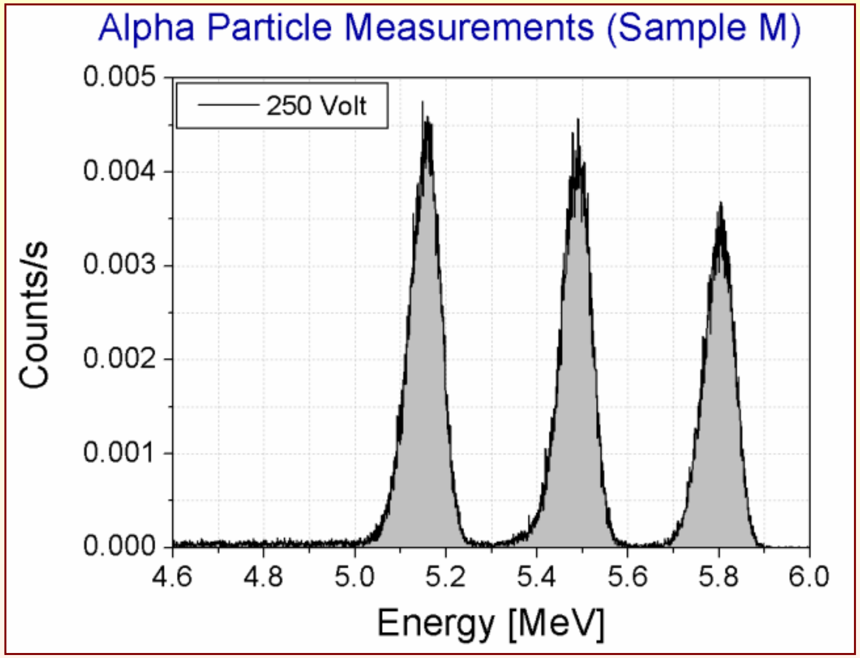




The source-sample-preamplifier box was placed in vacuum.

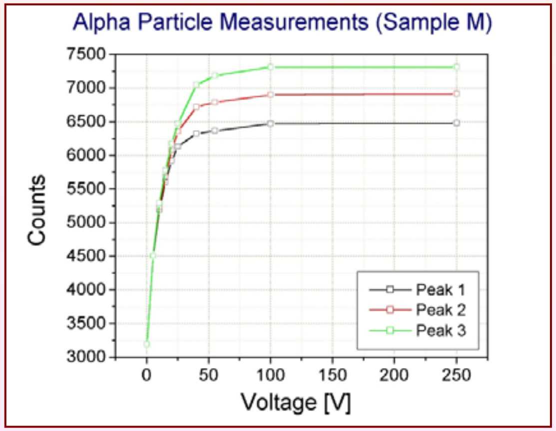
Alpha particle measurements





Energy Resolution = σ_E = 29 ± 5 keV

It was possible to calculate the electron-hole pair creation energy: 7.75 ± 0.13 eV



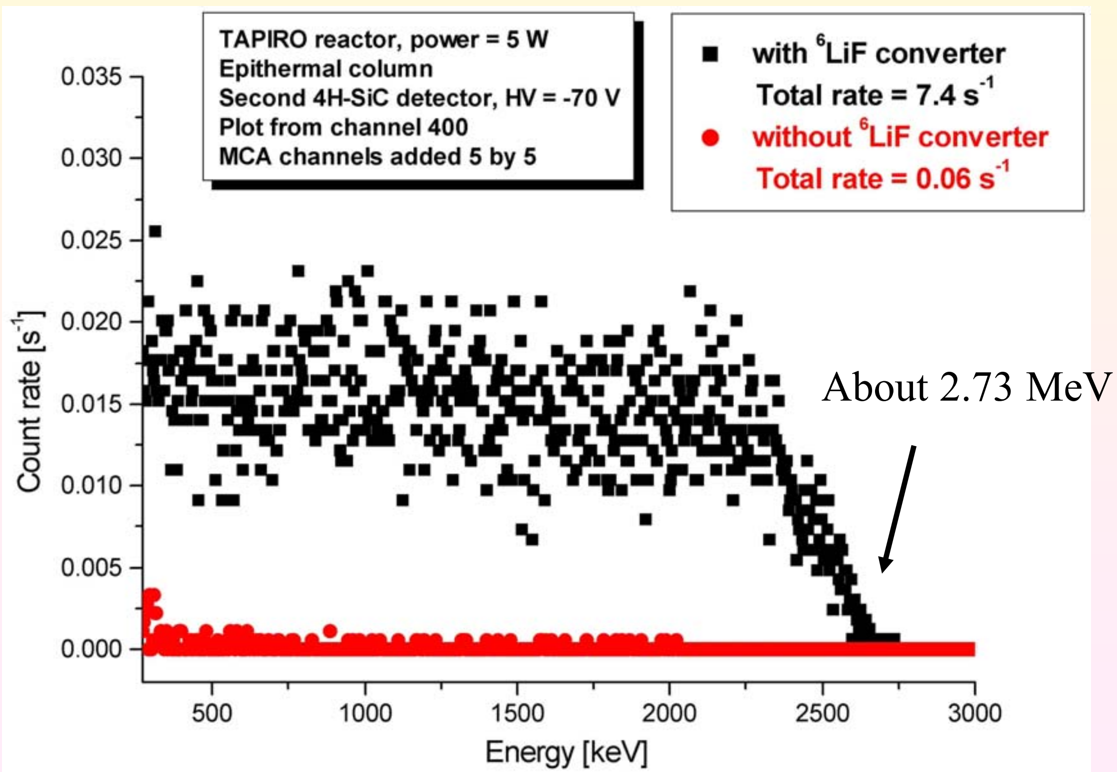
Preliminary neutrons detection measurements

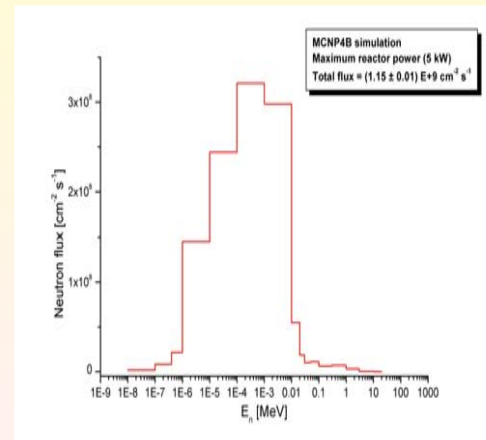
Using an old 1.5 diameter detector

TAPIRO: reactor located at ENEA Casaccia Research Centre, Roma. Epithermal column designed and realized in view of BNCT (Boron Neutron Capture Therapy) treatments (special application: brain tumours)

Total neutron flux @ maximum reactor power (5 kW): 1.15 10^9 cm^2 s^{-1}.

No significative change in count rate after about 10^{13} neutrons cm^2.





Conclusions

- We succesfully tested a 1.5 diameter SiC Schottky diode as neutron detector. No significative change in count rate after about 10^{13} neutrons cm^2.
- On purpose we produced large area Schottky SiC diodes (3 mm and 5 mm diameters) suitable for neutrons detection.
- From CV and IV characterizations we measured a full depletion of about 40 μm at about 200V-220V.
- From alpha detection we obtained a good response with an Energy Resolution of $\sigma_E = 29 \pm 5$ keV.