HPGe PLM Contact: Detector Process, Testing and Result Summary

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OUTLINE

- PLM Contact: N3G Call (2020-2024)
- Gamma detector state of the art
- *PLM (Pulse Laser Melting):* Next generation of segmented contact/junction on HPGe detectors
- Detectors processing and testing
- Conclusions

PLM Contact: N3G Call (2020-2024)

N3G: Next Generation Germanium Gamma Detectors

The **aim** of the proposal was to develop the PLM technology to produce complex coaxial HPGe segmented detectors and to test their potentiality to face the challenge of future nuclear science **high flux/high damage** experiments

- Development of **prototypes** with increasing complexity
- Application of **PLM junction production** and **segmentation on non-planar surfaces**
- Design of **ad-hoc mounting systems**
- Implementation of **advanced electronics**
- Performance testing after **neutron flux** and **annealing**

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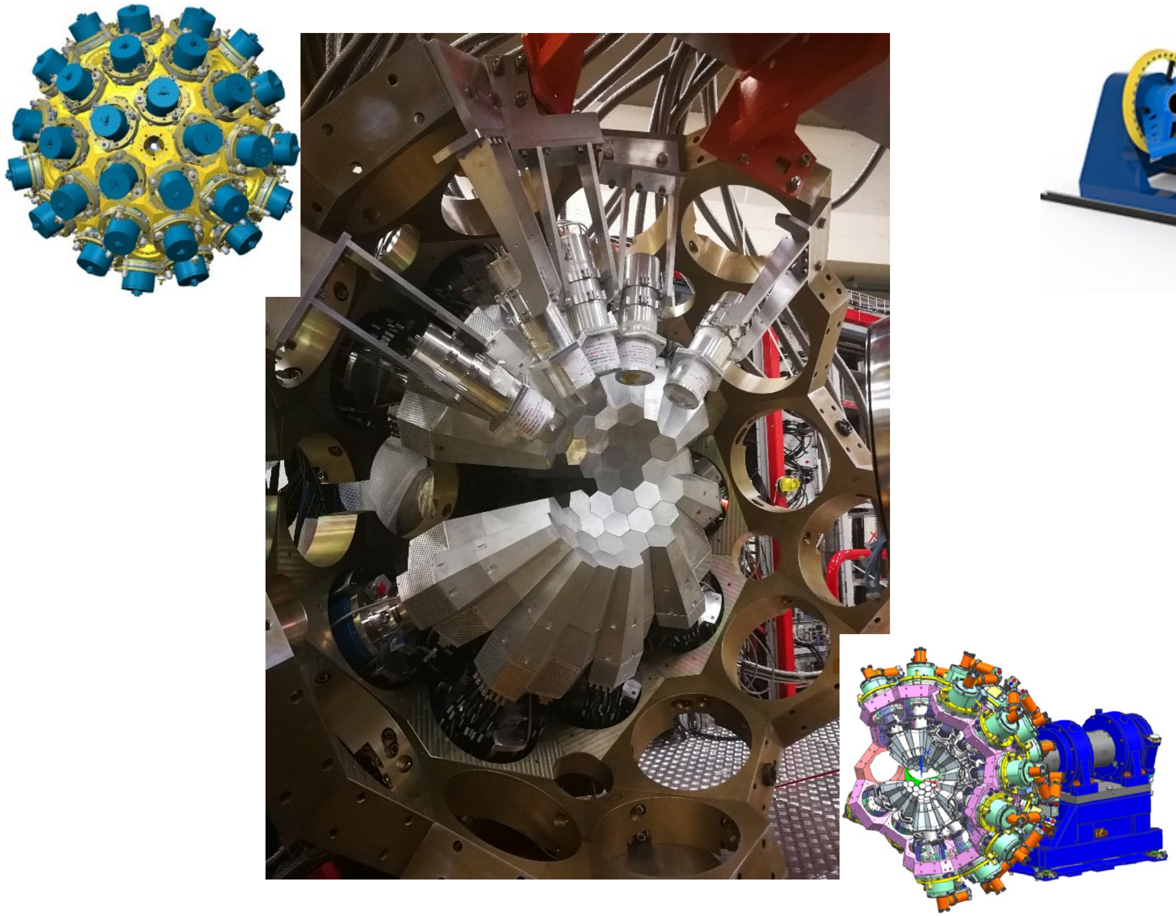
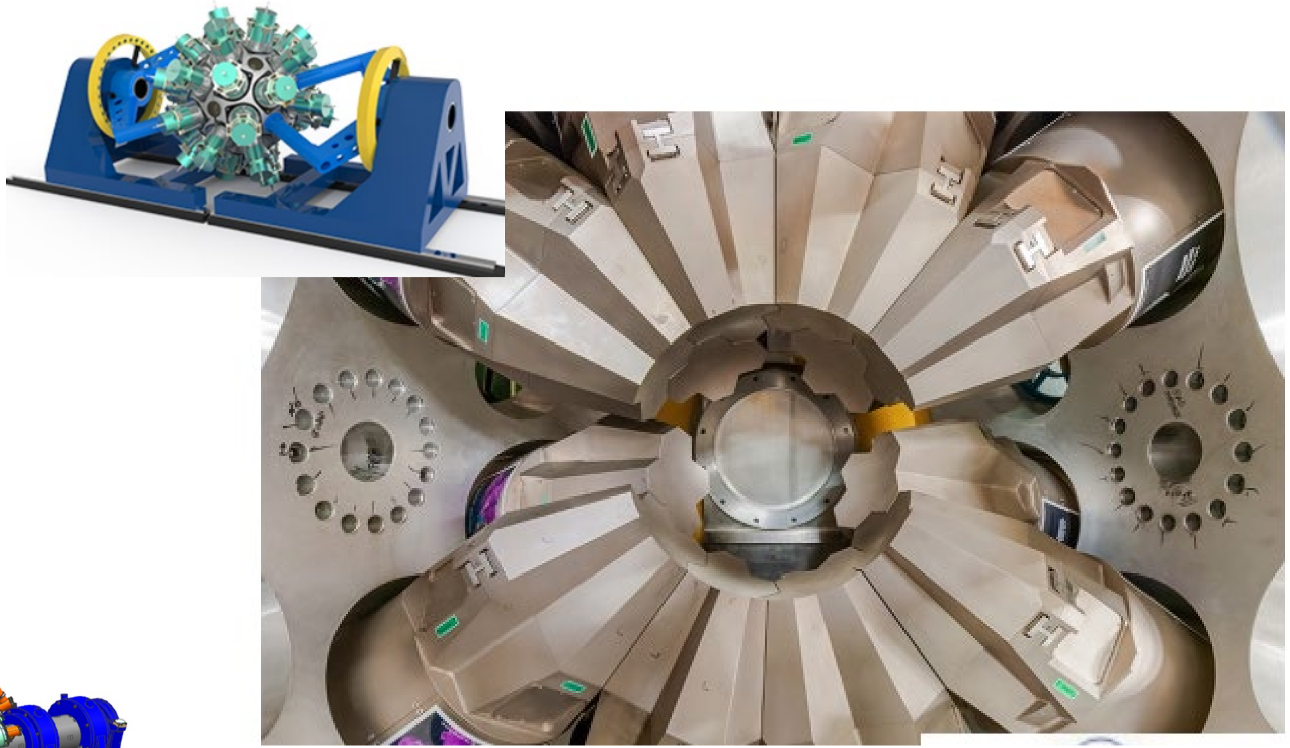
Gamma detector state of the art
(AGATA in EU or GRETA/GRETINA in USA)

Advanced GAmma Tracking Array (AGATA)



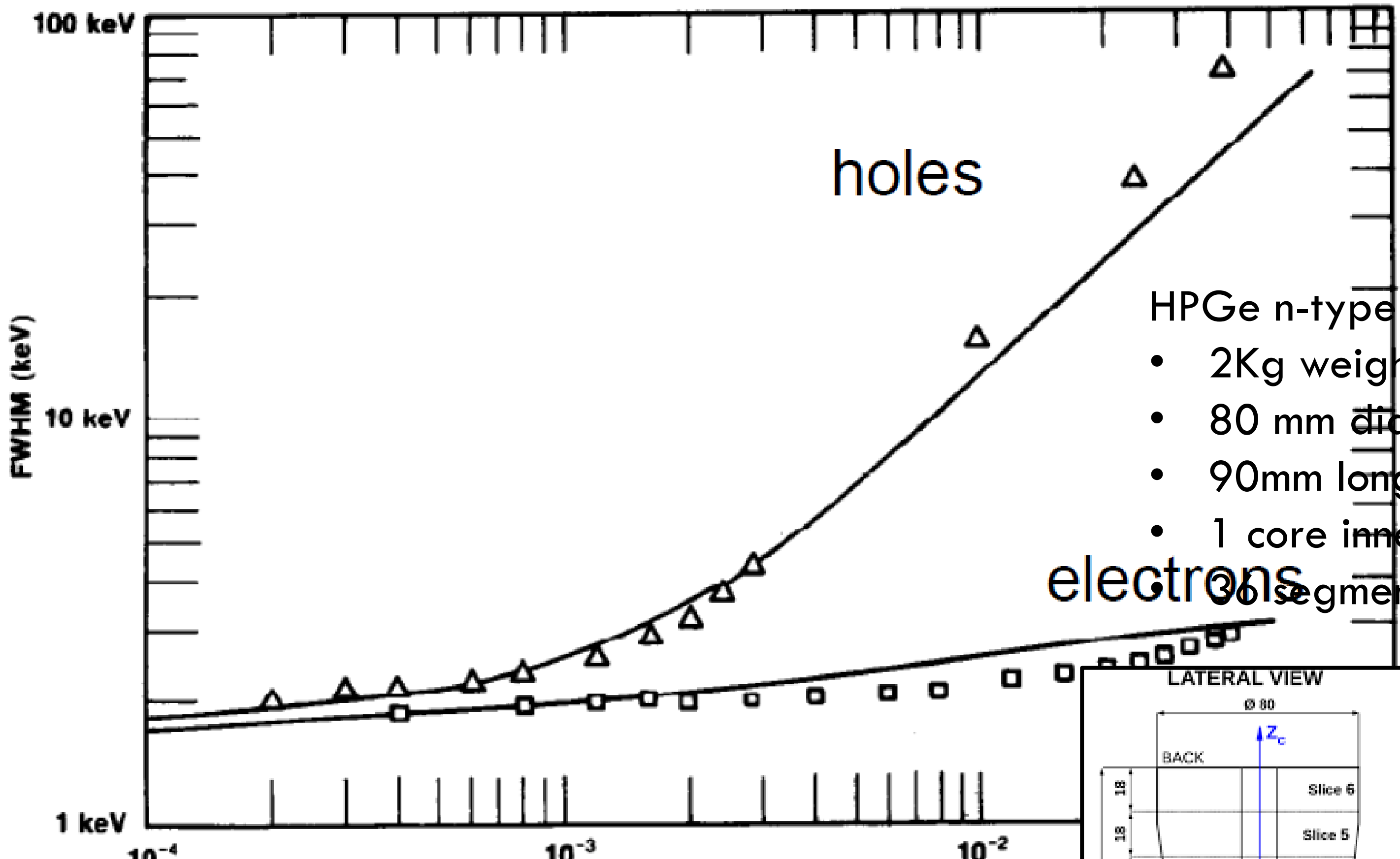
Gamma-Ray Tracking Array (GRETA)



J.J Valiente al. **NIM** Phys. Res. **A** (2023) 1049

N-type detector (AGATA – GRETA/GRETINA)

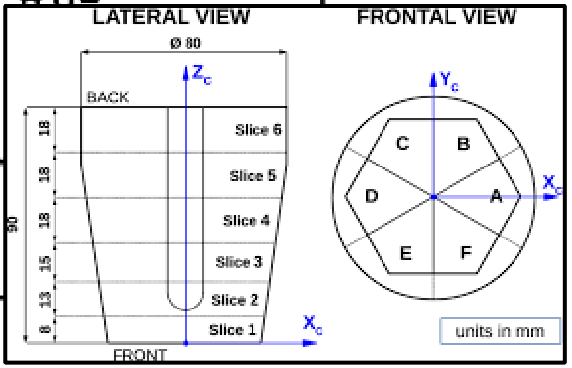
T.W. Raudorf, R.H. Pehl / Effect of charge carrier trapping



Collection of holes: more subjected to trapping caused by neutron damages

HPGe n-type detector:

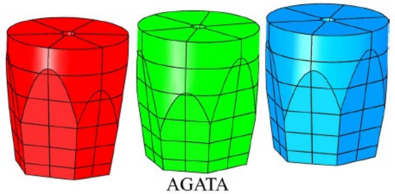
- 2Kg weight
- 80 mm diameter
- 90mm long
- 1 core inner contact
- 36 segments



Encapsulated coaxial HPGe n-type detector (Mirion France)

Polarity inversion
higher damage
trapping by ne

3 asymmetrical HPGe detector



J. Eberth et al. **Eur. Phys. J. A** (2023) 59: 179

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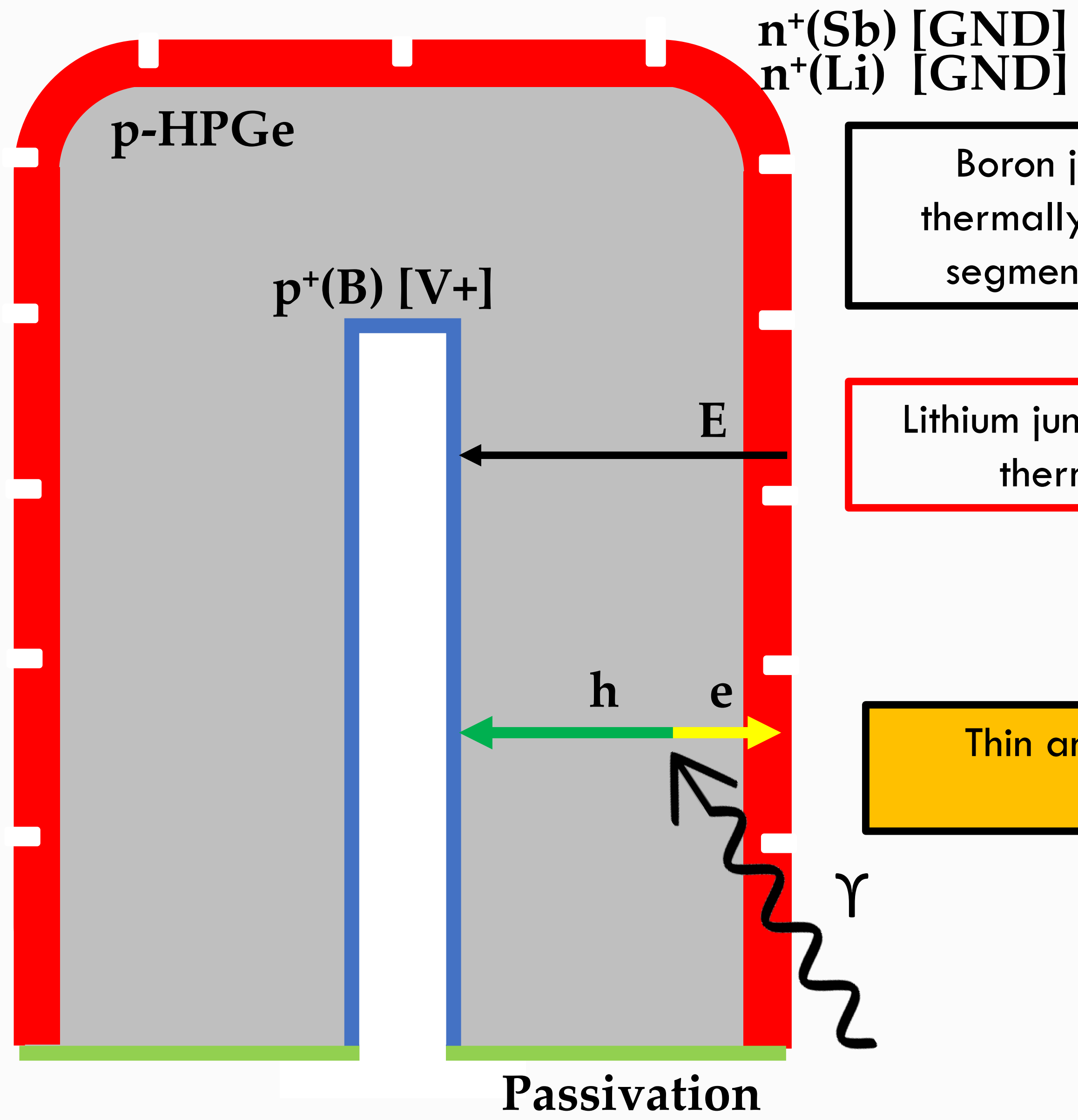
P-type detector (new contact/junction)



Boron junctions are thin, thermally stable and easily segmentable on n-HPGe

Collection of holes: more subjected to trapping caused by neutron damages

Polarity inversion demanded to test higher damage resistivity (hole trapping by neutron damage)

Lithium junctions are thick and thermally unstable

Thin and thermally stable n-type dopants (Pulsed Laser Melting)

p-HPGe with segmentable n+ junction collecting electrons

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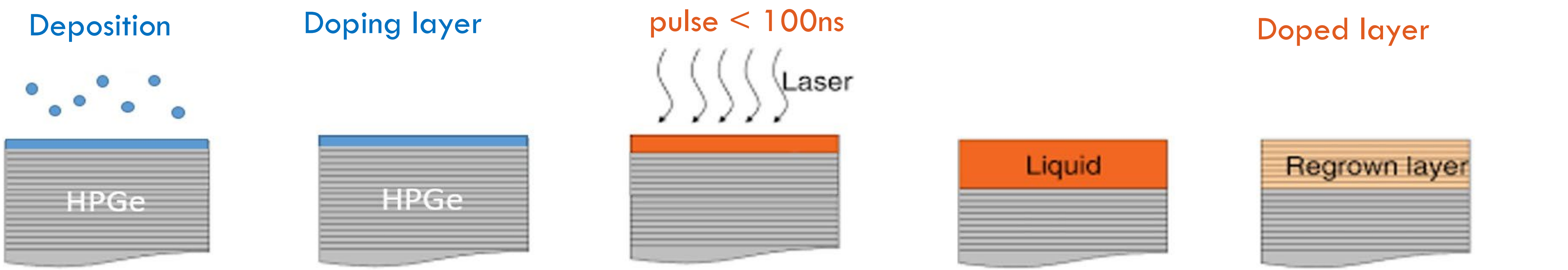
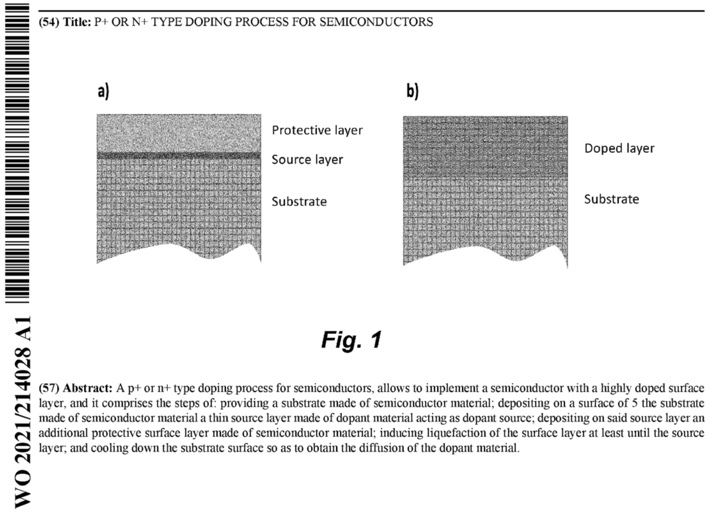
New contact/junction on HPGe: PLM (Pulse Laser Melting)





(54) **Title:** P+ OR N+ TYPE DOPING PROCESS FOR SEMICONDUCTORS

a)
Protective layer
Source layer
Substrate

b)
Doped layer
Substrate

Fig. 1

(57) **Abstract:** A p+ or n+ type doping process for semiconductors, allows to implement a semiconductor with a highly doped surface layer, and it comprises the steps of: providing a substrate made of semiconductor material; depositing on a surface of 5 the substrate made of semiconductor material a thin source layer made of dopant material acting as dopant source; depositing on said source layer an additional protective surface layer made of semiconductor material; inducing liquefaction of the surface layer at least until the source layer; and cooling down the substrate surface so as to obtain the diffusion of the dopant material.

WO 2021/214028 A1

Autors:
D. De Salvador, G. Maggioni, D. Napoli, E. Napolitani

Advantages:

- **Melting temperature** is reached and maintained for a very short time **(<100 ns)**
- Only the **surface (< 200 nm)** is melted, the bulk is at room temperature
- **High dopant concentrations** with very sharp dopant profile
- Doping with **heavy elements** without crystal damage
- Very **clean process** suitable for preserving the Ge hyperpurity
- Suitable for **complex contact geometries** (**segmentation**)

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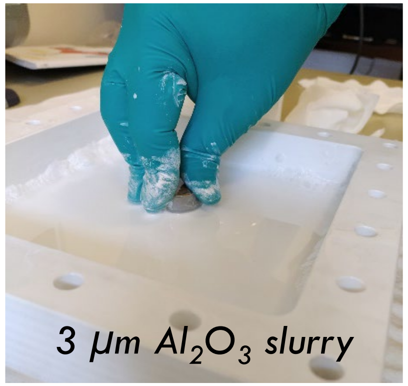
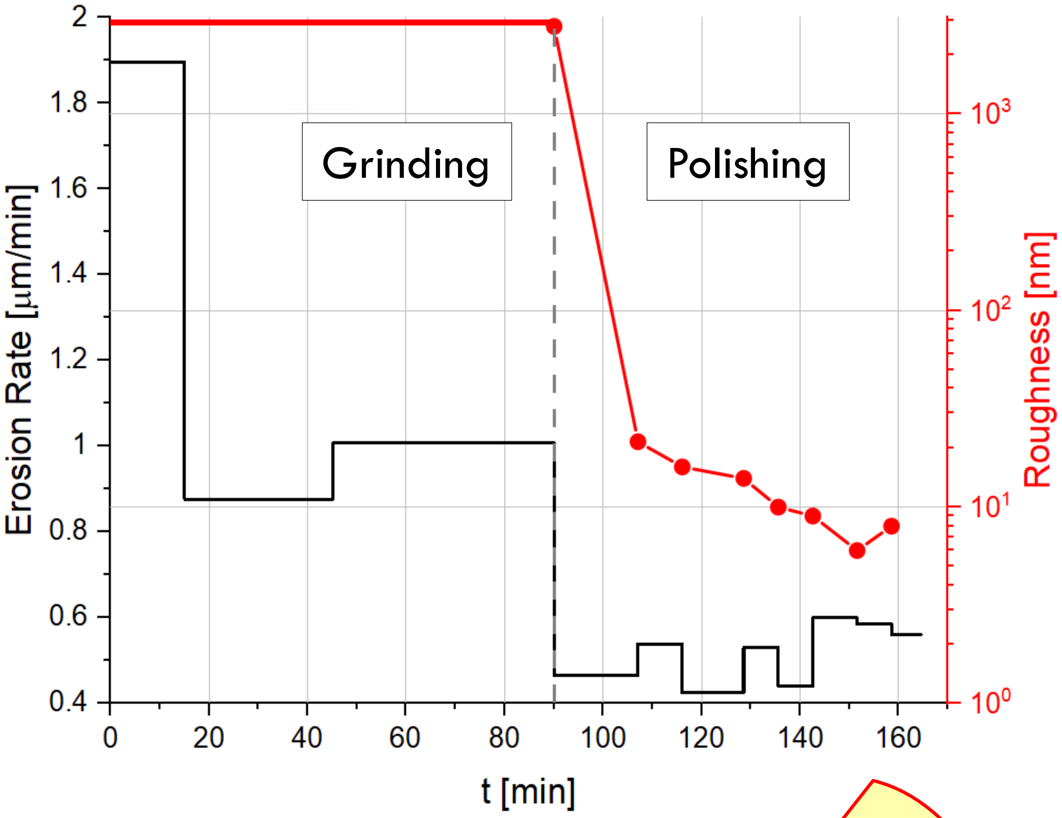
New contact/junction on HPGe: crystal surface preparation

Grinded surface (opaque)





Etched surface (High waviness, low roughness)

(3:1) HNO_3 : HF

Polished surface (CMP) (Low waviness, low roughness)

rotating disc rinsed with H_2O_2 1% (pH 12 with KOH) Rate: ≈200 nm/min

… + Colloidal Silica (30nm size) Rate: ≈ 400 nm/min

2024-2025

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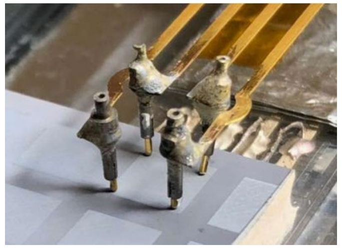
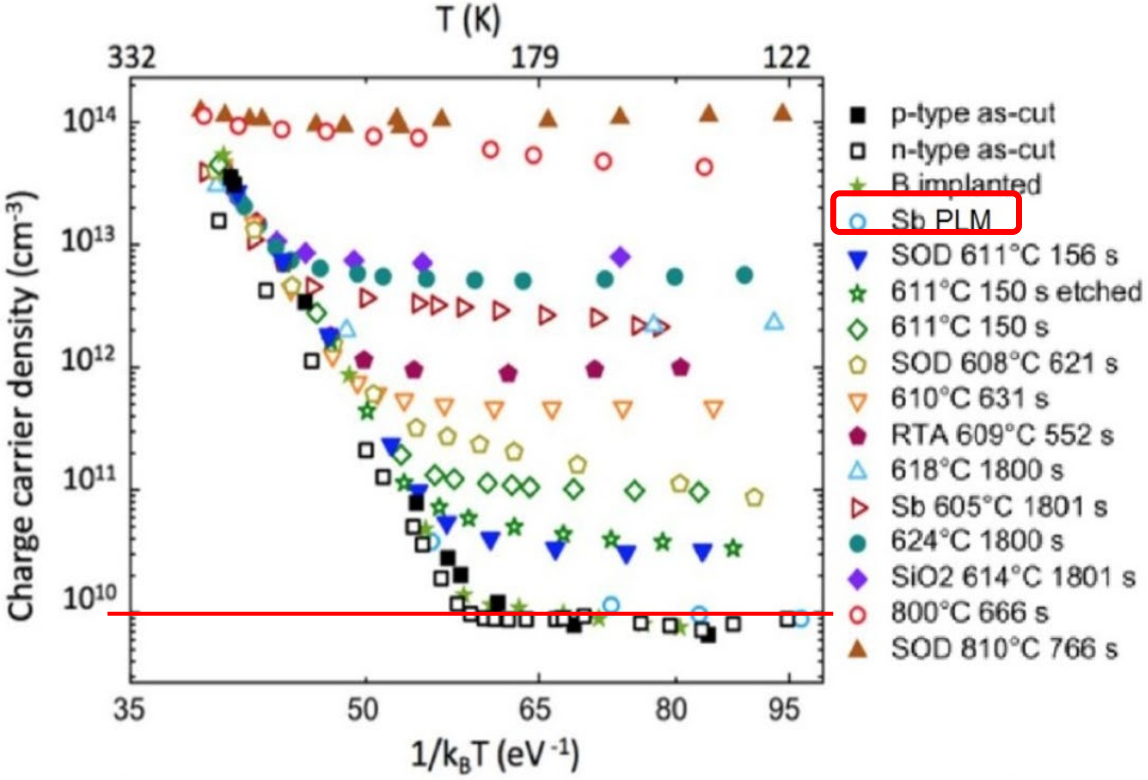
New contact/junction on HPGe: PLM on HPGe crystal

Van Der Pauw Hall

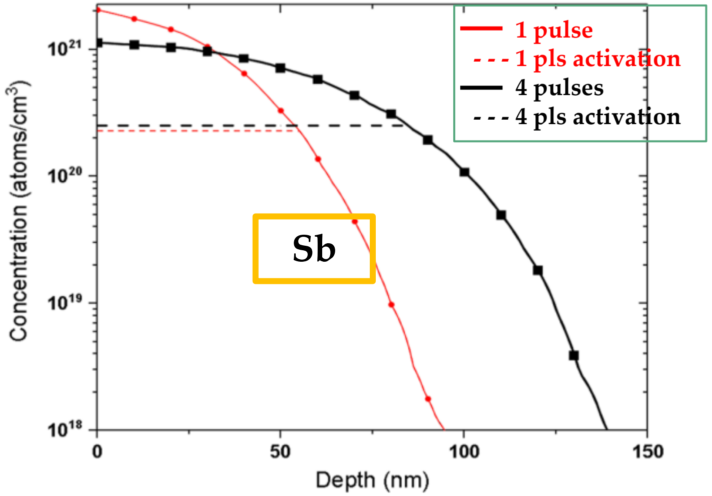


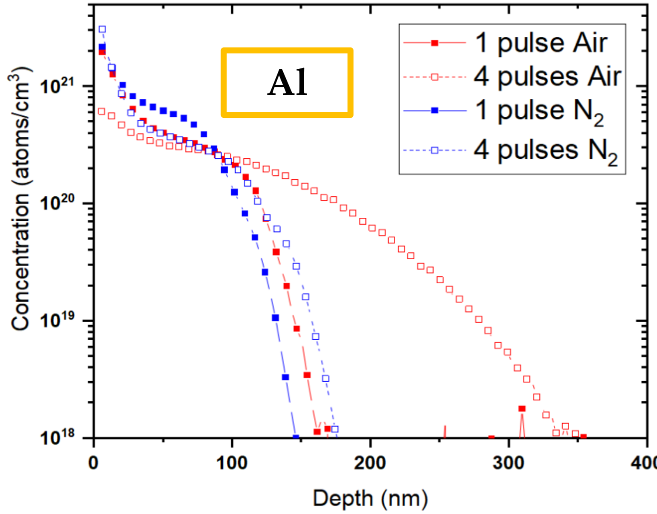
Impurities concentration in Ge bulk



V. Boldrini et al., **Journal of Physics D: Applied Physics** (2018) volume 52, 3

SIMS (Secondary Ions Mass Spectrometry)





Narrow
Contact/Junction

C. Carraro et al. "**Applied Surface Science**, 509 (2020)

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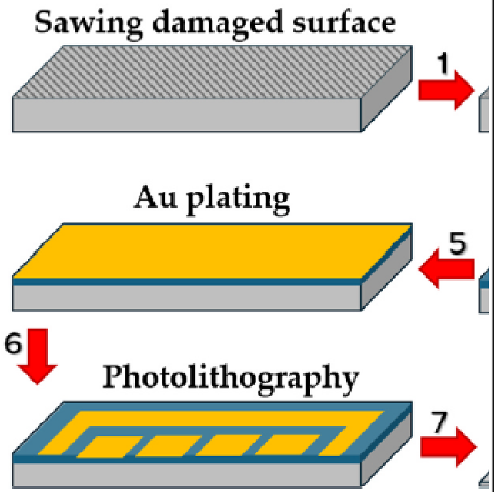
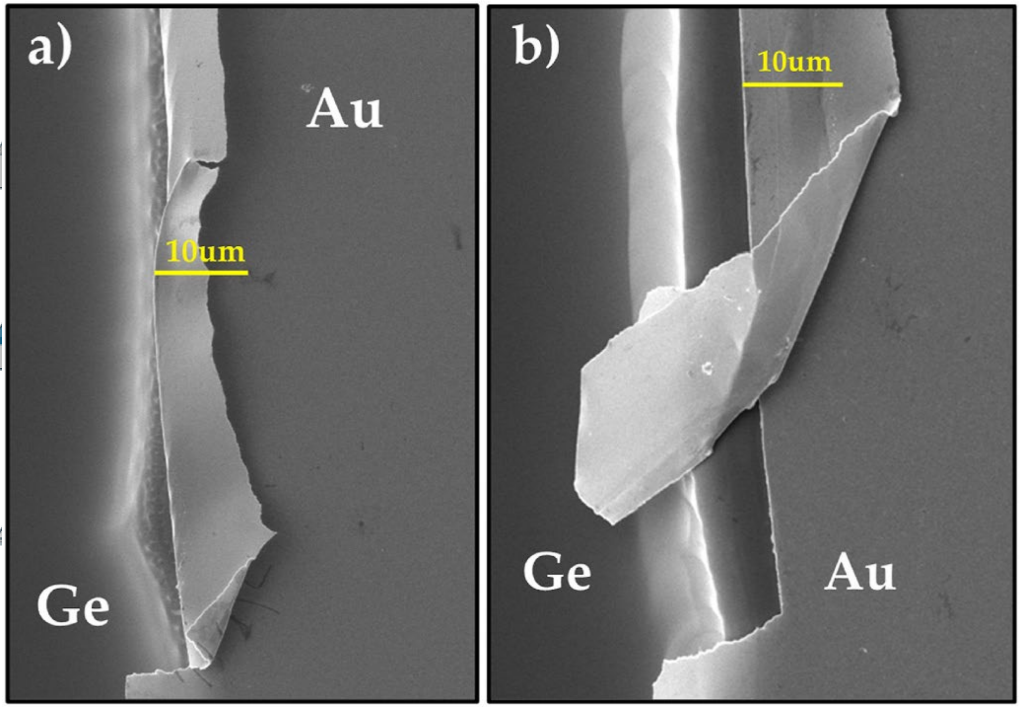
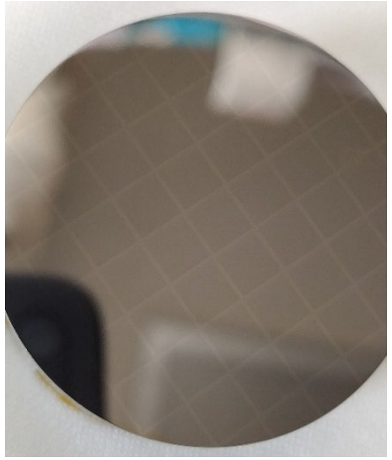
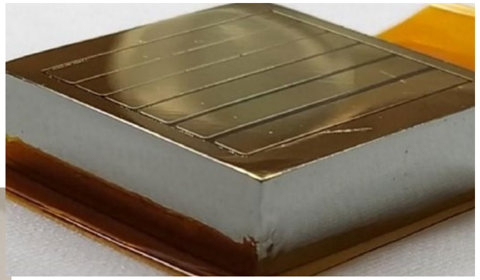
PLM contact/junction: 1° type Segmentation





Full area PLM





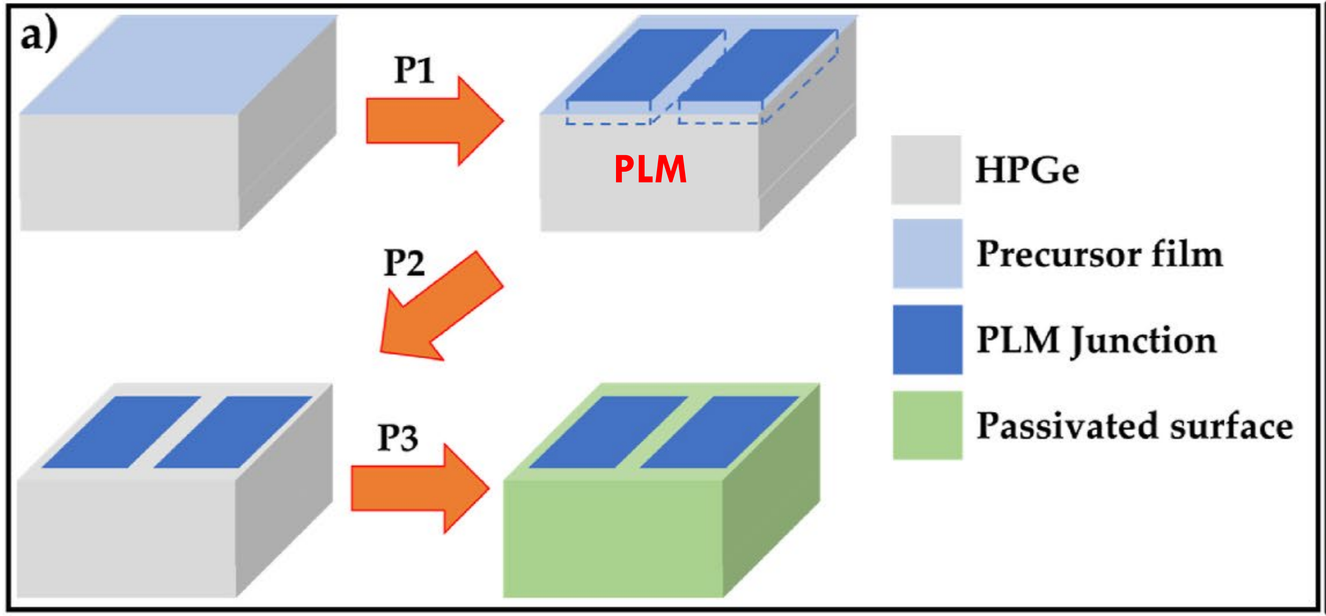
Full area PLM

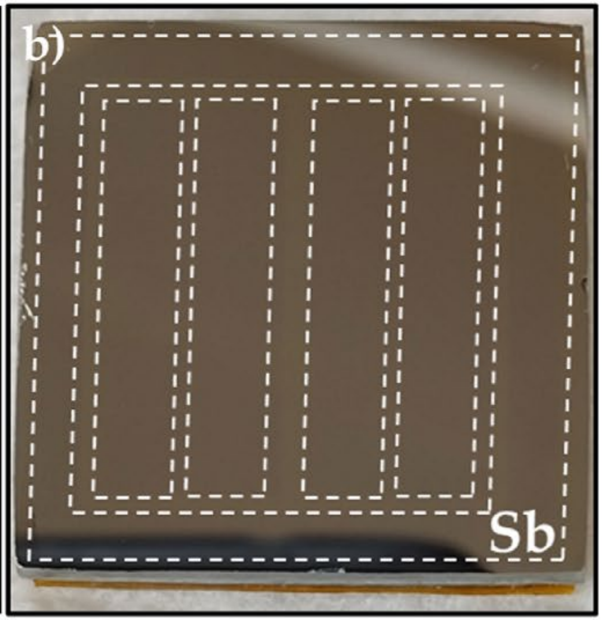
Au deposition
100 nm PVD deposition of Au in Ar plasma with ultrapure target in vacuum (10^{-6} mbar)

Photolithography
Photoresist deposition, baking, exposure and development, followed by Au stripping and resist removal.

Intercontact gaps passivation
(3:1) HNO_3 : HF etching followed by chemical quenching passivation.

PLM contact/junction: 2° type Segmentation





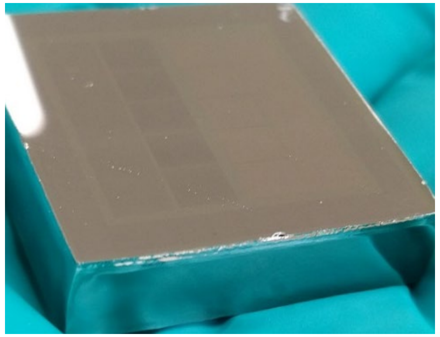
Lithographic process using selective etching solutions:

- Hot pure H_2SO_4 for Sb deposition (preserve Sb junction)
- H_2O_2 for GeP deposition (slowly etches everywhere)
- Kern solutions (H_2O_2, H_3PO_4, Ethanol) for Al-Ge deposition (preserve Al junction)

PLM (Selective area)

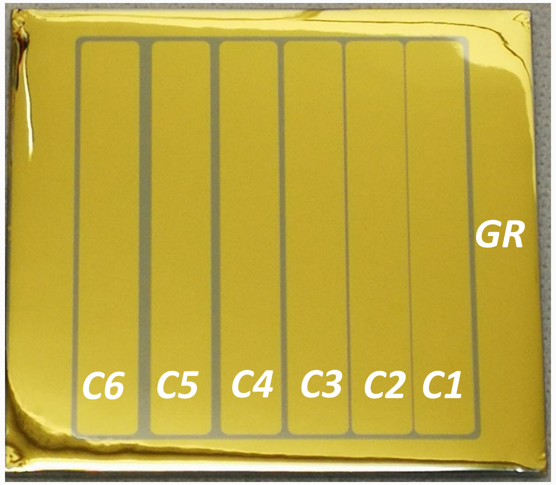
Selective etching
Removal of untreated dopant using selective etchants to protect the near junction.

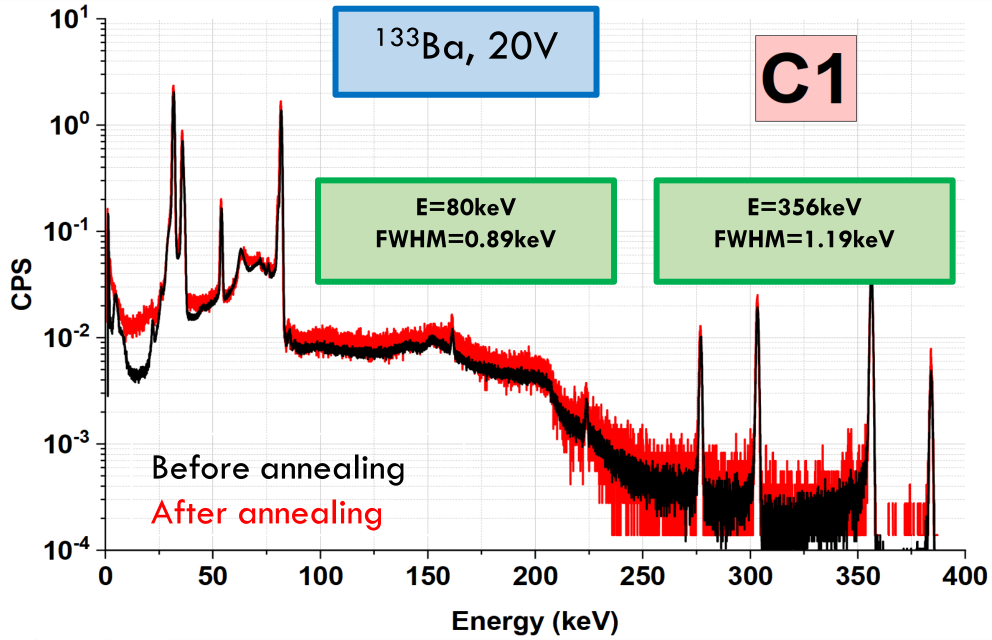
Chemical passivation
Passivation of undoped surfaces with suitable solutions.

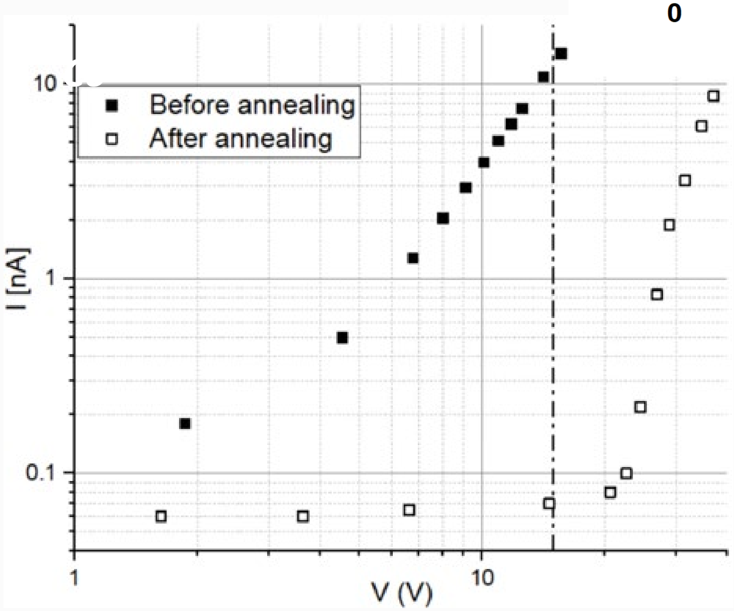


Thin planar HPGe detectors

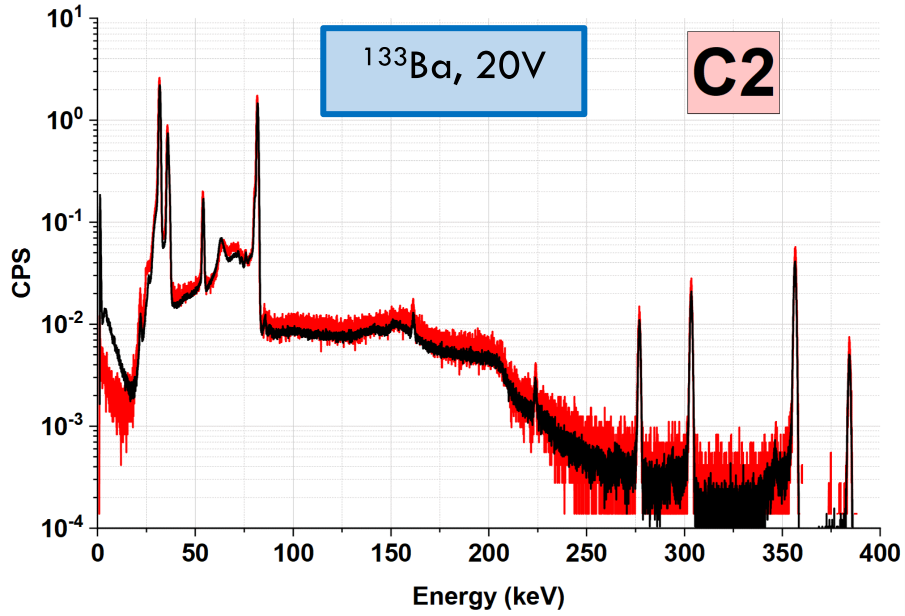
Sb/p-HPGE/Al, L=35mm, t=1.6mm







..... Scale up (PLM Area)



W. Raniero et al., **Il NUOVO CIMENTO 44 C** (2021) 154

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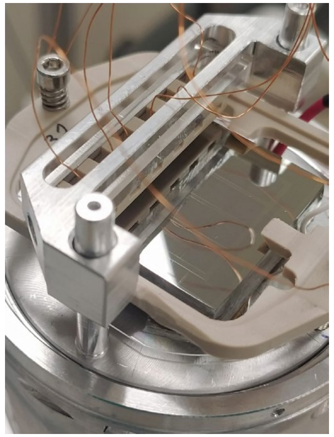
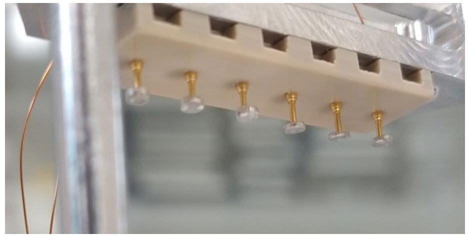
Thick planar detectors

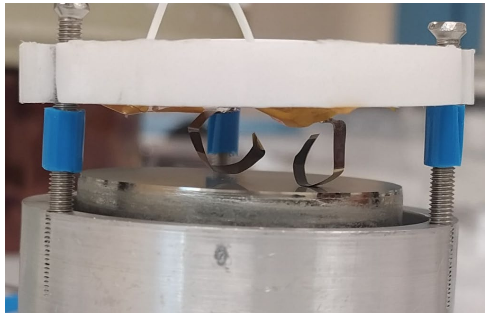


Sb/p-HPGE/Al,
N=1.6x10^{10} cm^{-3}
L=35mm, t=10mm

n+ junction
(**spring contact**)



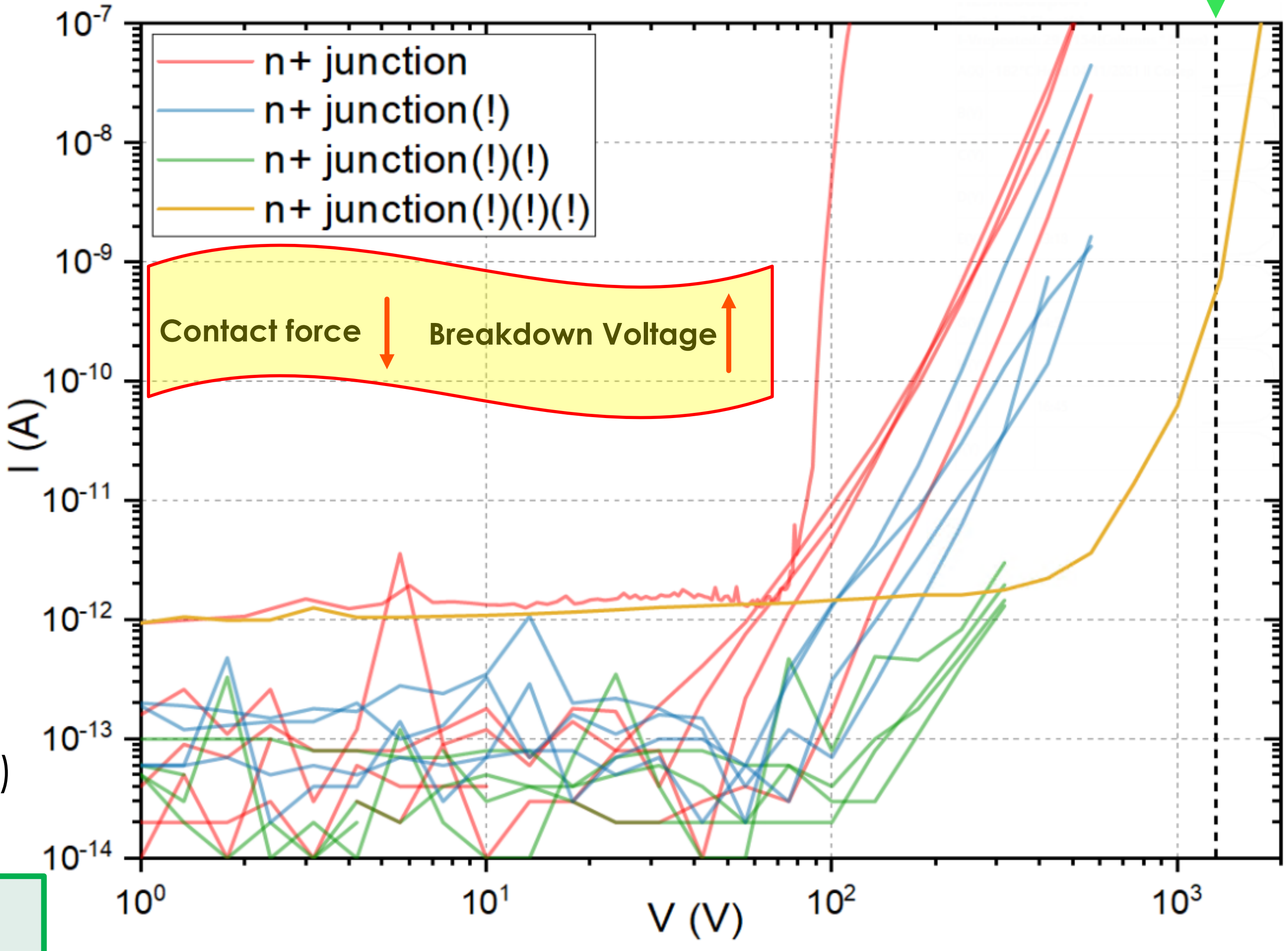
n+ junction (!) / (!)(!)
(**indium pad**)



n+ junction (!)(!)(!)
(**elastic tabs**)

Sb/p-HPGE/Al,
N=6x10^{9} cm^{-3}
D=40mm, t=20mm

$V_{depl.}$: 1300V



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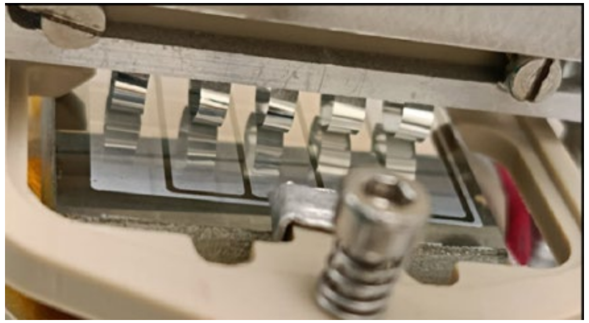
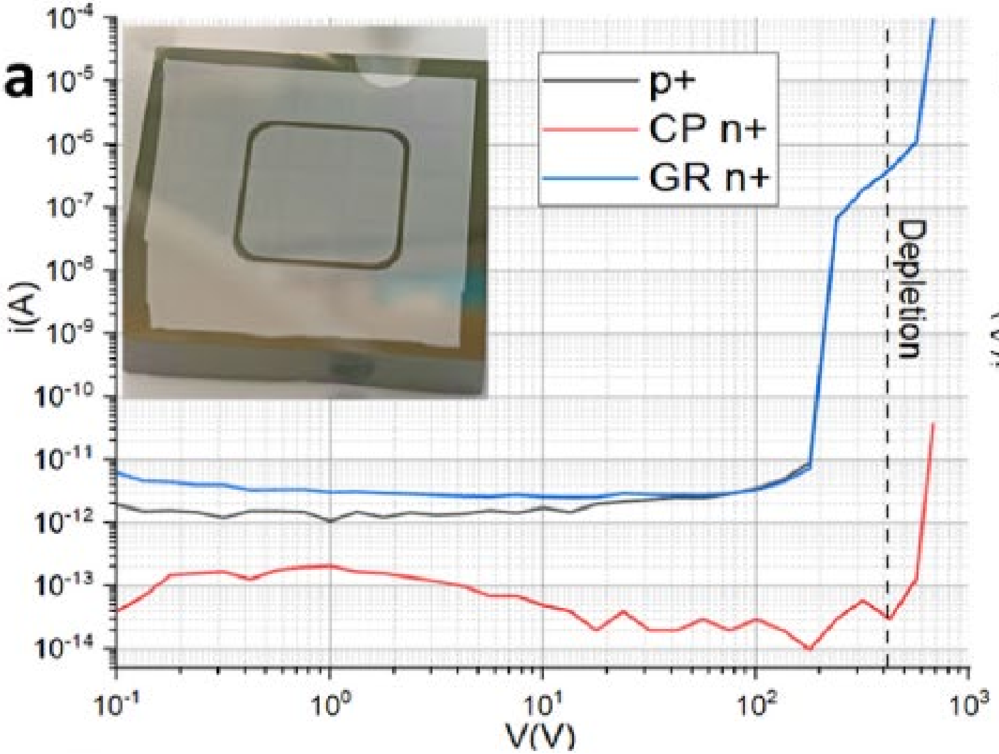
Thick planar detectors

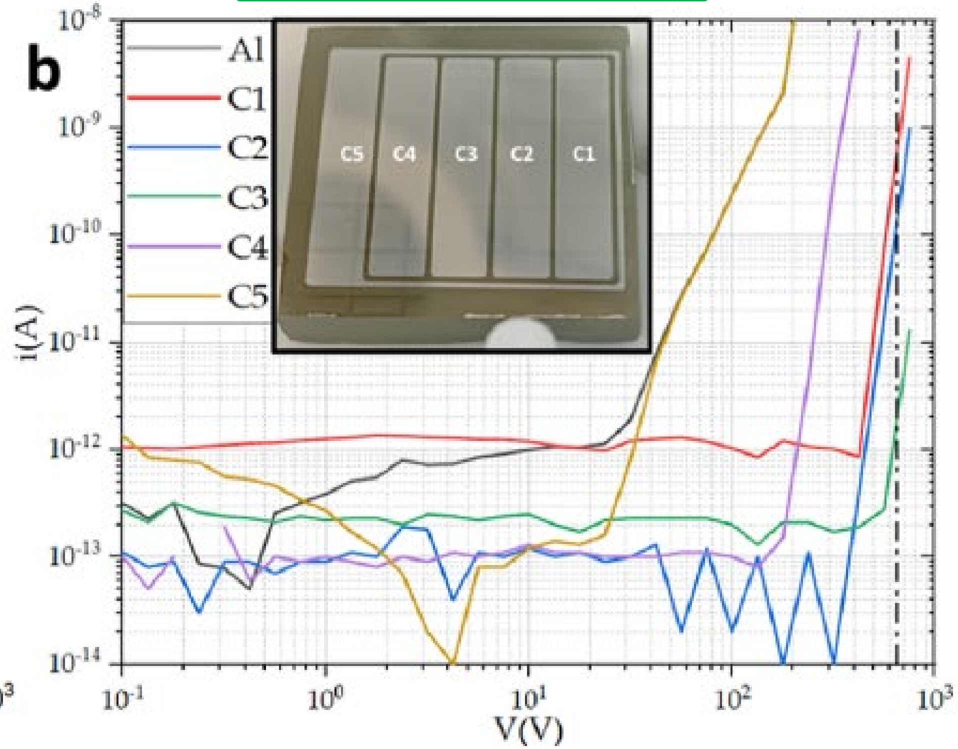
Soft contact + Al plated (segmented)



Sb/p-HPGE/Al,
$N=6x10^9$ cm^{-3}
L=28mm, t=10mm



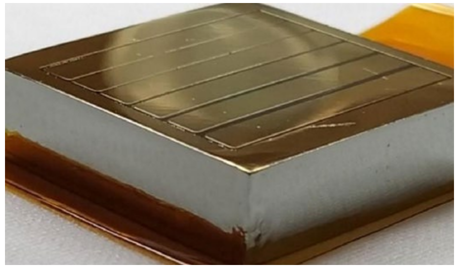
Sb/p-HPGE/Al,
$N=1.6x10^{10}$ cm^{-3}
L=33mm, t=8.5mm



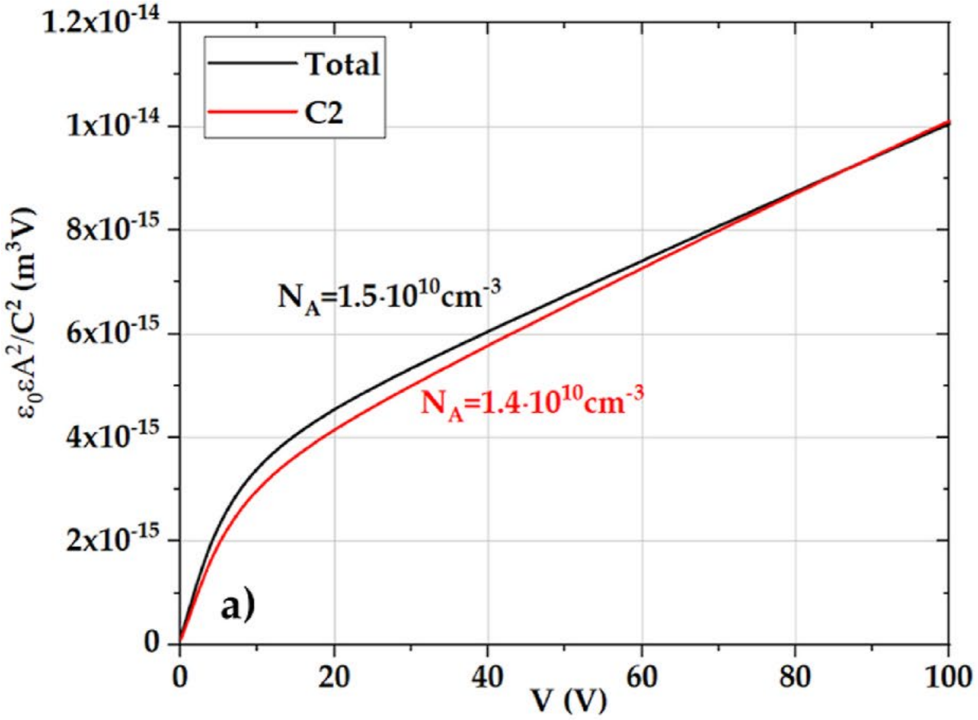
S. Bertoldo et al., **MSSP**(2025) volume 200

Thick planar detectors

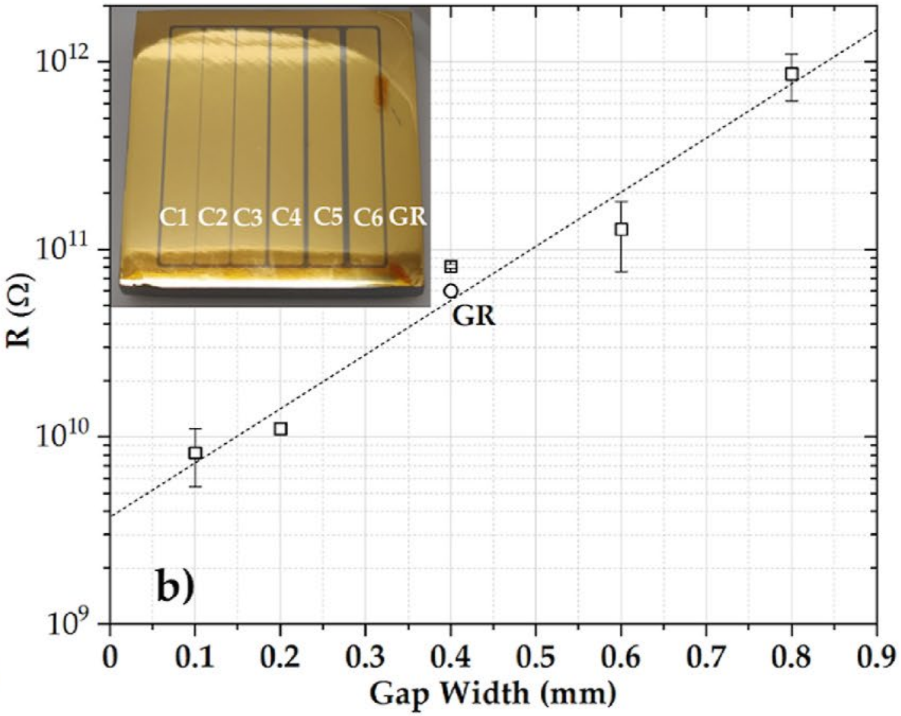
Sb/p-HPGE/Al, L=35mm, t=10mm



C-V test to estrapolate HPGe purity



R(Ω) segmentation gap



This confirms that the PLM process is highly safe against bulk contamination of HPGe material.

S. Bertoldo et al., **MSSP**(2025) volume 200

Thick planar detectors: Summary Process

S. Bertoldo et al., **MSSP** (2025) volume 200
https://doi.org/10.1016/j.mssp.2025.109967

August 2025

Materials Science in Semiconductor Processing 200 (2025) 109967

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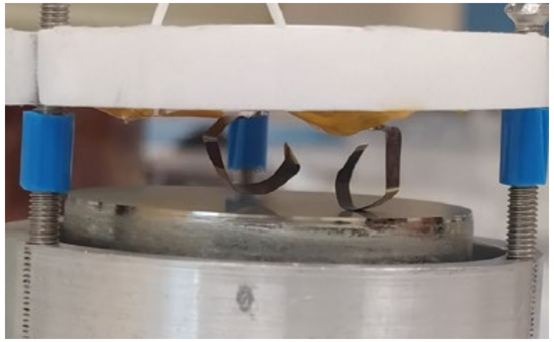
journal homepage: www.elsevier.com/locate/mssp

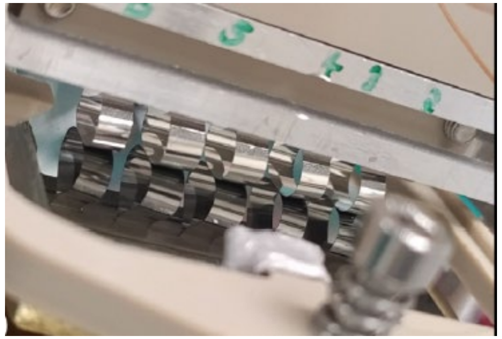
ELSEVIER

Lithium-free hyperpure germanium detectors with enhanced thickness, area, and segmentation via pulsed laser melting

P-type detector

Detector	d (mm)	N_A [10^{10} cm^{-3}]	V_D [V]	Process	V_B [V]	$\|\vec{E_B}\|$ [kV/cm]
D2-A	9.20	1.6	760	Dust-proofed equipment	15–25	0.2–0.3
D2-B	9.15	“	750	Aggressive solvents	20–40	0.3–0.4
D2-C	9.15	“	750	Au-free lithography	50–60	0.4–0.5
D2-D	9.10	“	740	Chemical-mechanical polishing	60–90	0.5–0.6
D2-E	8.8	“	690	Indium discs	80–110	0.5–0.6
D3	19.8	0.6	1320	Kapton foils contact	1200	1.3
D2-F	8.6	1.6	660	Mylar foils contact	150–300	0.7–1.1
D4	10	0.6	335	Thick Al plating and mylar foils contact	500–600	0.8–0.9
D2-G	8.6	1.6	660	Thick Al plating and mylar foils contact	400–600	1.2–1.5





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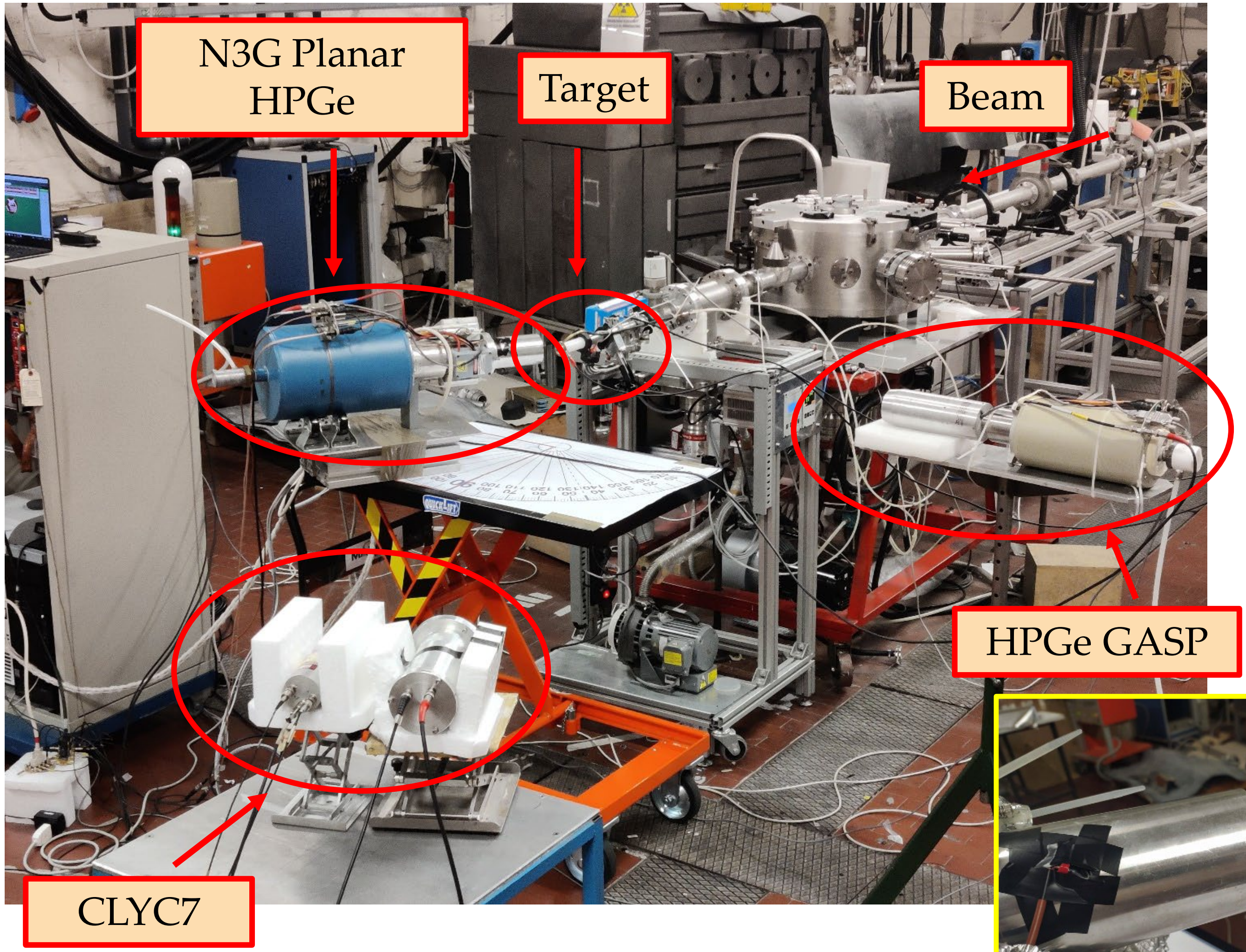
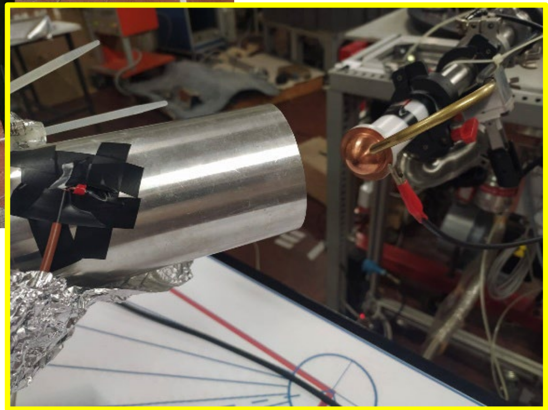
Neutrons damage on planar PLM segmented detector





380nA 4MeV proton beam
^{7}Li target, 100μm

Reaction: $^{7}Li\ (p,n)\ ^{7}Be$

Prototype detector is located at 30° 9.5 cm

Neutrons are directly measured with

- CLYC7 scintillators, 30° 2 m
- GASP HPGe γ detector, 90° 1 m

$$^{7}Be + e^- \xrightarrow{53.3\ days} {}^{7}Li \rightsquigarrow 477.6\ keV$$

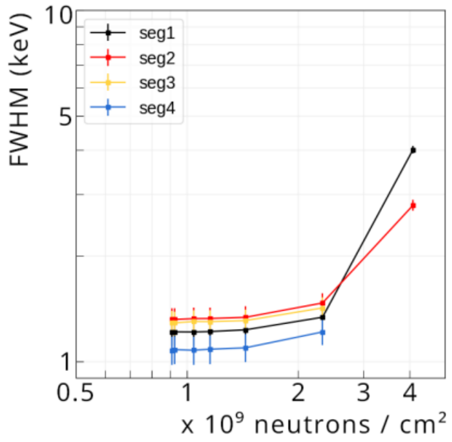
R. Escudeiro at all. "**Neutron radiation damage on a planar segmented germanium detector**" Acta Physica Polonica B Proceedings Supplement 17, 3-A14 (2024)

DOI:10.5506/APhysPolBSupp.

Neutrons damage on planar PLM segmented detector

Detector prototype:
Sb/p-HPGE/Al, L= 32mm, t= 8.6mm
4 contacts + guard ring

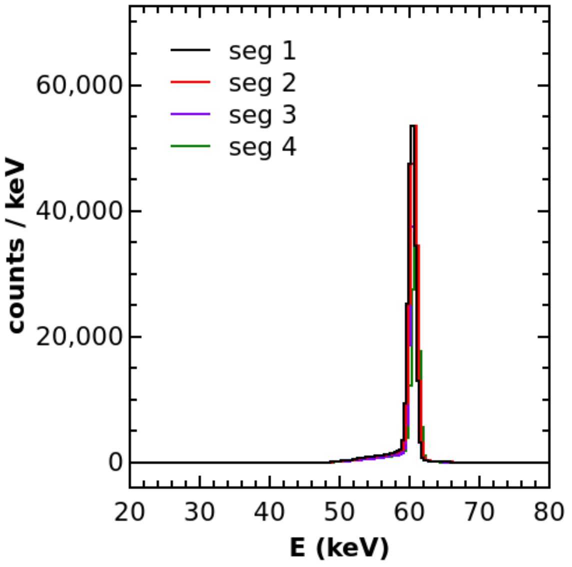
Resolution at **80V** operational bias



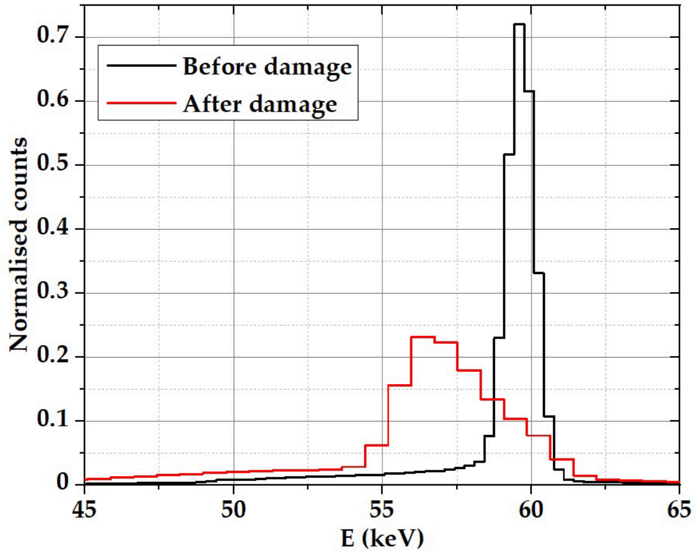
After 4 hours of irradiation time, $\approx 4 \cdot 10^9$ neutrons/cm^2

Annealing procedure: 7 days at 105°C continuously pumped

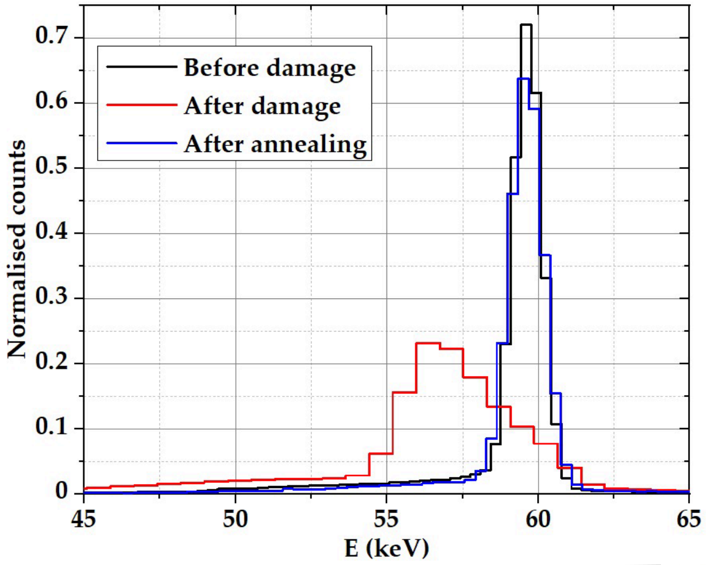
^{241}Am
E = 59,5 keV
FWHM < 1,1 keV



^{241}Am
E = 59,5 keV
FWHM = 3,2 – 4,2 keV



^{241}Am
E = 59,5 keV
FWHM < 1,6 keV



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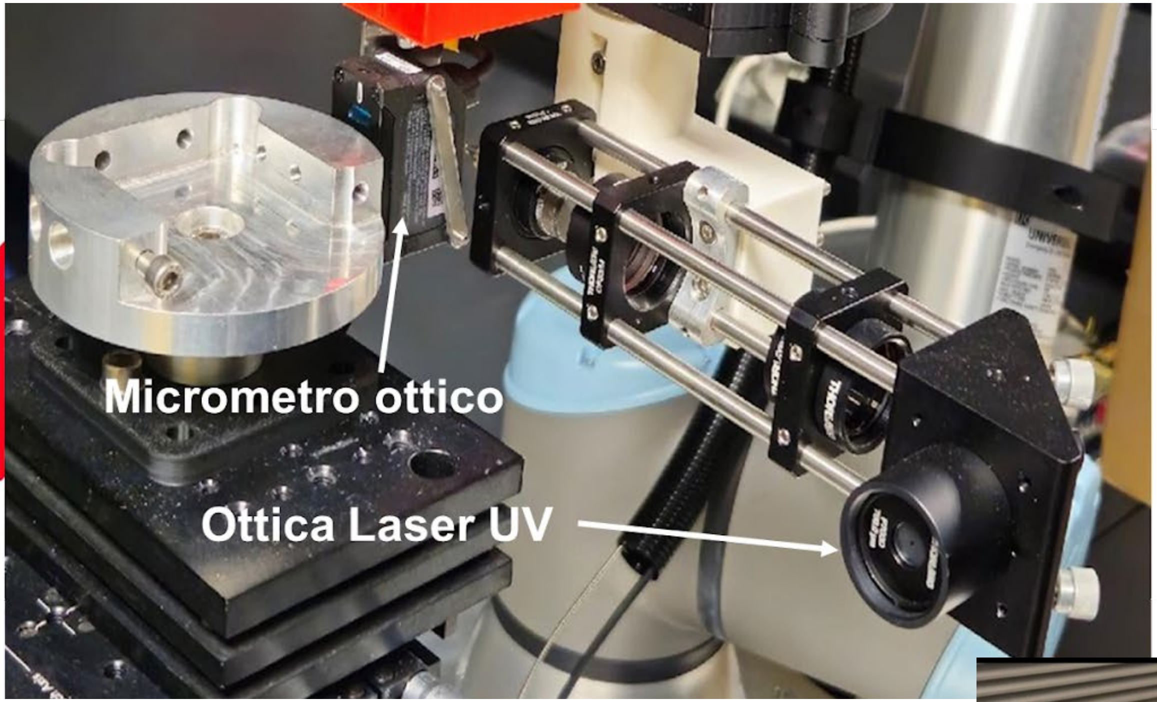
3D shape detector…. Pholitography and Segmentation



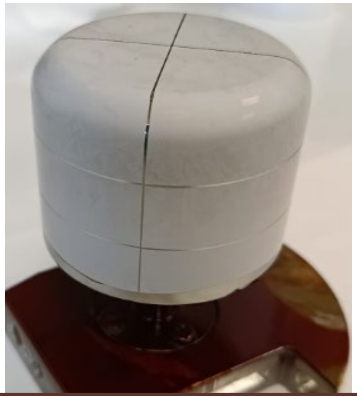
Scanning, reconstruction, and pattern

3D shape detector…. Pholitography and Segmentation

50mm d, 50mm h,
n-type crystal,
AlGe PLM junction,
Li core

Al plated

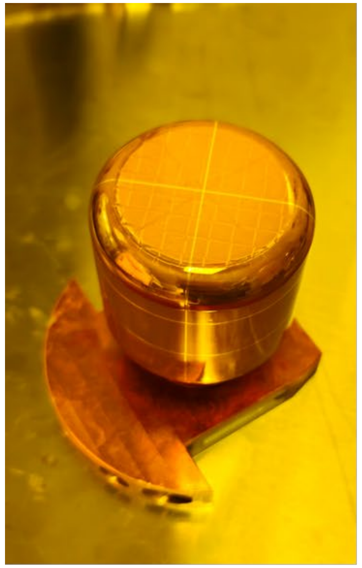
Al plated + photoresist
spry coating

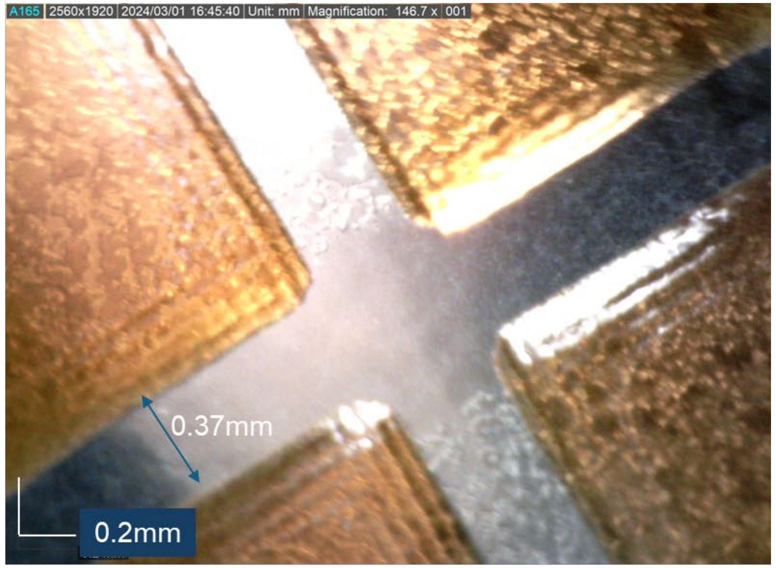


After
photolithography

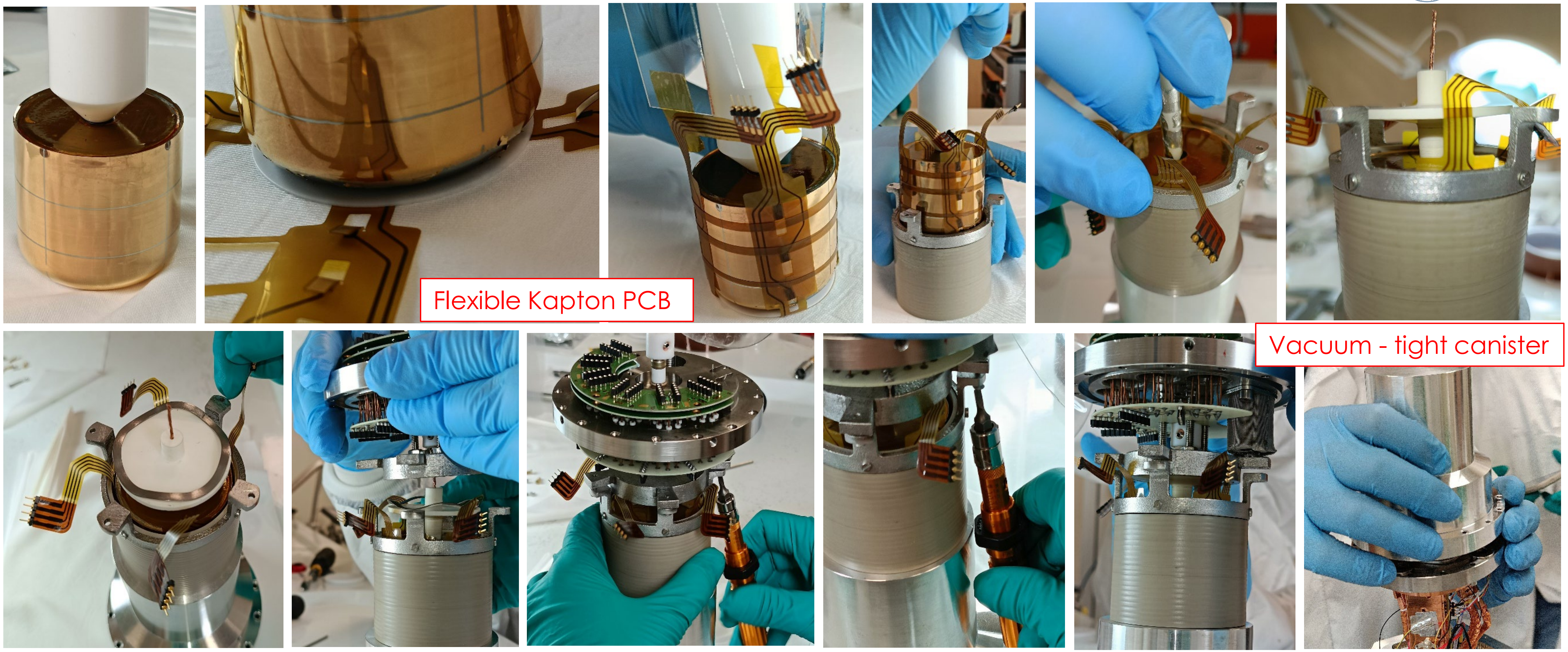
3D photolitography

Università
degli Studi
di Ferrara





Encapsulation of Coaxial detector: ad-hoc mounting systems



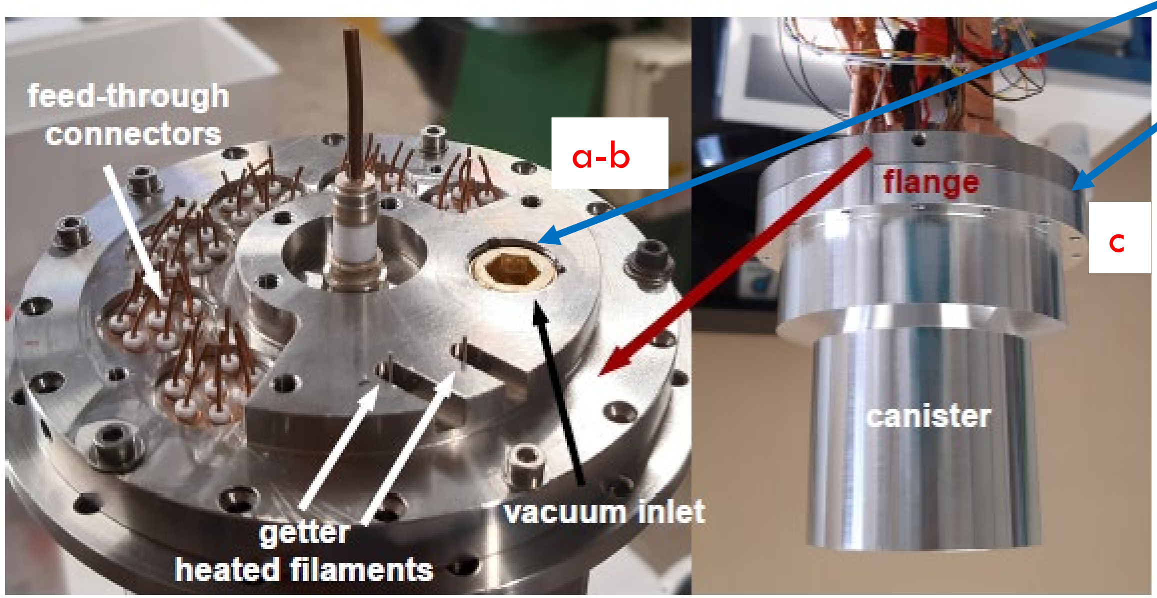
S. Capra et al, **JINST 19 C01011** (2024)

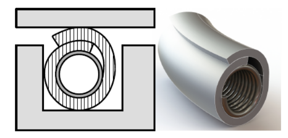
Encapsulation: test of vacuum canister

Giacomo Secci (UniMI/INFN)

UNIVERSITÀ DEGLI STUDI DI MILANO

Test on-going

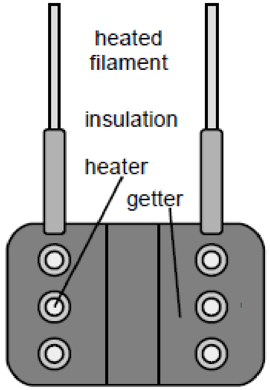


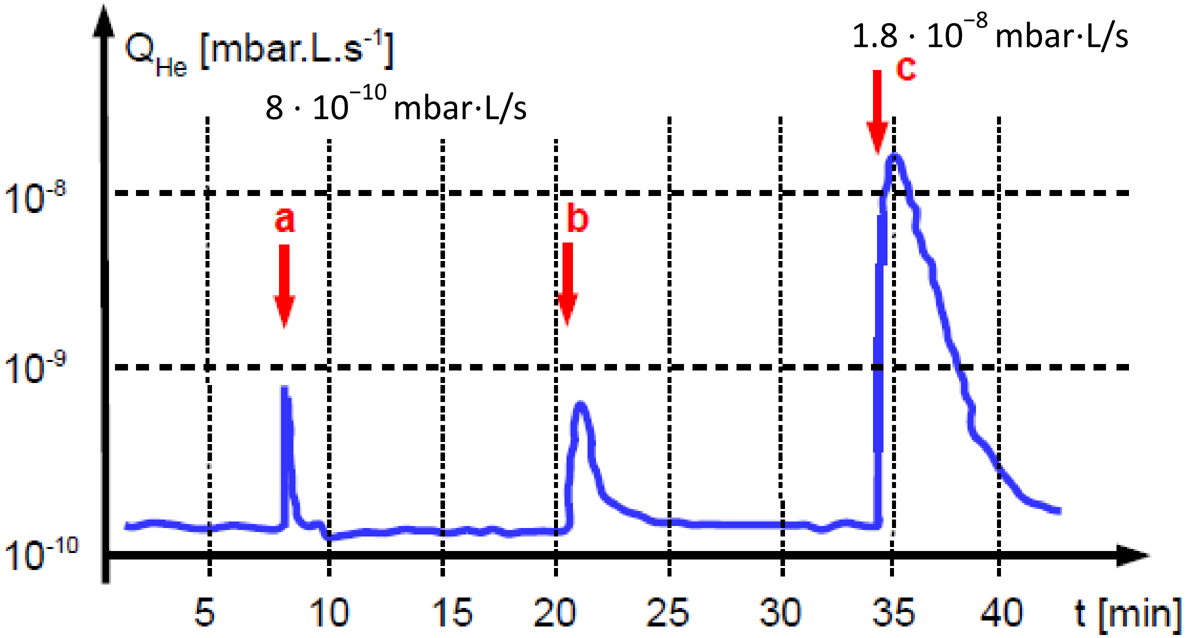


Helicoflex® gasket

Leak rate with Helium at $\tau = 2.13$ Nm
a-b: evacuation port
c: canister/flange

Non-Evaporable Getters (NEGs)
The ST 172 is a zirconium-based NEGs require thermal activation (450–900°C) to expose their reactive sites. Once activated, they effectively absorb gases such as O2, N2, H2, CO, and CO2.





Over Torque $\tau = 2.3$ Nm canister/flange (c)
leak rate is $8 \cdot 10^{-10}$ mbar·L/s

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Encapsulation: test of Getter attivation

Test on-going

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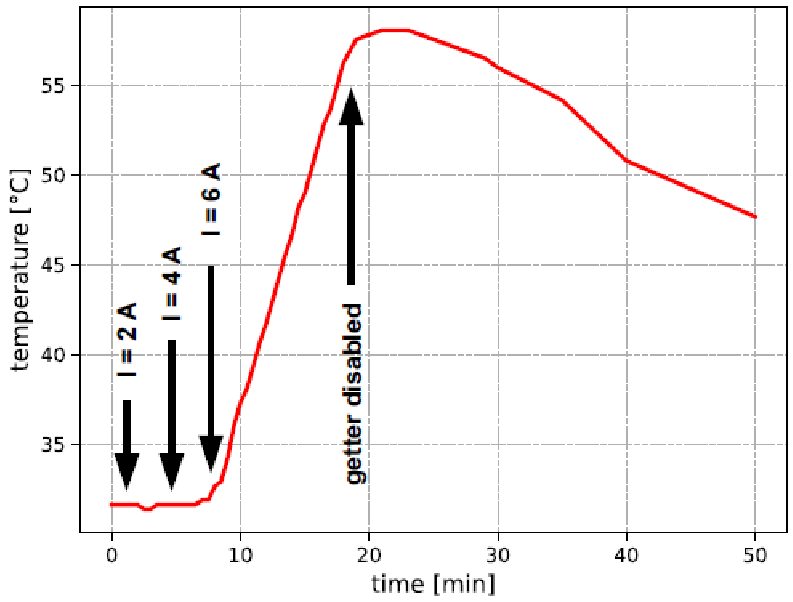
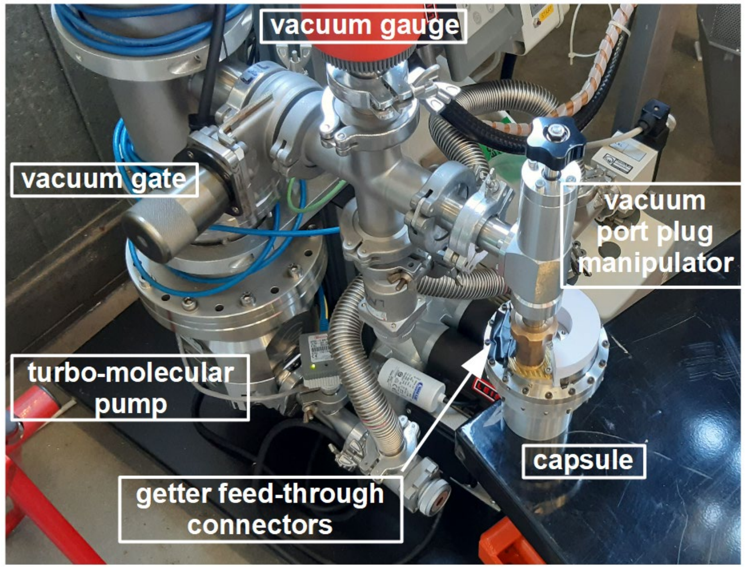
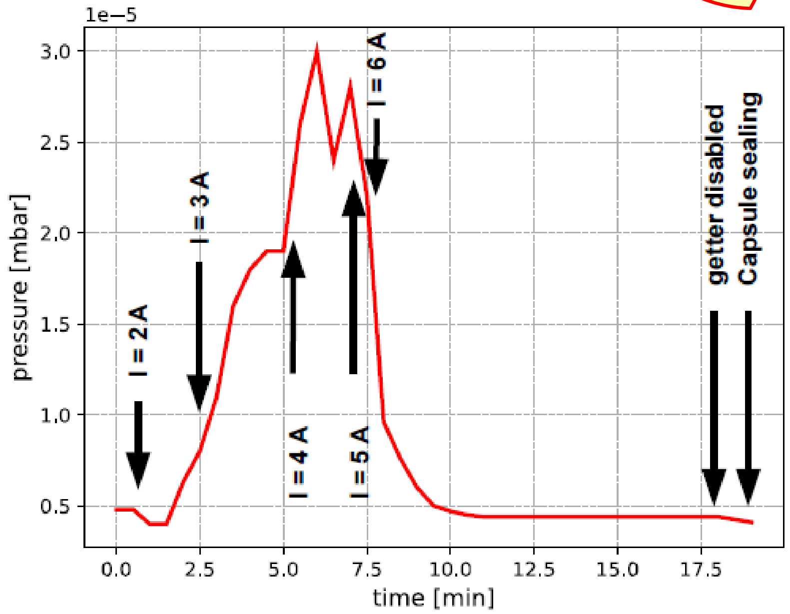


Getter activated by applying a 6A current across its terminals and maintaining it for 10 min.





Temperature (PT 100 inside the cannister) and Pressure (Pirani –Penning) constantly monitored

After 5 days with the activated getter the vacuum measured when reopened the capsule was around $2 \cdot 10^{-5}$ mbar

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SUMMARY

- PLM technology preserve the hyperpurity of Germanium
- PLM junction is narrow, segmentable and termally stable (annealing)
- The HPGe crystal surface preparation (polishing) and the electrical contact force (soft contact) are fondamental
- Detector encaspulation shows promising results for integrating a new PLM detector
- PLM segmented detector recovers after Neutron damage while maintaning excellent resolution

R&D Gamma ray detector Team

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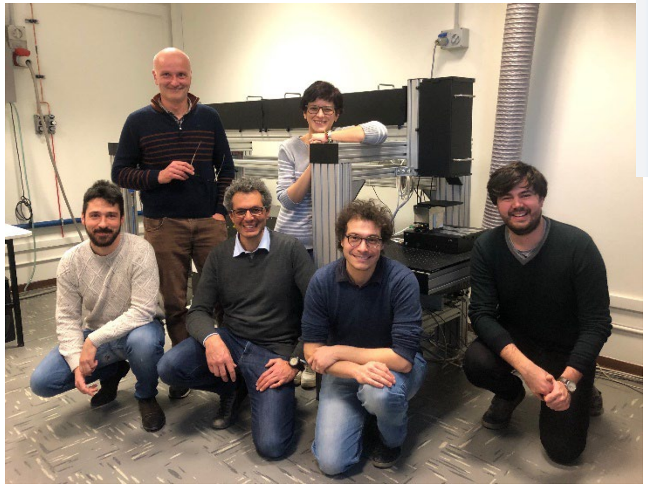
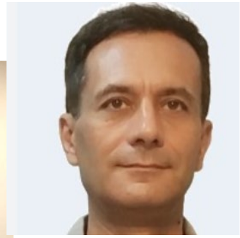
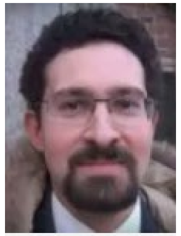
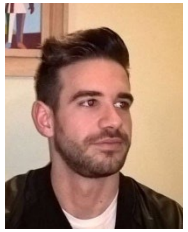
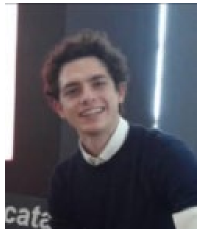
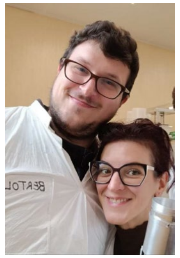
Andres Gadea





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HPGe PLM Contact: Detector Process, Testing and Result Summary

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