Istituto Nazionale di Fisica Nucleare

PSeGe @ ENSAR2

4rd Position Sensitive Germanium Detectors (PSeGe)

Segmentation of PLM contacts in HPGe detectors

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ENSAR2 has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654002

OUTLINE

- Introduction
- PLM (pulse laser melting) technology
- n^+ contacts application
- Photolithography segmentation
- summary

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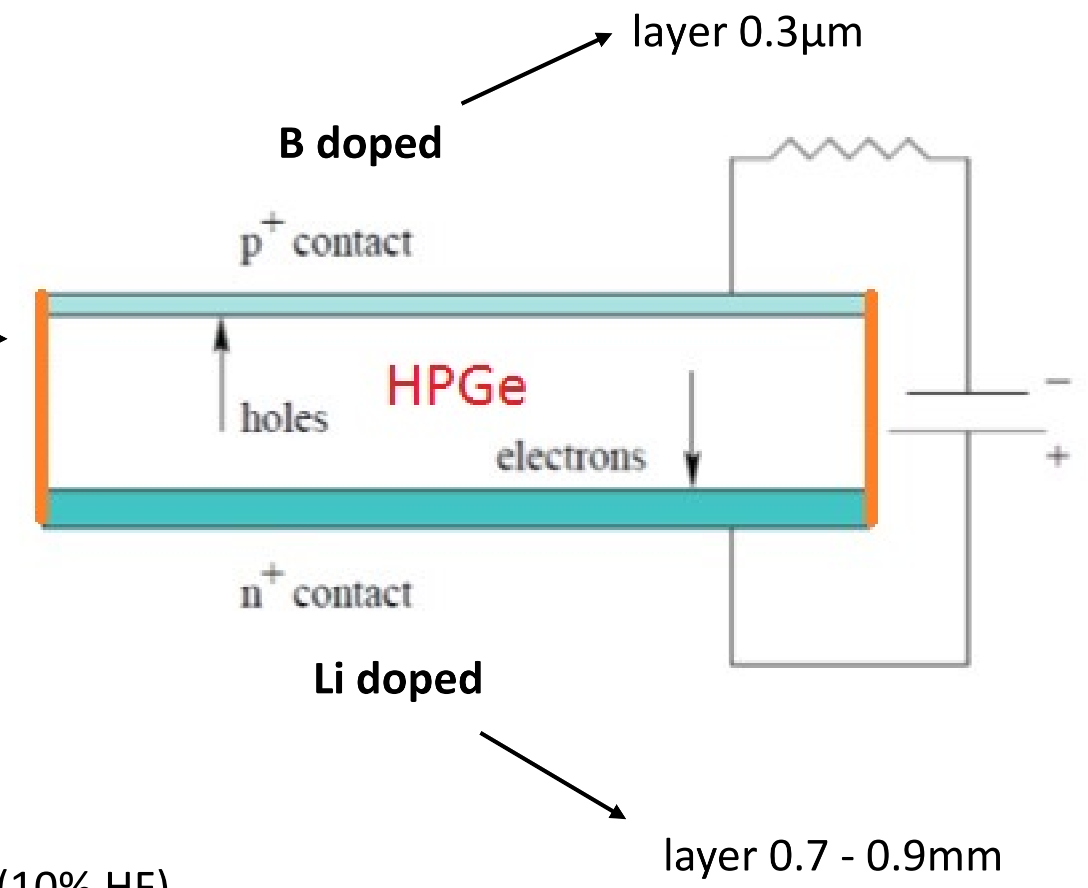
HPGe detector: p^+/n^+ contact and lateral surface passivation

Surface passivation:

- Chemical passivation
- Eletrical passivation

- **Methanol** termination
- **Sulphide** termination
- **Low Hydride** termination (10% HF)
- **High Hidride** termination (50% HF)

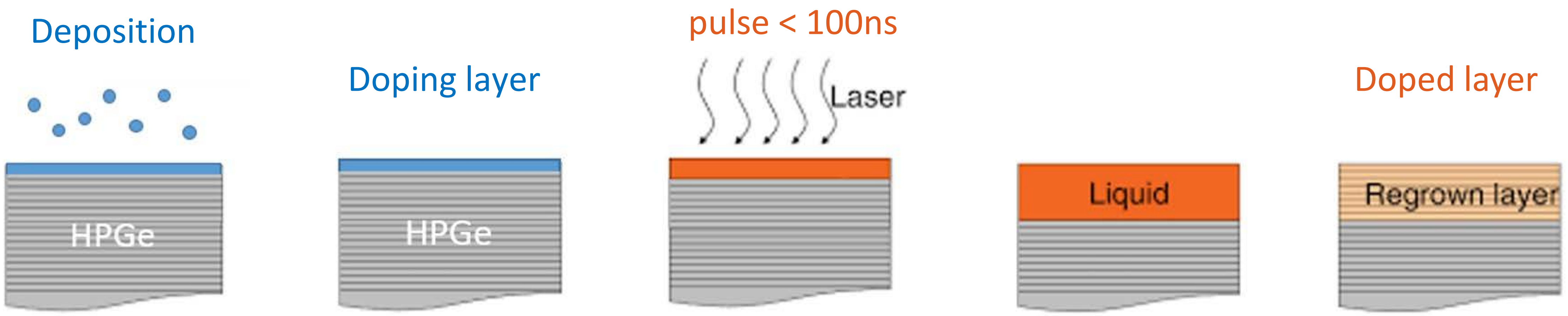
G. Maggioni et al. **Eur. Phys. J. A** (2015) 51: 141



Umicore:
Charge carrier density: 10^{10} cm^{-3}

Diameter: 40mm
Height: 20mm

PLM (Pulse Laser Melting) technology



New laser UNIPD – INFN:

- High homogeneity
- High stability
- High reproducibility

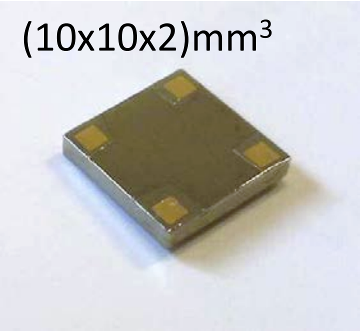
PLM (pulse laser melting) technology

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**)

Contamination of HPGe – PLM technology

Four-wire resistance and Hall measurement

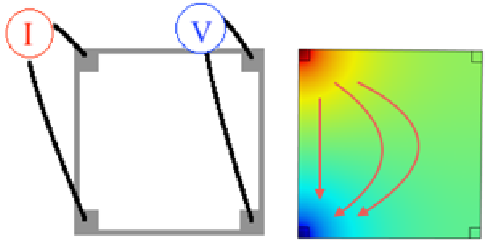


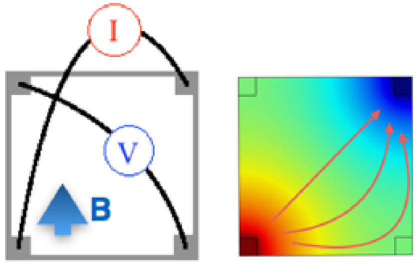
Van der Pauw method

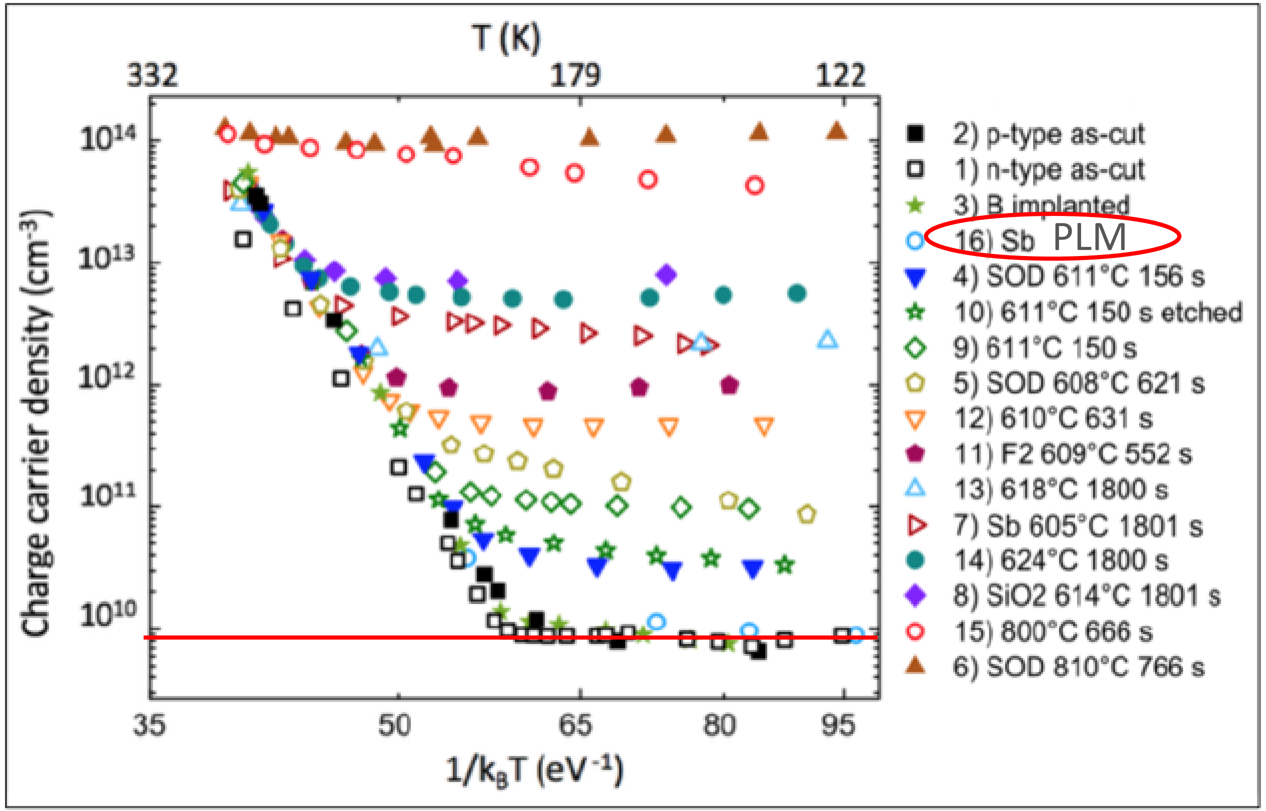
R_{sheet}

Hall-effect method

Carrier type







Carrier density within the specifications (10^{10} cm^{-3})

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

PLM technology : out of equilibrium diffusion

Treatment time ↓   Treatment temperature ↑

At melting temperature, dopants diffuse orders of magnitude faster

↳ Treatment times can be drastically reduced ☺

At melting temperature, contaminants diffuse faster too

↳ Contamination can drastically increase ☹

Melting can be limited to a thin, surface layer of HPGe

↳ Bulk contamination is prevented ☺

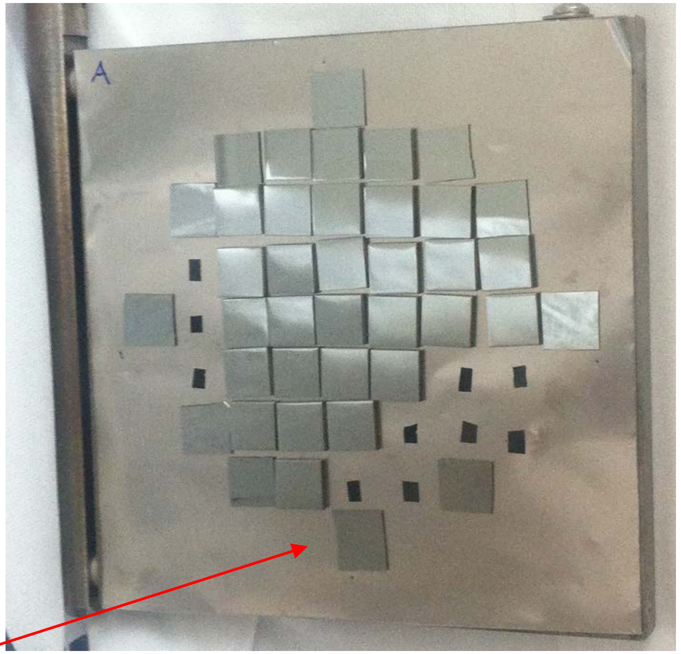
} Pulsed laser melting

p^+ contact on HPGe

^{11}B Ion Implantation (standard technique) IMM (Institute for Microelectronics and Microsystem) – Bologna

HPGe wafer cut and cleaning (isopropanol 80°C and DW 80°C)

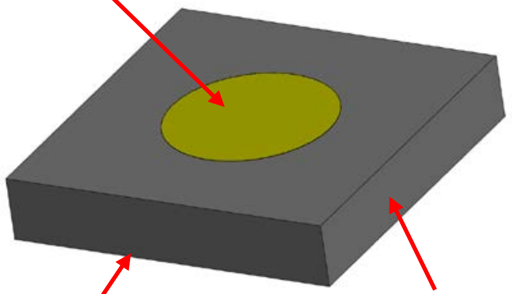
Energy = 23KeV
Dose = 1 x 10^{15} atoms/cm^2
(pressure = 3.8 x 10^{-7} torr)



HPGe
(10x10x2) mm^3

Prototype HPGe by PLM technology at LNL-INFN

Sb deposition Ø= 5mm

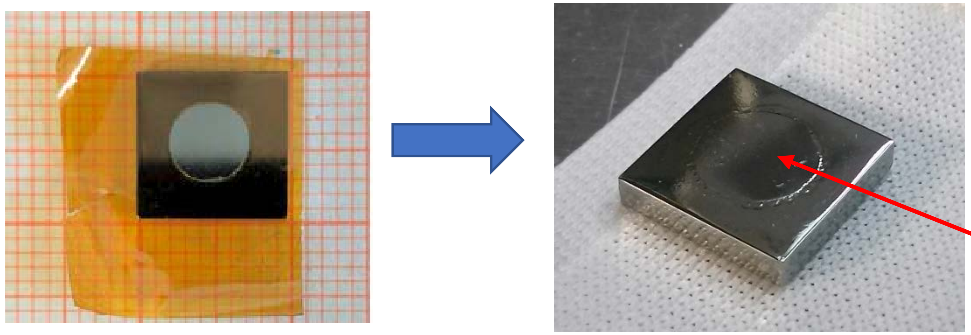


HPGe p-type
(2x10x10)mm^3

B implantation
(10x10)mm^2

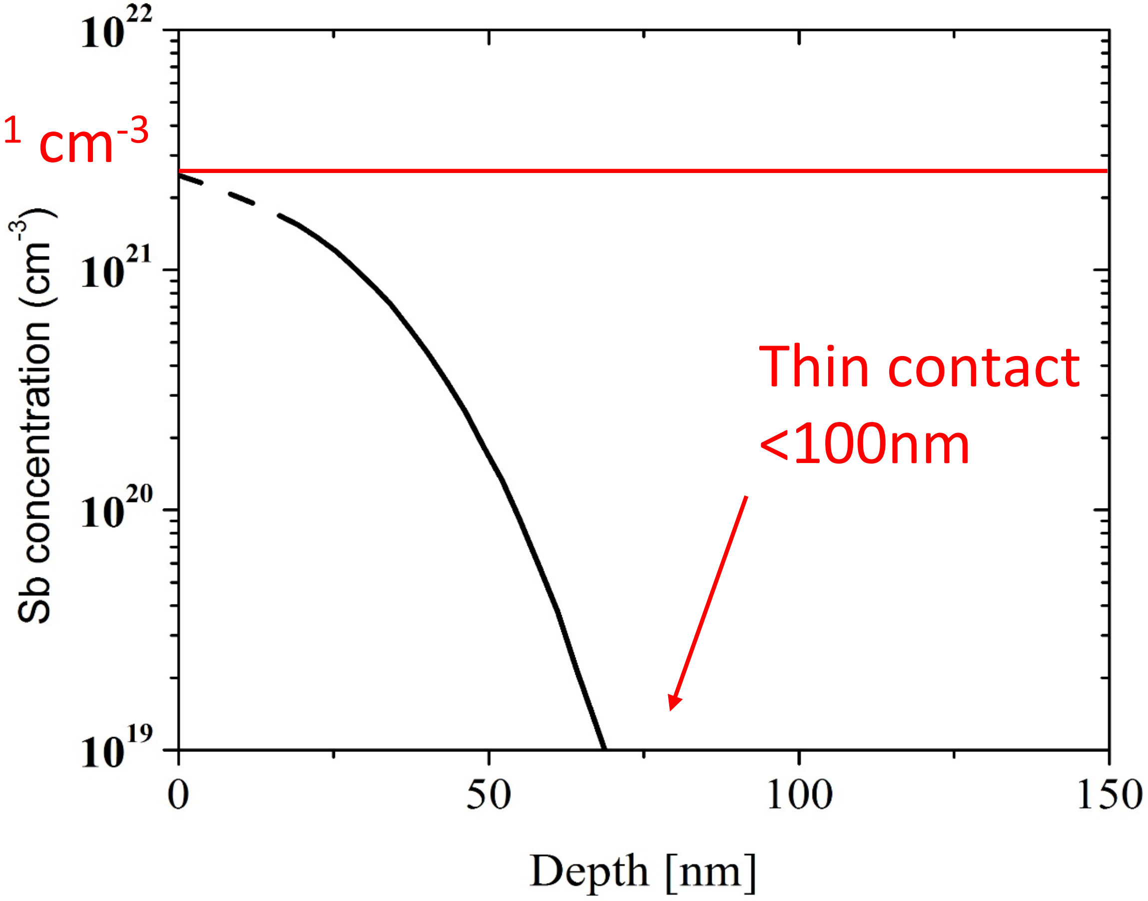
Methanol
passivation

No guard ring



PLM laser spot
Ø= 6.5mm

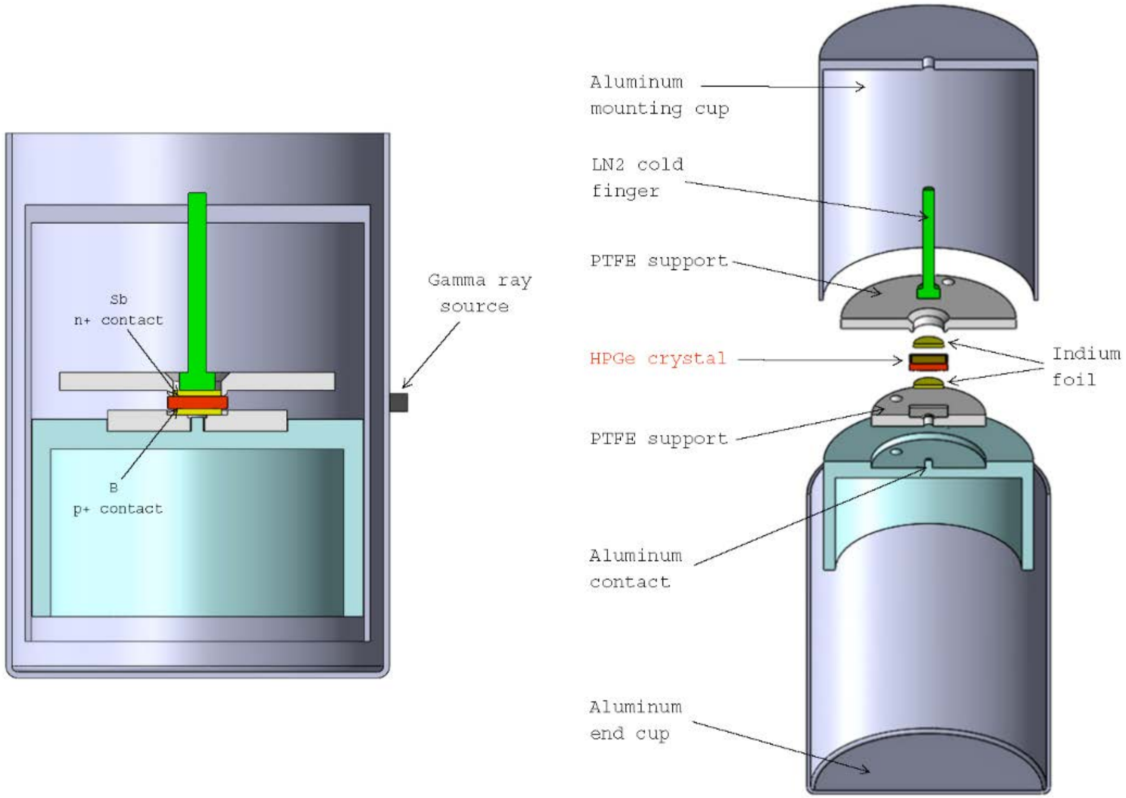
SIMS profile of Sb diffusion



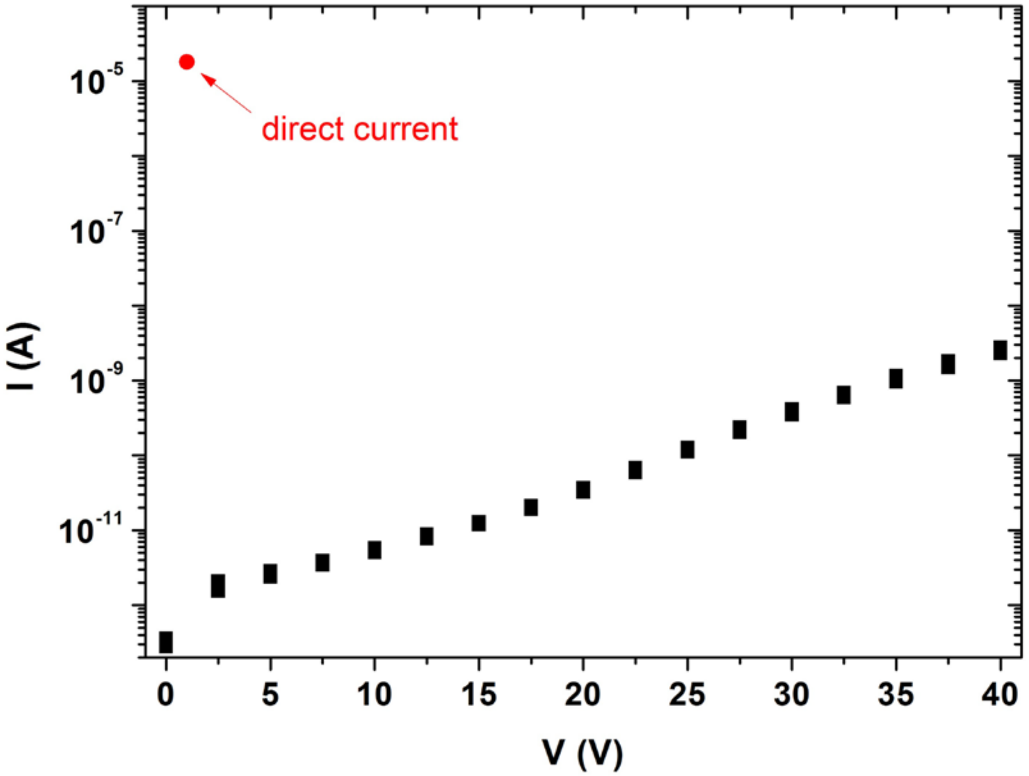
2.5x10^{21} cm^{-3}

Thin contact
<100nm

Test of small HPGe prototype: I-V diode configuration



I-V characteristic curve

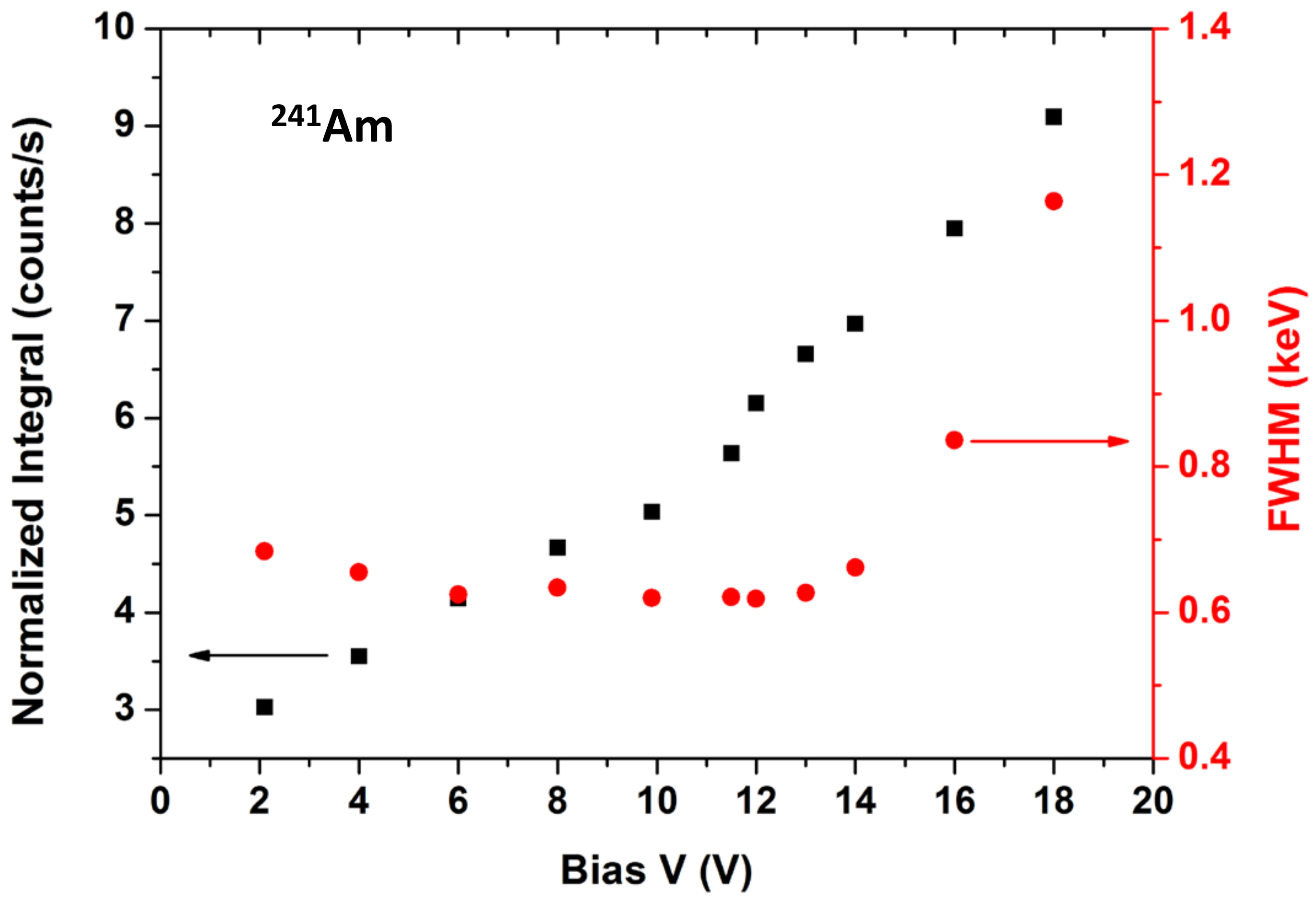


[G. Maggioni at al. Eur. Phys. J. A (2018)]

- Low leakeage current
- p-n junction is obtained

Test of small HPGe prototype: detector configuration

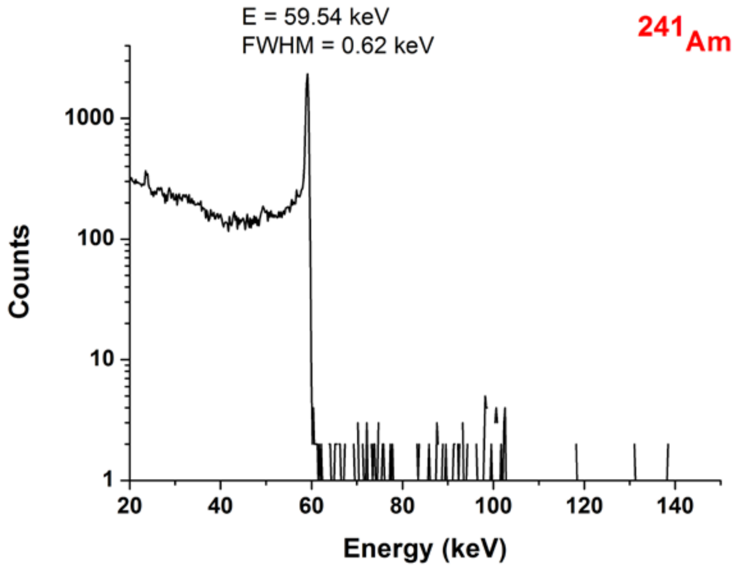
Depletion Voltage - Energy resolution

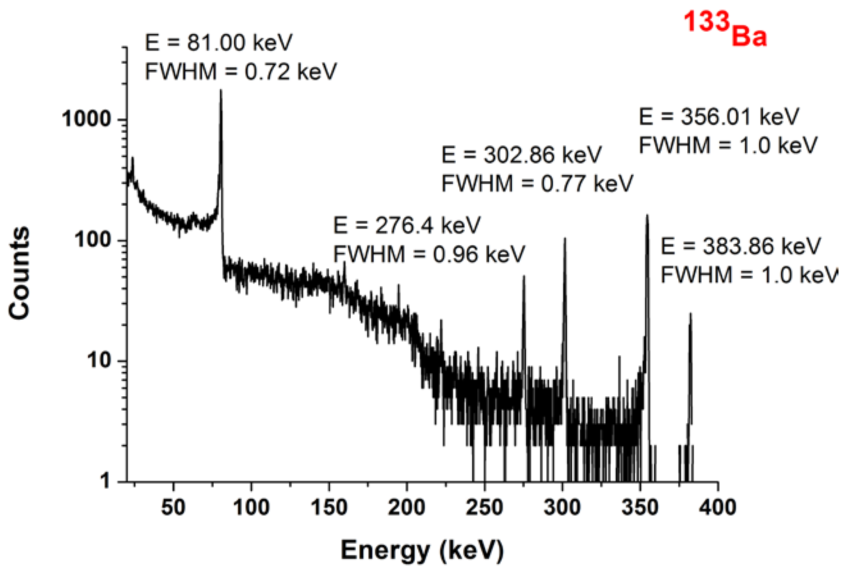


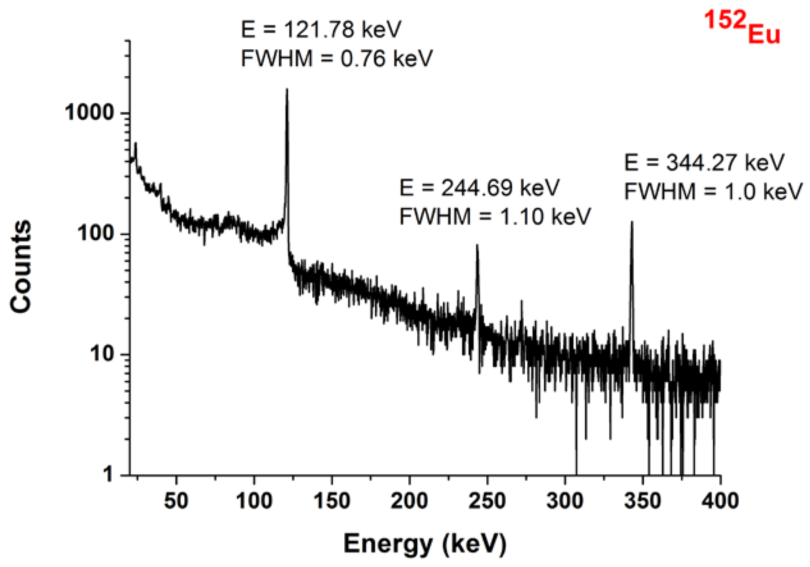
0.62 keV @ 59.54 keV (^{241}Am)

Detector not fully depleted when energy resolution worsens (contact geometry is not optimal)

Test of small HPGe prototype: detector configuration







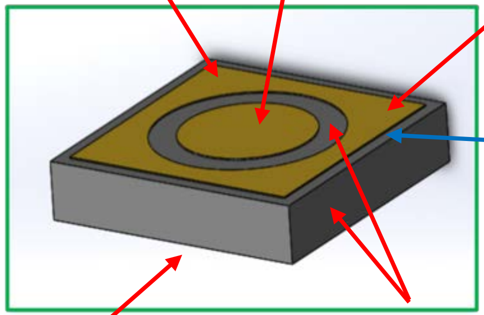
Good energy resolution in all the energy range up to 400KeV

Scaling up detector size by PLM technology at LNL-INFN

Deposition of gold
<100nm (mask)

Central contact

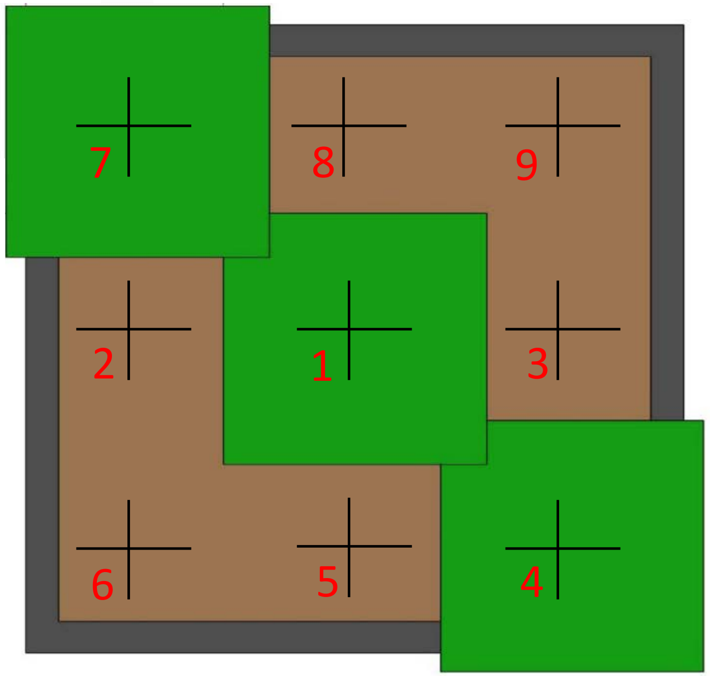
Guard ring



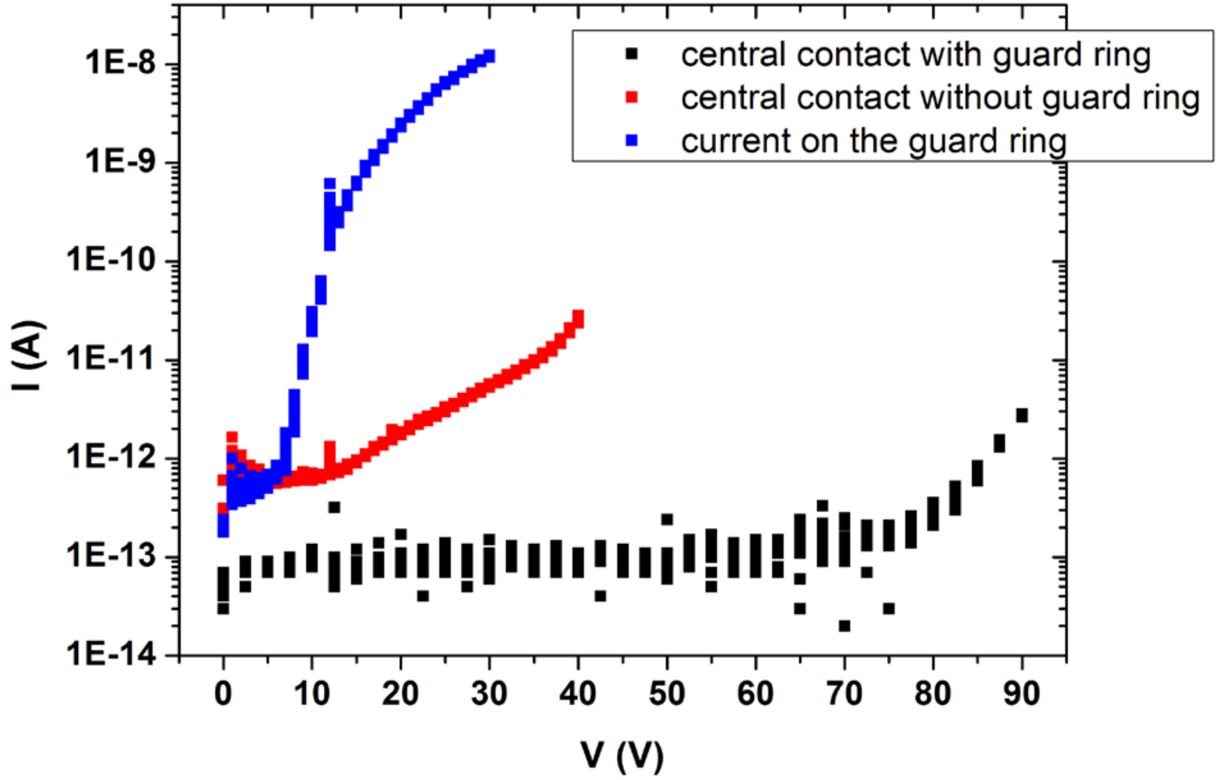
Sb deposition all the surface $(10x10)mm^2$

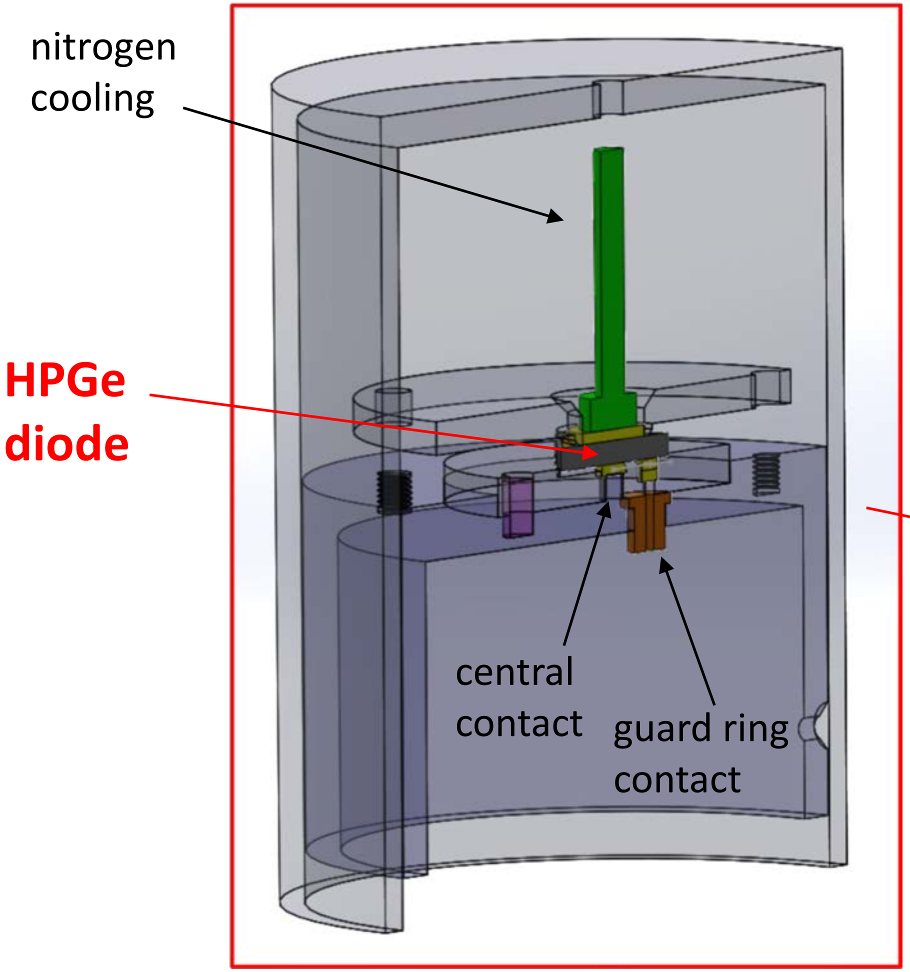
B implantation $(10x10)mm^2$

Methanol
Passivation surface



Test of small HPGe prototype: I-V diode configuration



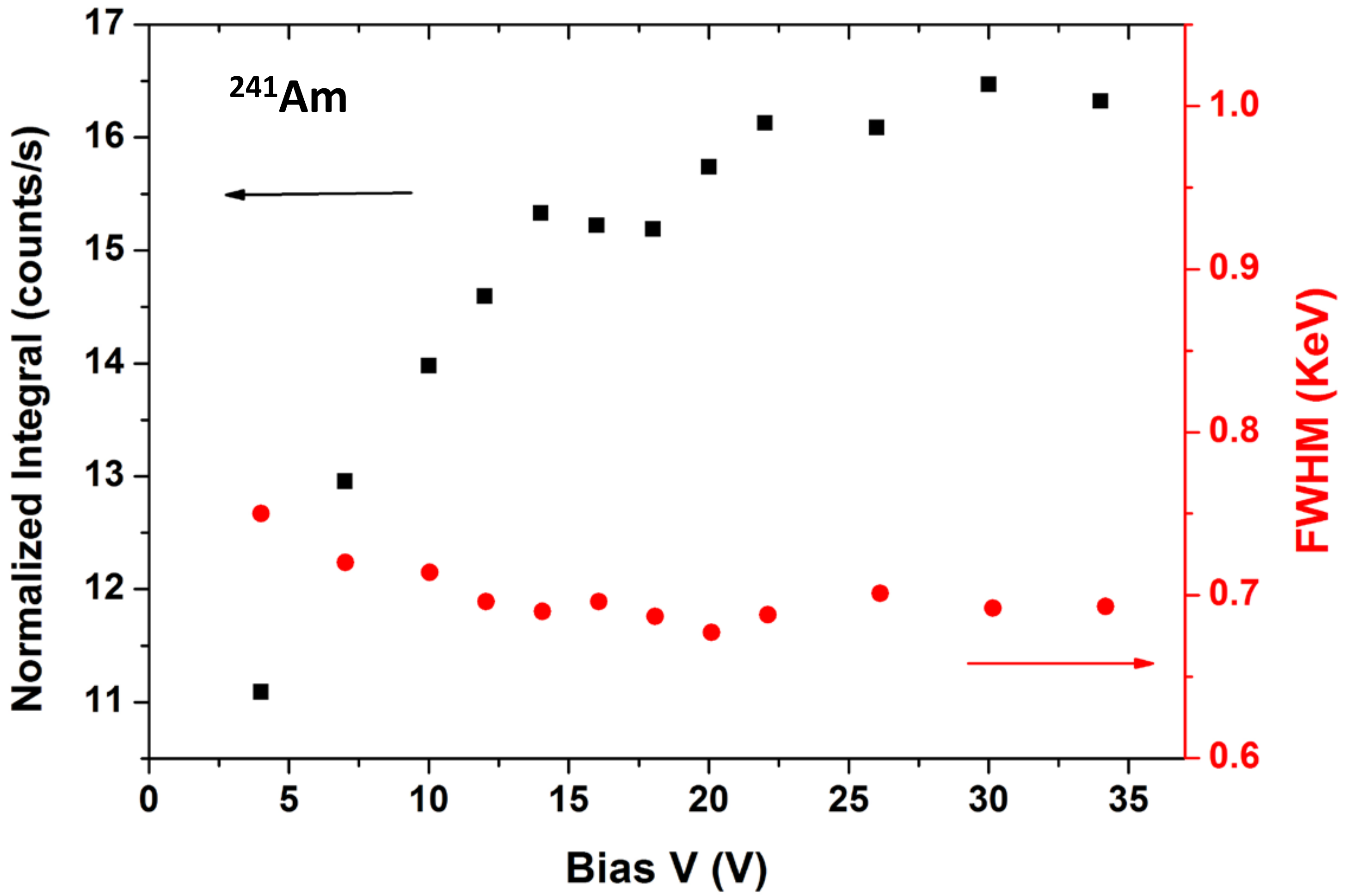


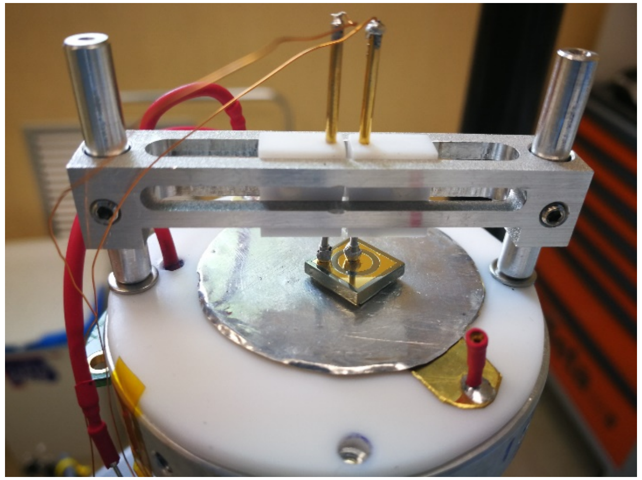
Central contact low level of leakage current, <1pA @ 80V

Direct bias V=0.5 V I=0.8 μA

Test of small HPGe prototype: detector configuration

Depletion Voltage - Energy resolution



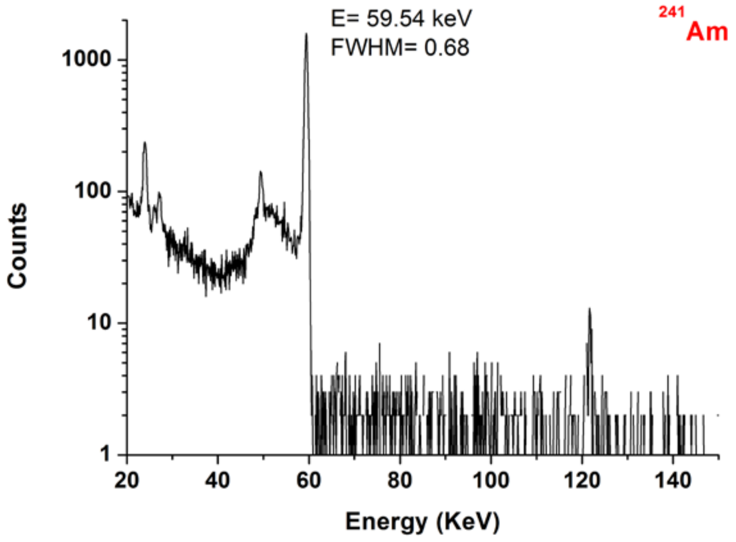


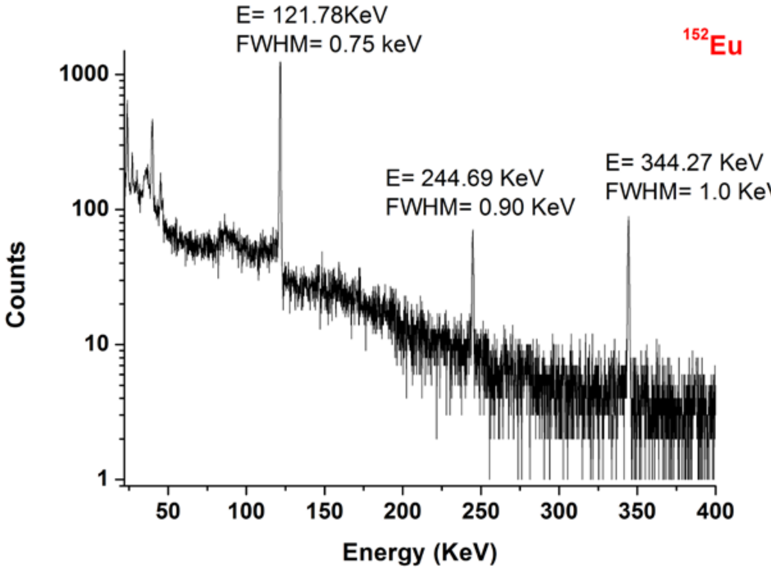
central contact

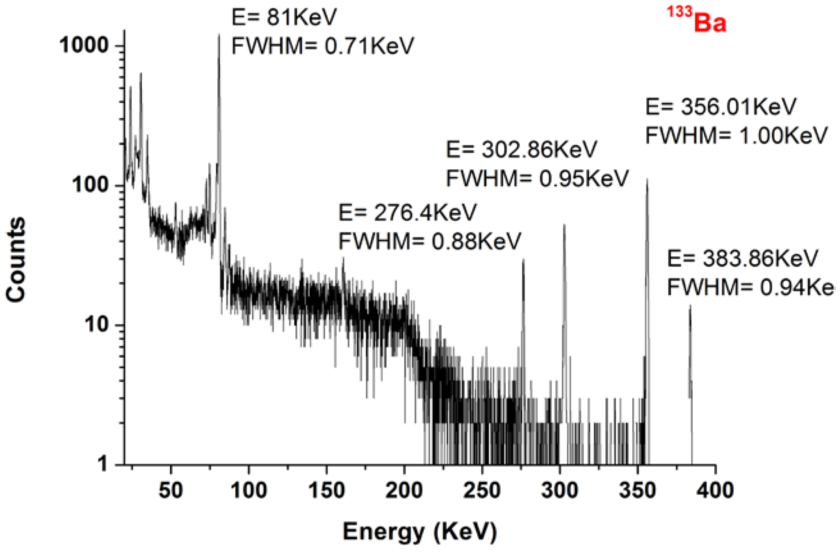
0.68 keV @ 59.54 keV (^{241}Am)

- ➢ detector fully depleted (plateau of normalize integral)
- ➢ very good energy resolution

Test of small HPGe prototype: detector configuration





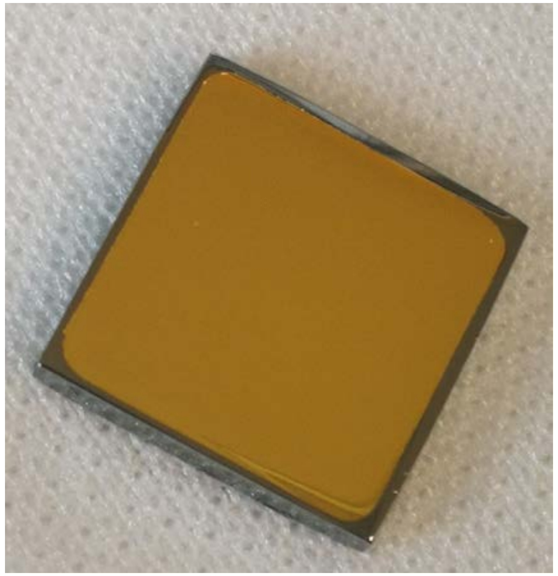


Good energy resolution in all the energy range up to 400KeV

HPGe segmentation process at LNL-INFN

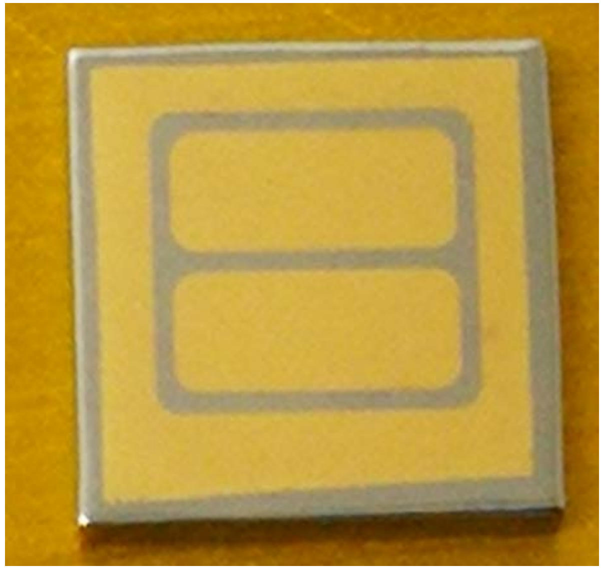
Shallow n^+ (Sb) **contact by PLM**
P-type HPGe

Gold deposition (sputtering) on n^+ contact



Area: 1 cm^2

Photolithography segmentation of n^+ contact (2 segments and guard ring)



Segments gap:
- 0.4mm
- 0.2mm

Esternal gap fixed: 0.4mm

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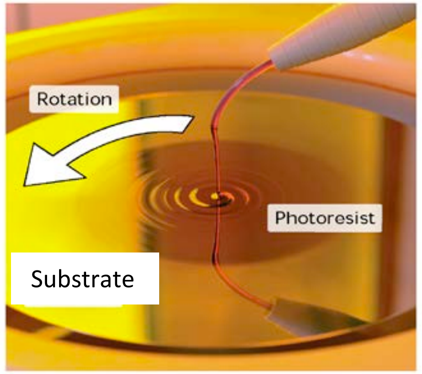
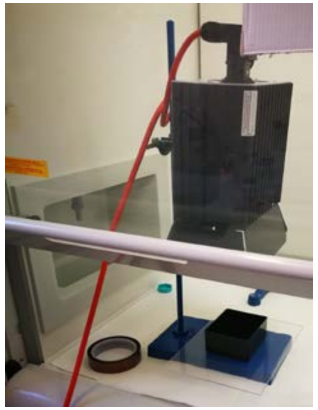
Photolithography segmentation detector (LNL-INFN)

Spin coating positive photoresist on gold coating surface



→ Short Soft bake photoresist (1 min)

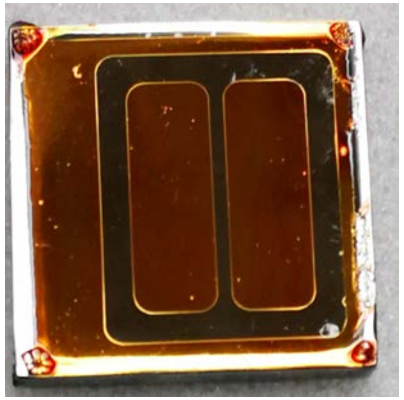
→ UV exposure (mask)



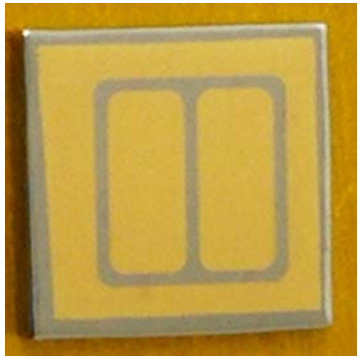
→ Dissolve the exposed photoresist

→ long soft bake photoresist (15min)

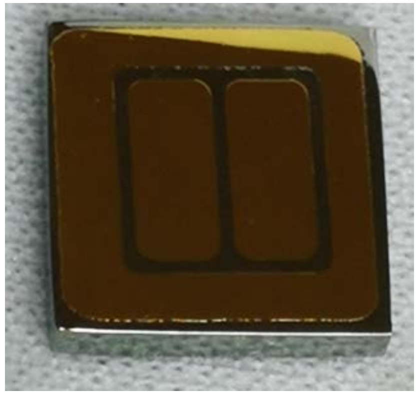
→ Gold etchant



→ Photoresist removal (aceton)



→ HPGe etching and passivation



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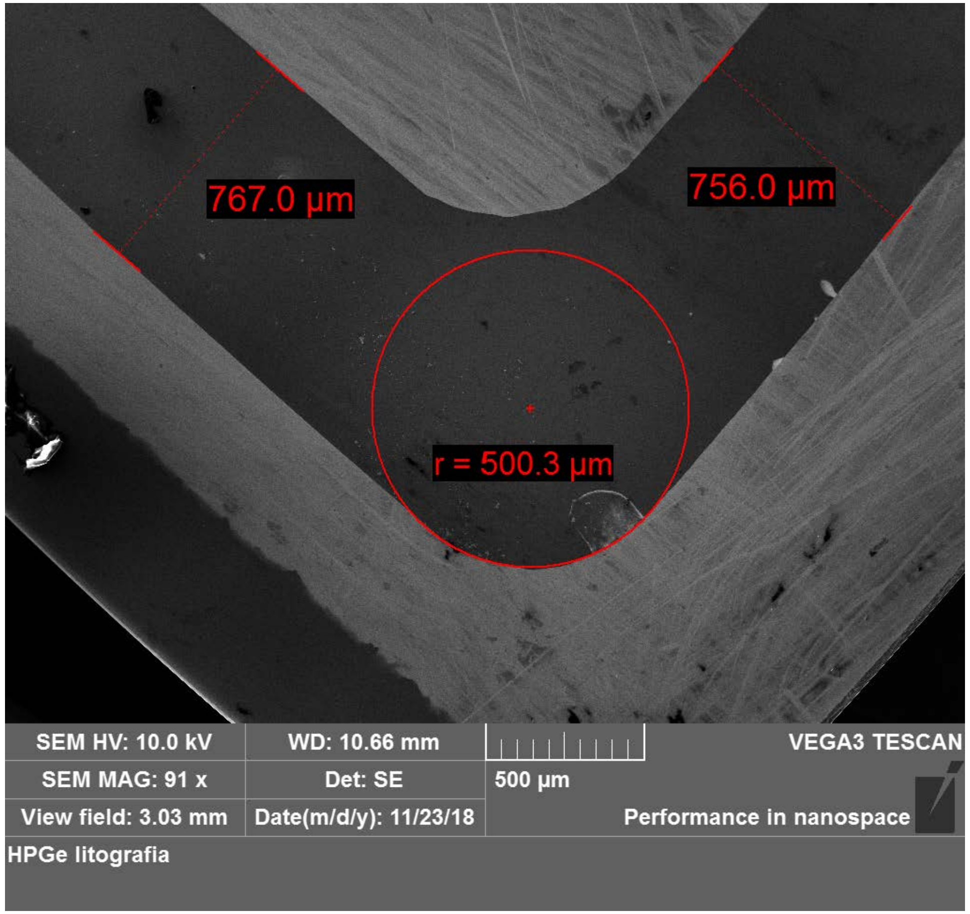
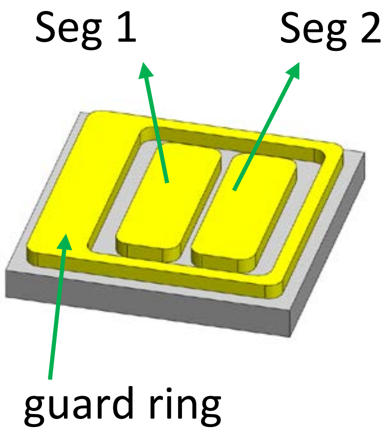
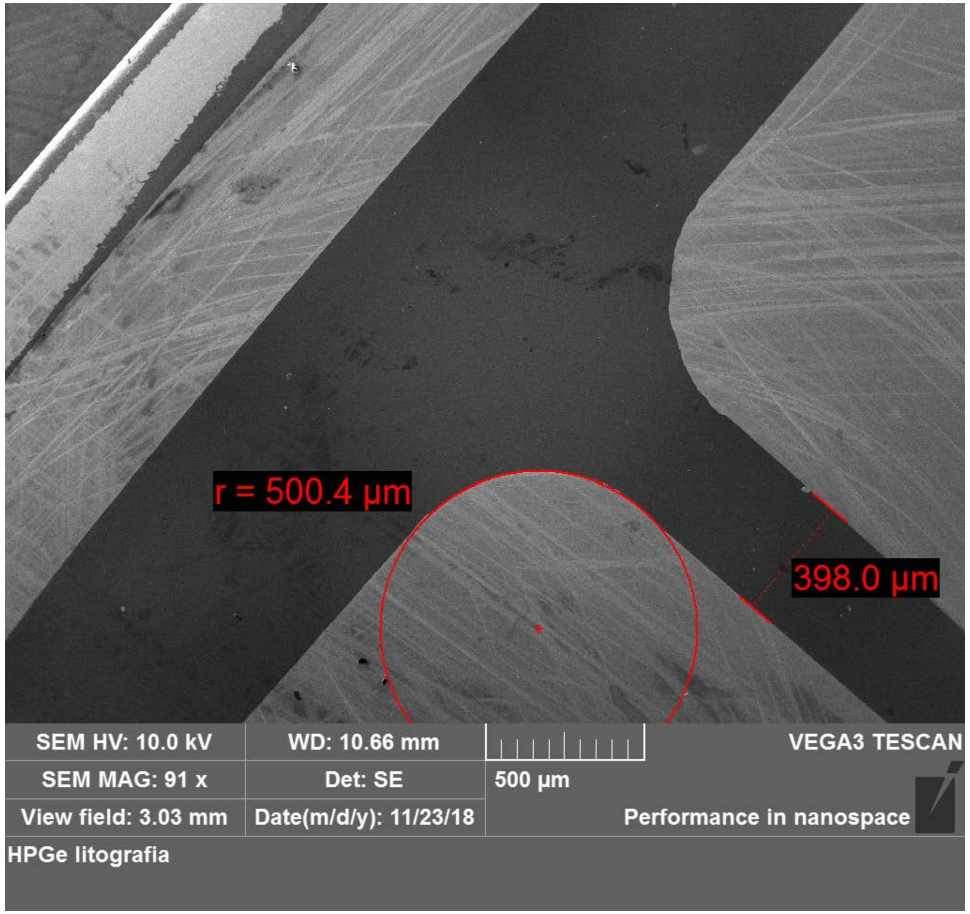
Segmentation morphology characterization

Gap between segments: **0.4 mm**

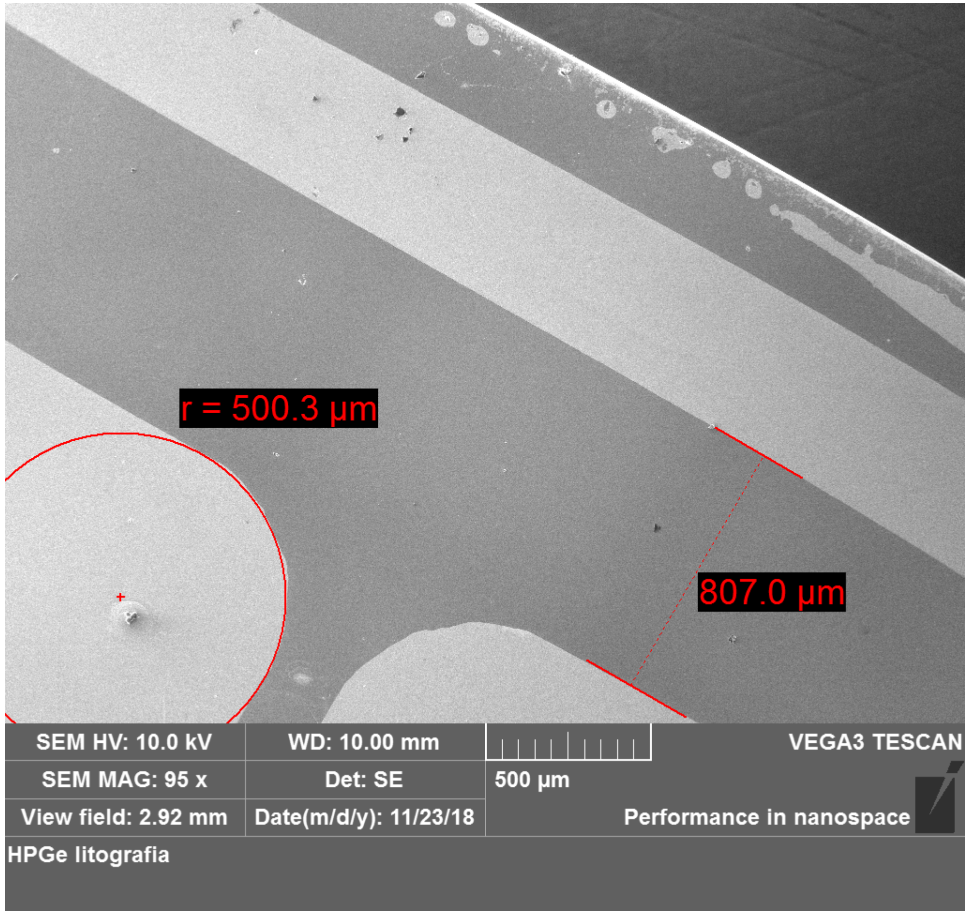


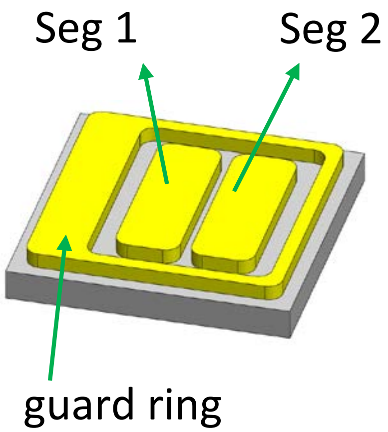


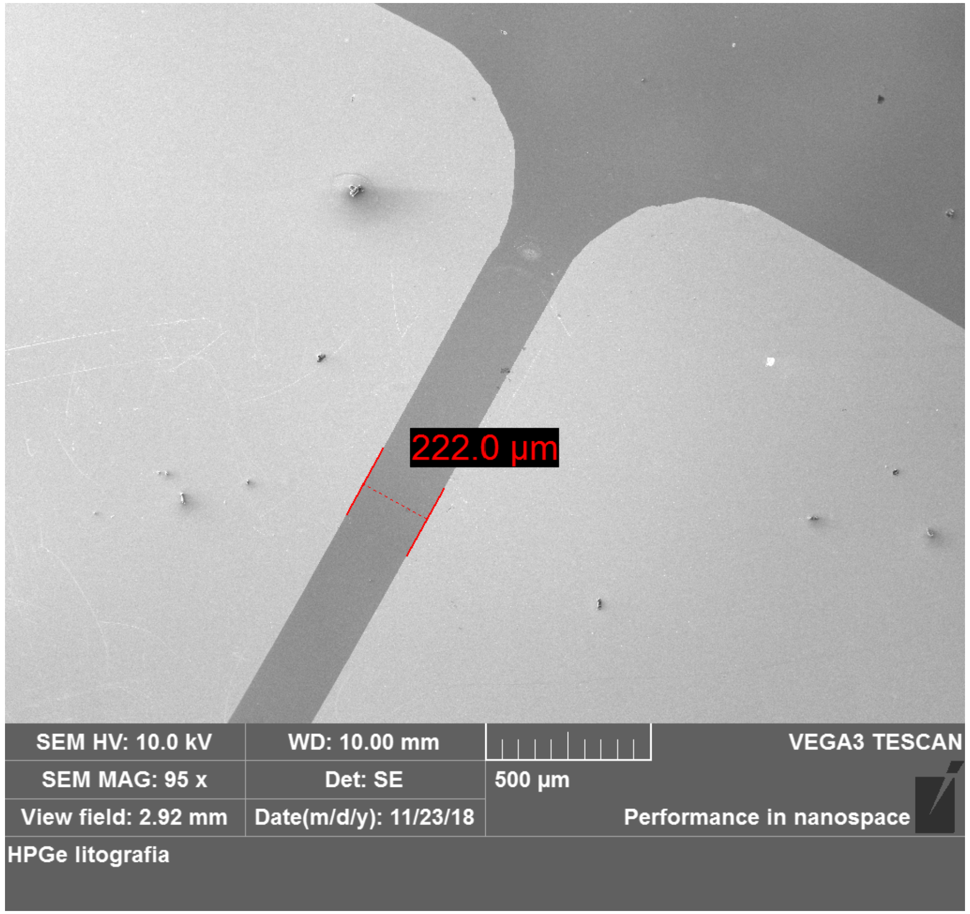


Segmentation morphology characterization

Gap between segments: **0.2 mm**

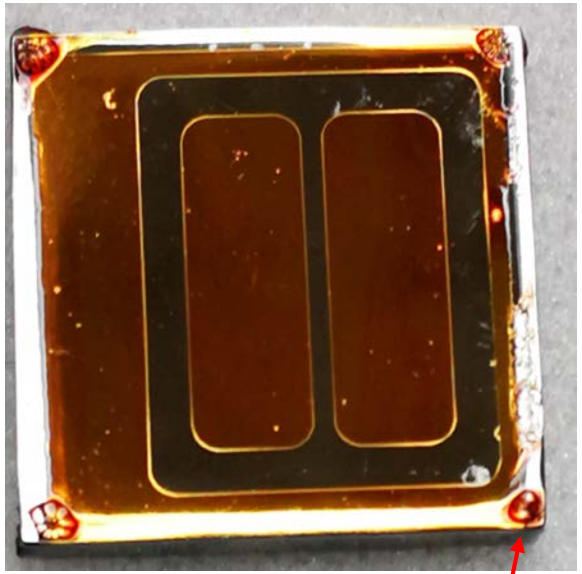




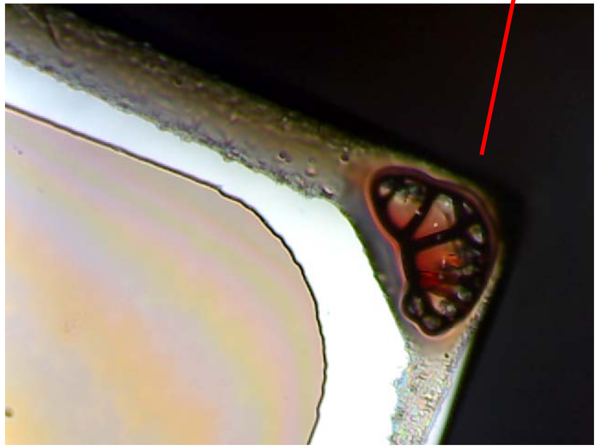


Segmentation morphology characterization: critical points

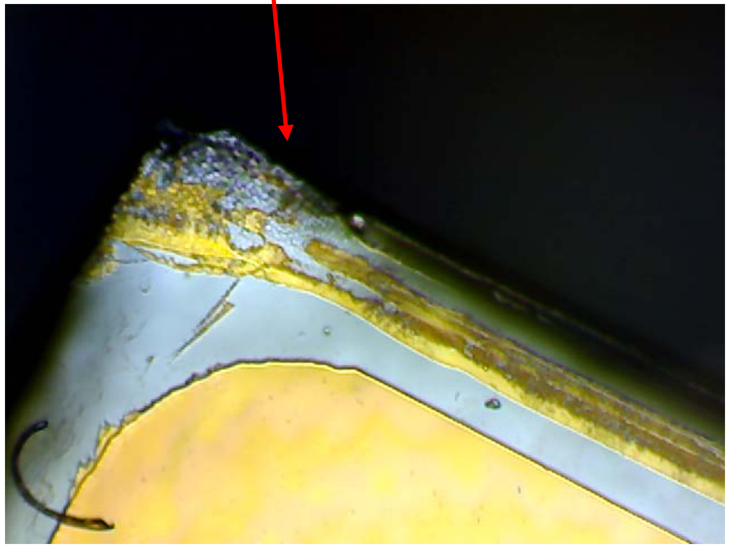
Spin coating



Photoresist accumulation on the corners

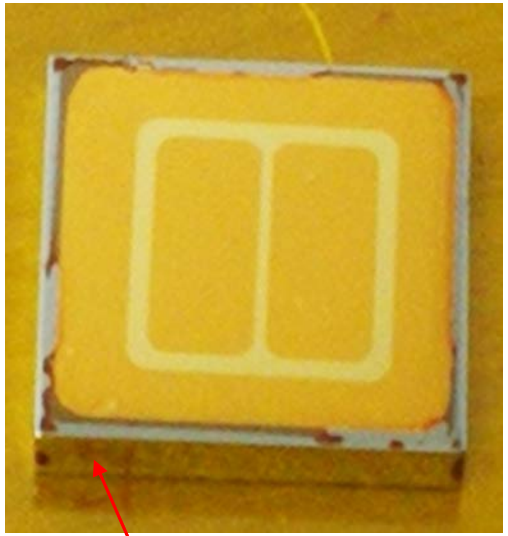


Residual gold layer after gold etchant (not uniform etching and passivation)

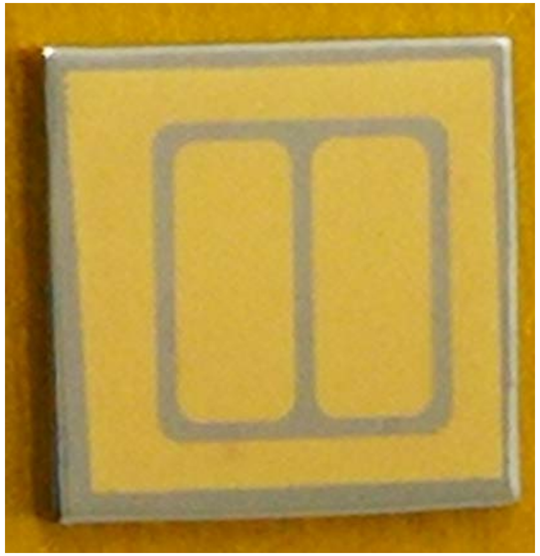


Segmentation morphology characterization: process optimization

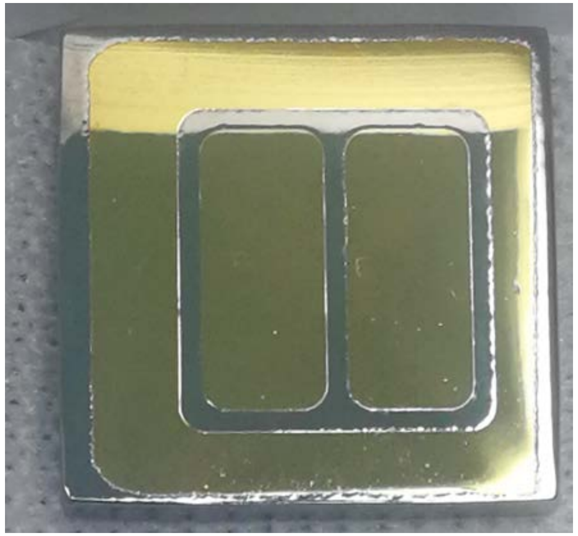
Gold deposition mask
Spin coating optimization parameters (time, rotation speed)



hot acetone, Gold etching →



HPGe etching (HNO_3:HF, 3:1) →



Thin photoresist layer

Clean surface out off the gold contacts

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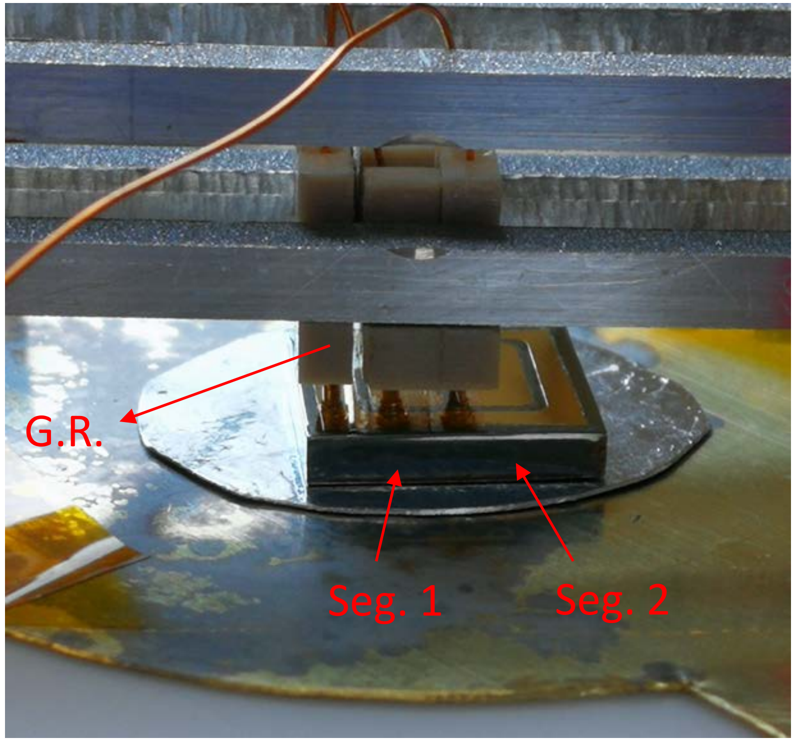
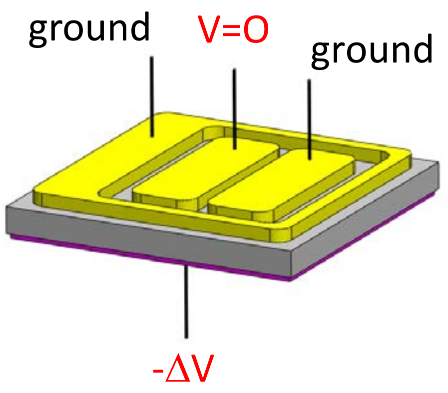
Test of small segmented HPGe prototypes



Test (T=110K):

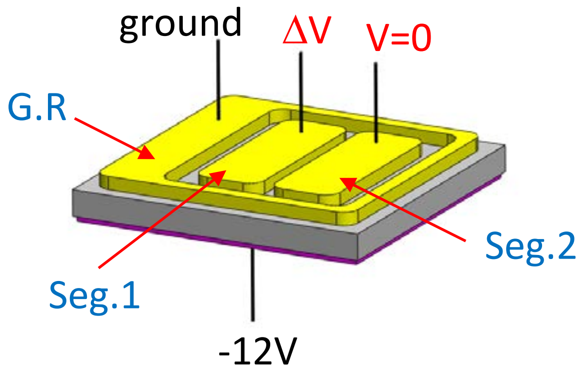
- Diode configuration
  - I-V segments
  - Electrical passivation resistance
- Detector configuration
  - Depletion voltage
  - Energy resolution

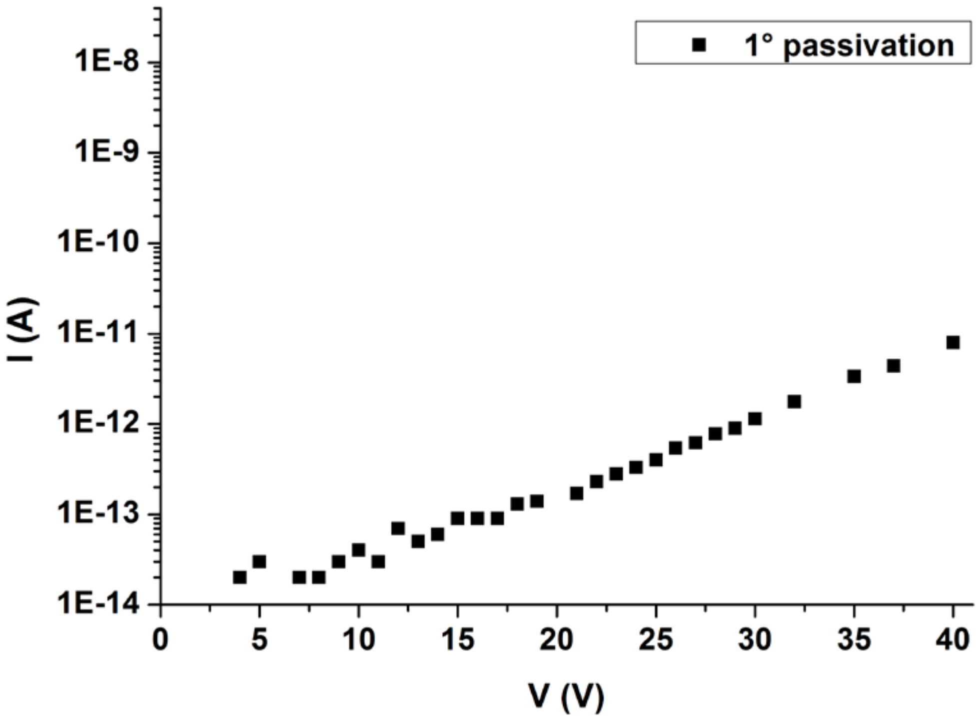
Test of small HPGe prototype: diode configuration

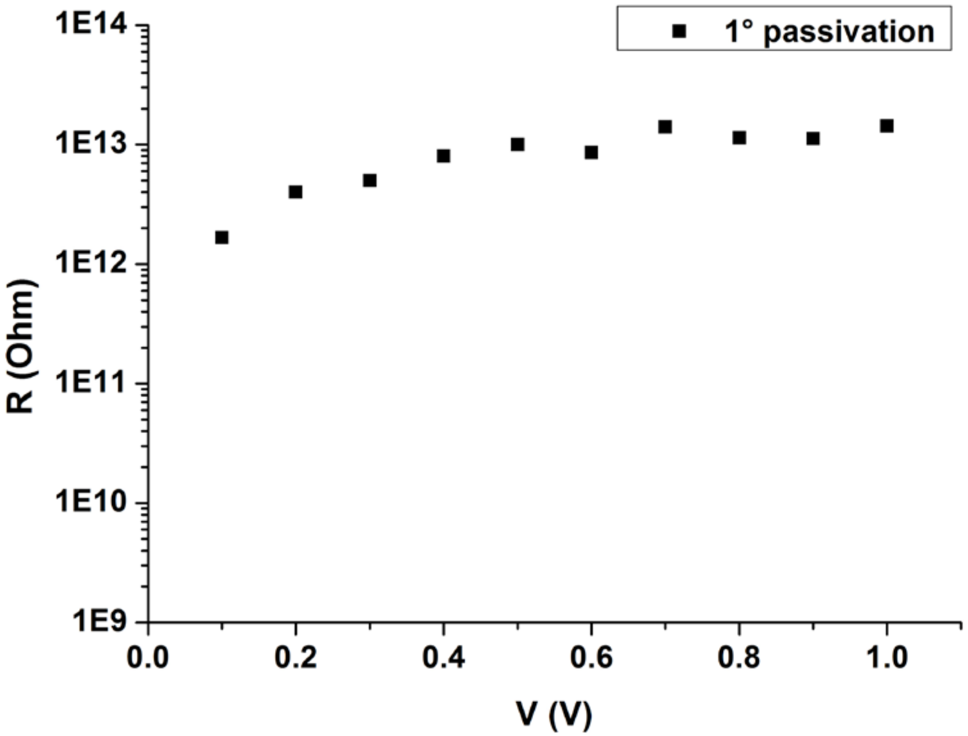


First methanol passivation

gap 0.4mm



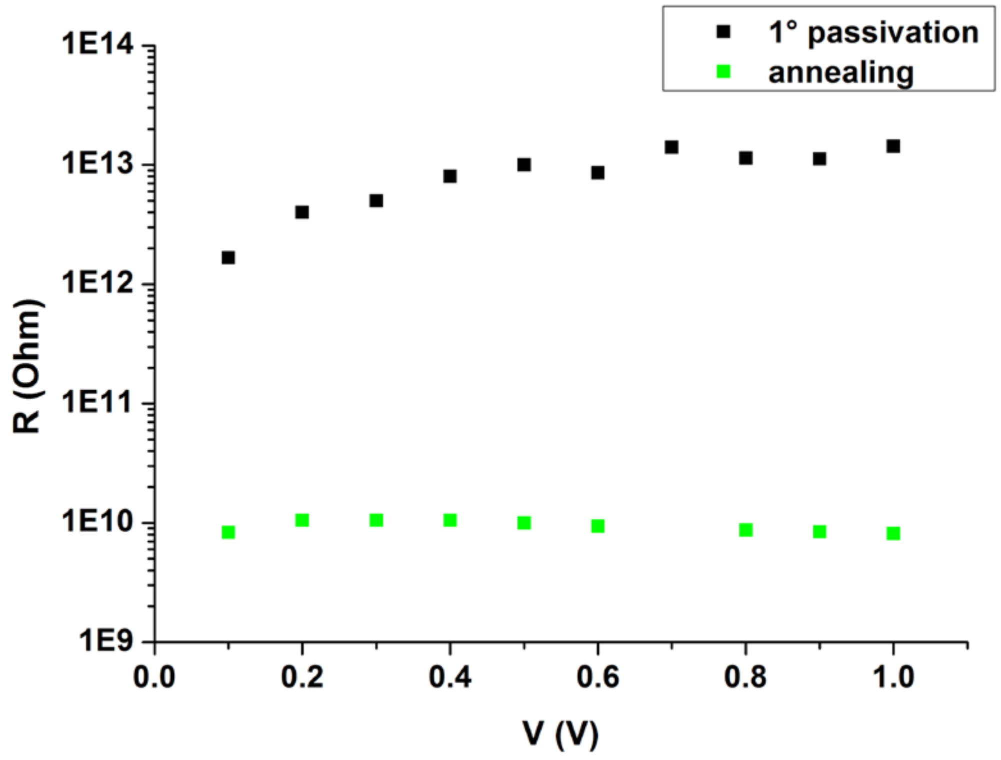




Test of small HPGe prototype: diode configuration

gap 0.4mm

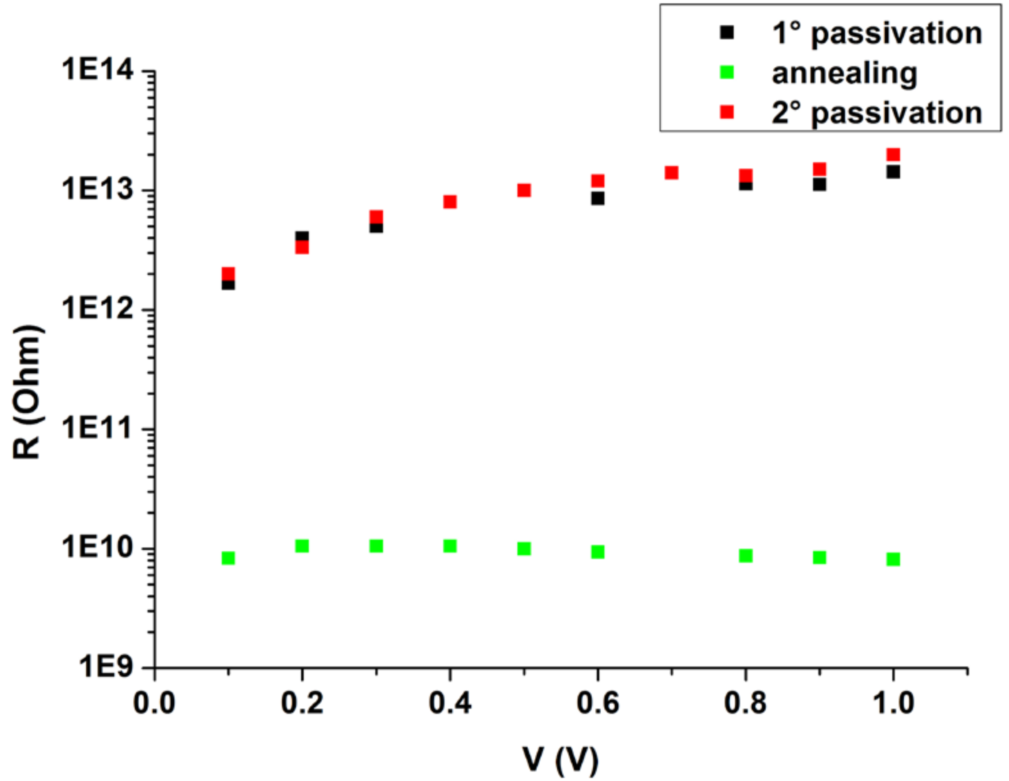
Annealing: 100°C - 40h



Test of small HPGe prototype: diode configuration

gap 0.4mm

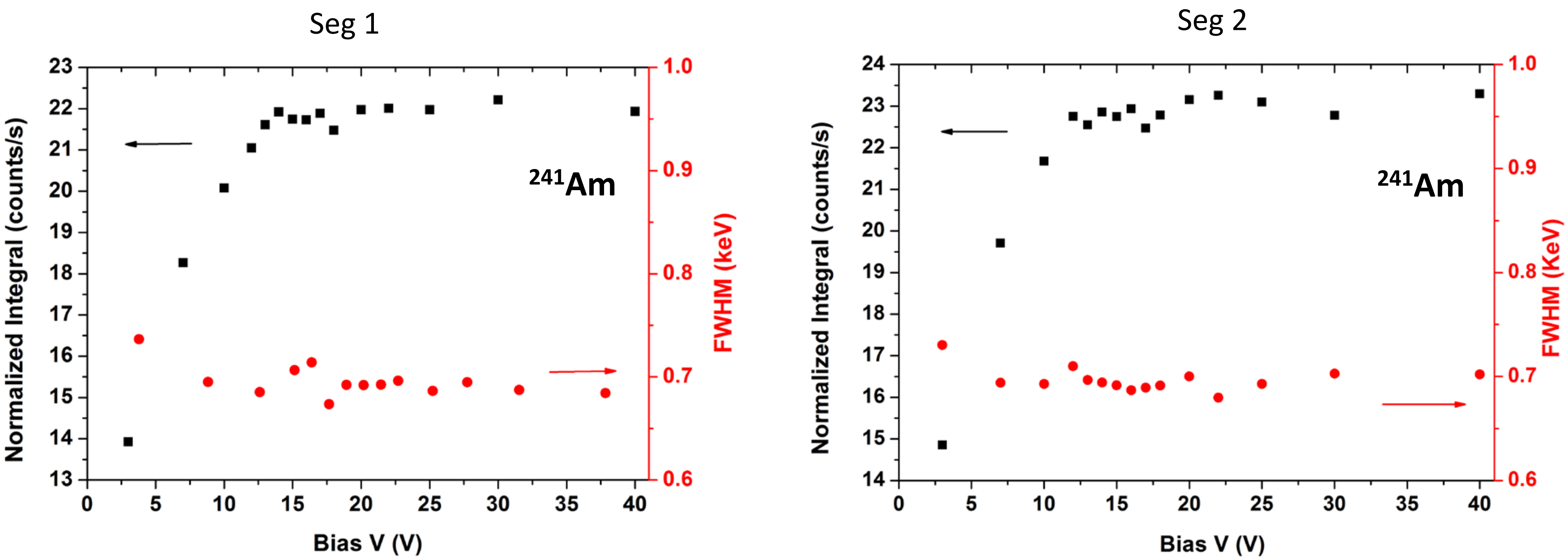
Second methanol passivation



Test of small HPGe prototype: detector configuration

gap 0.4mm

Depletion Voltage - Energy resolution

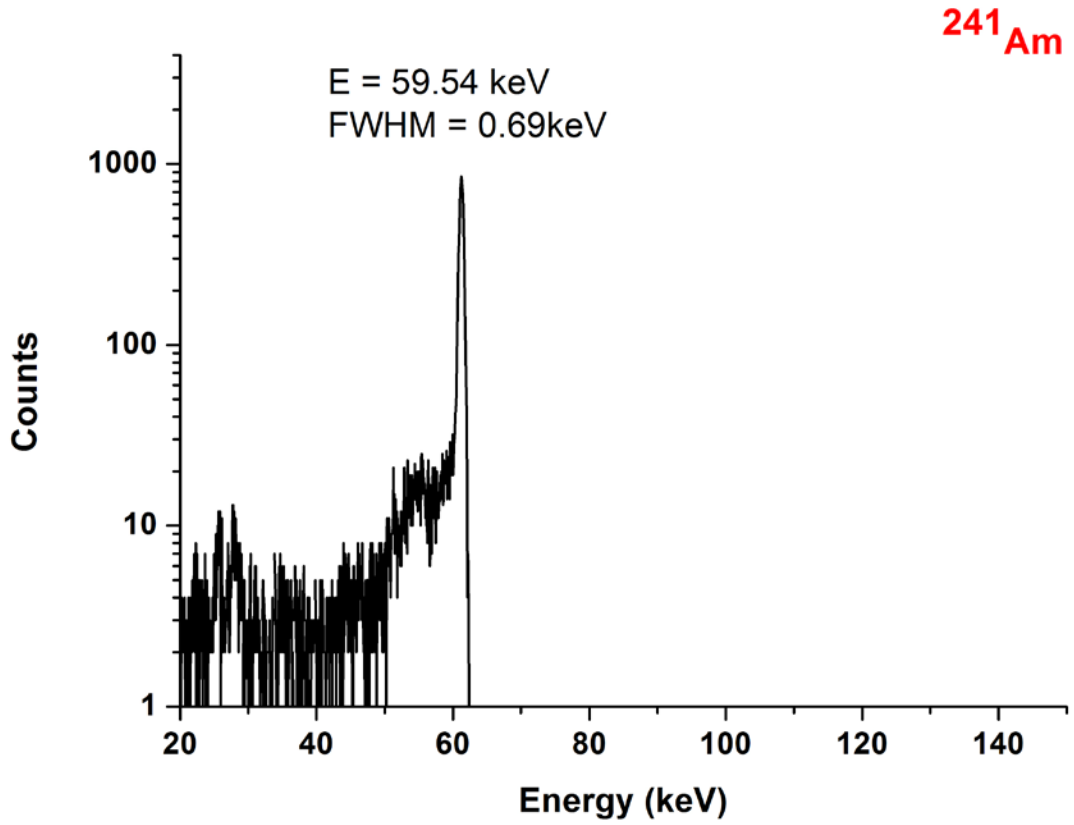


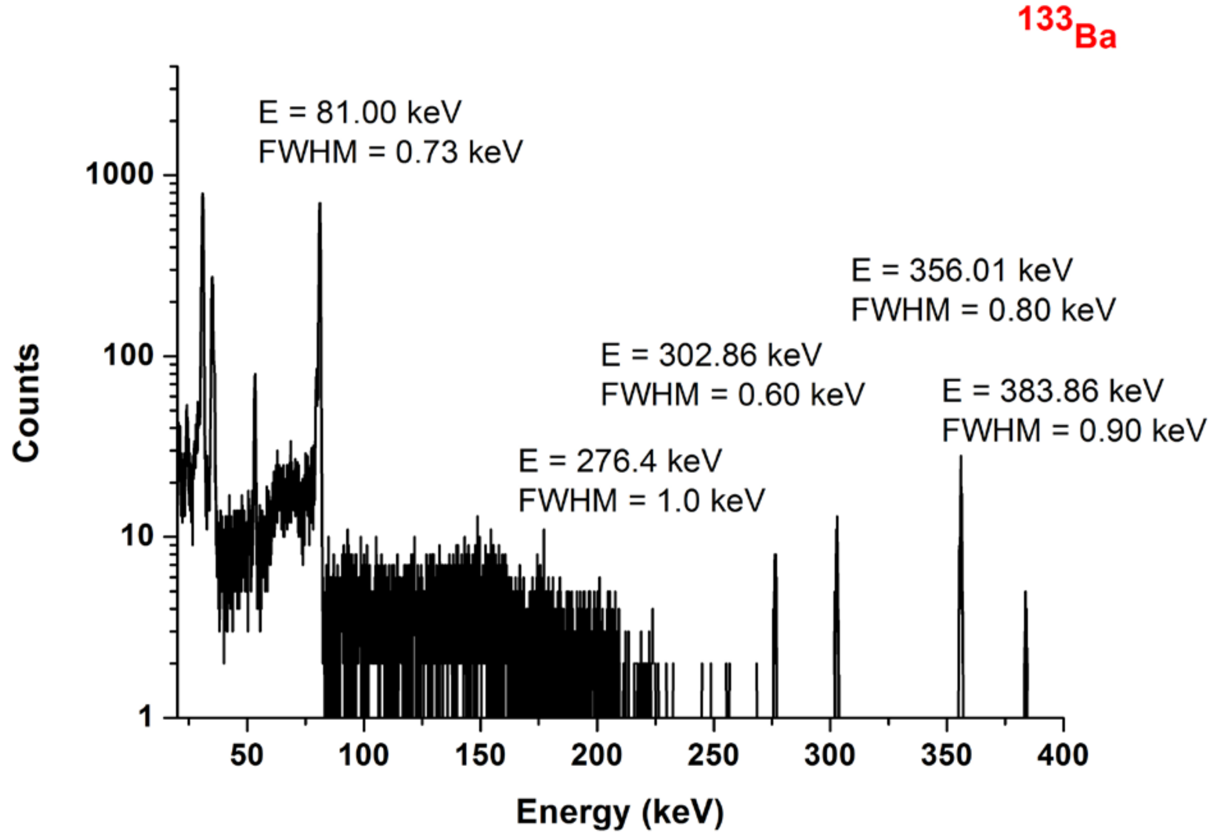
0.7 keV @ 59.54 keV (^{241}Am)

- detector fully depleted
- very good energy resolution

Test of small HPGe prototype: detector configuration

Segment **1** **gap 0.4mm**

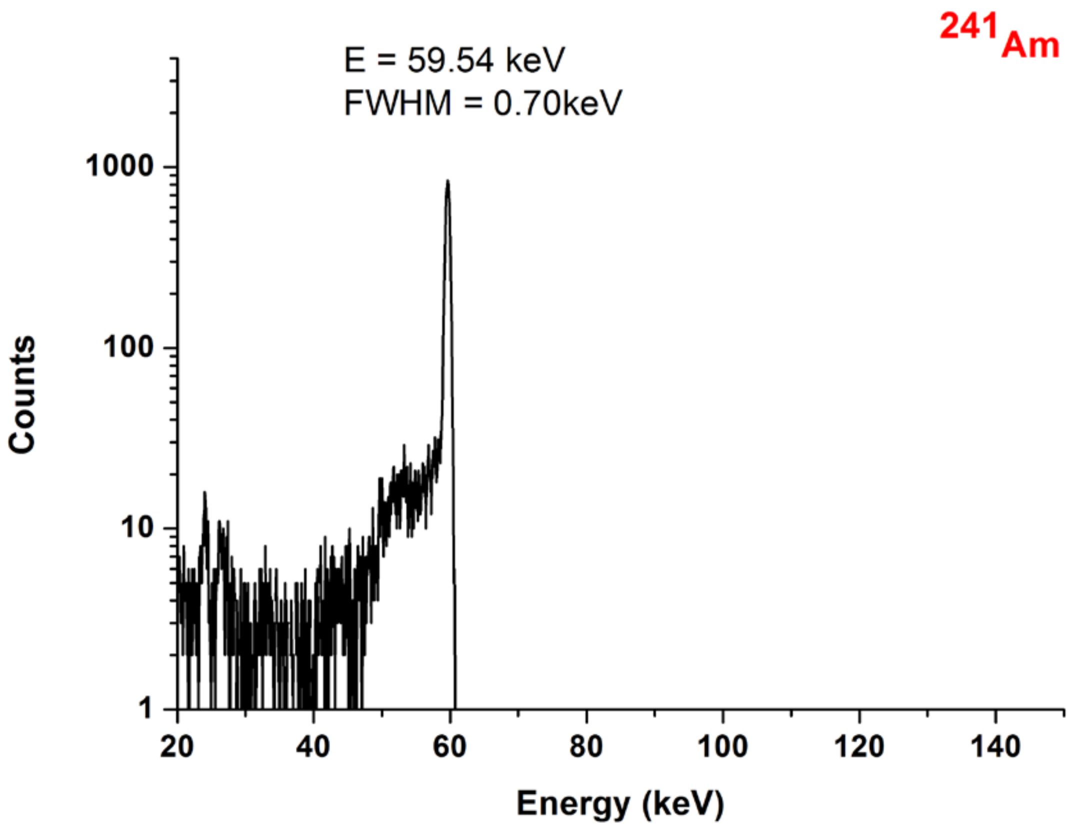


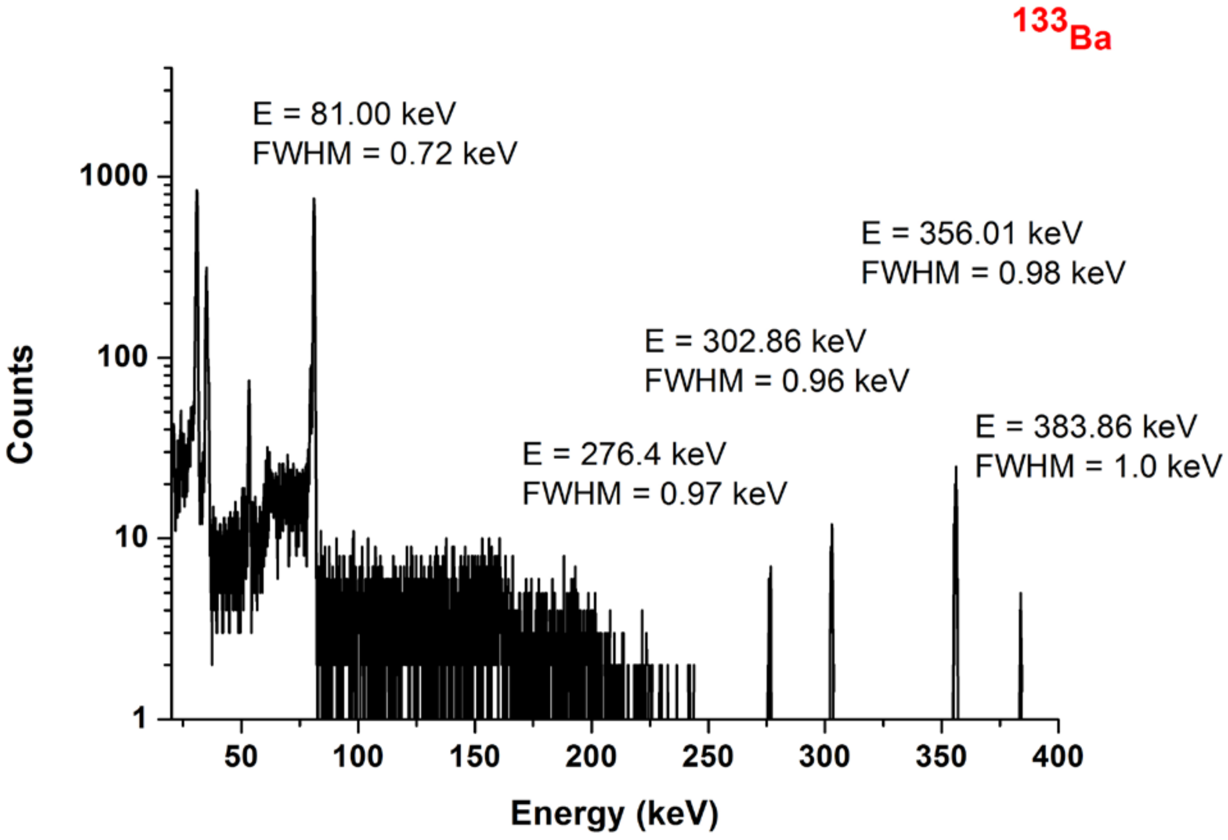


Good energy resolution in all the energy range up to 400KeV

Test of small HPGe prototype: detector configuration

Segment 2 gap 0.4mm





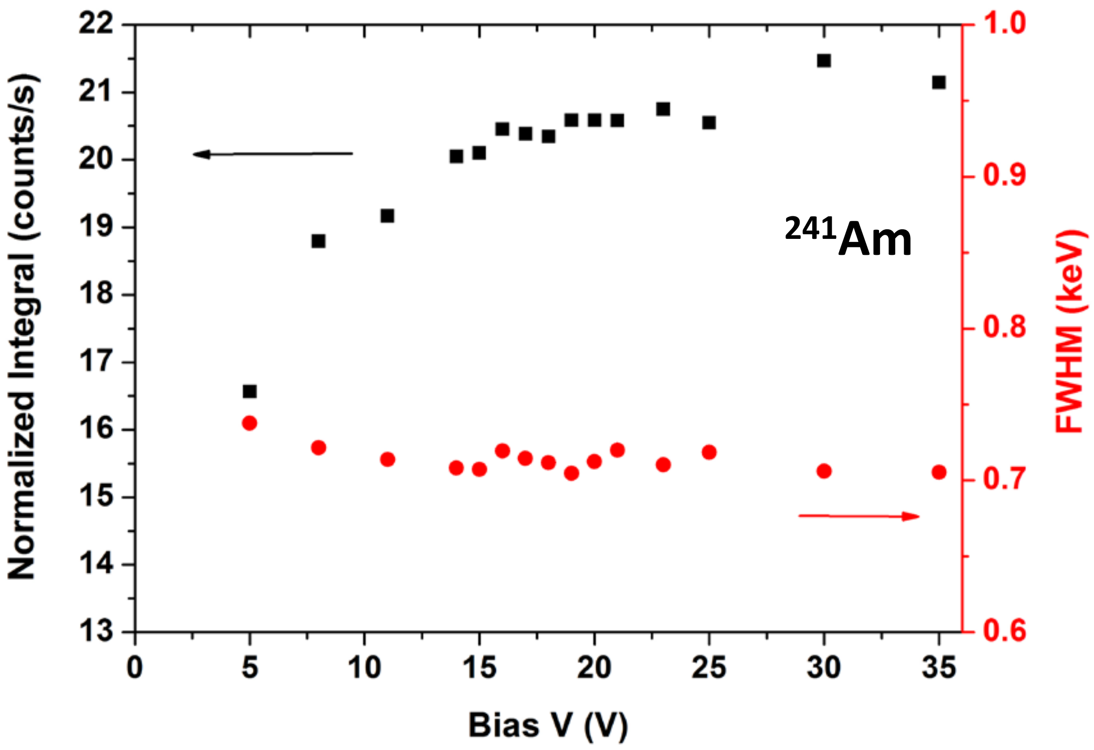
Good energy resolution in all the energy range up to 400KeV

Test of small HPGe prototype: detector configuration

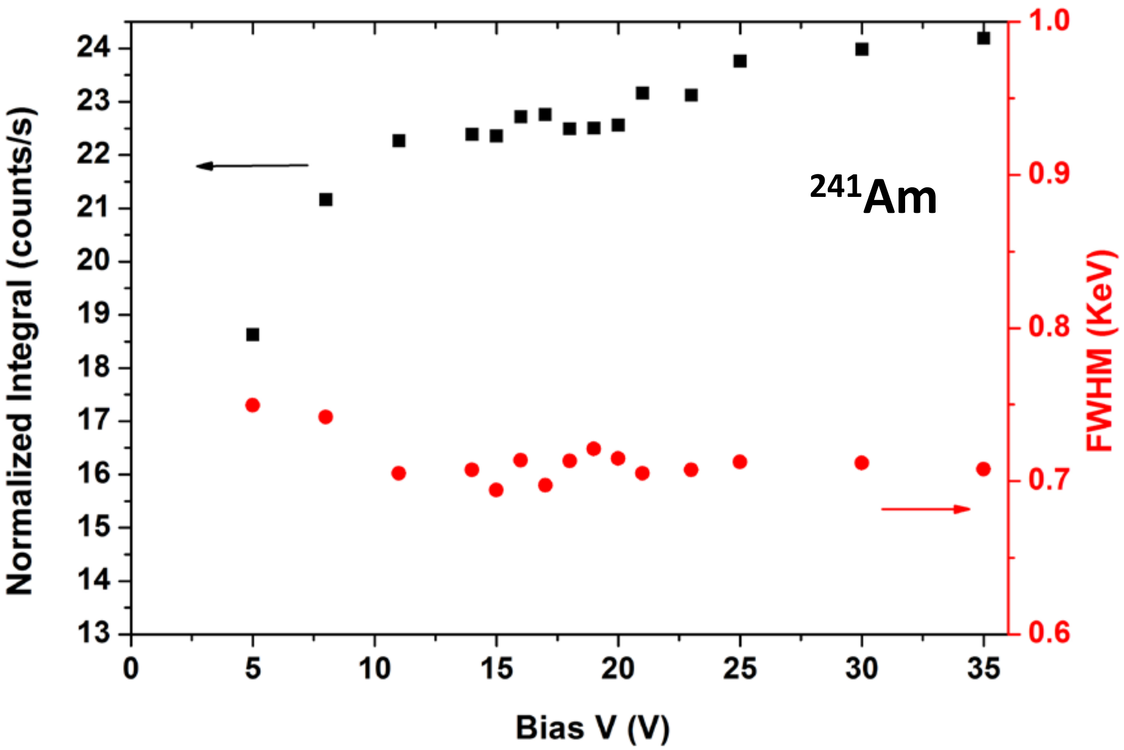
gap 0.2mm

Depletion Voltage - Energy resolution

Seg.1



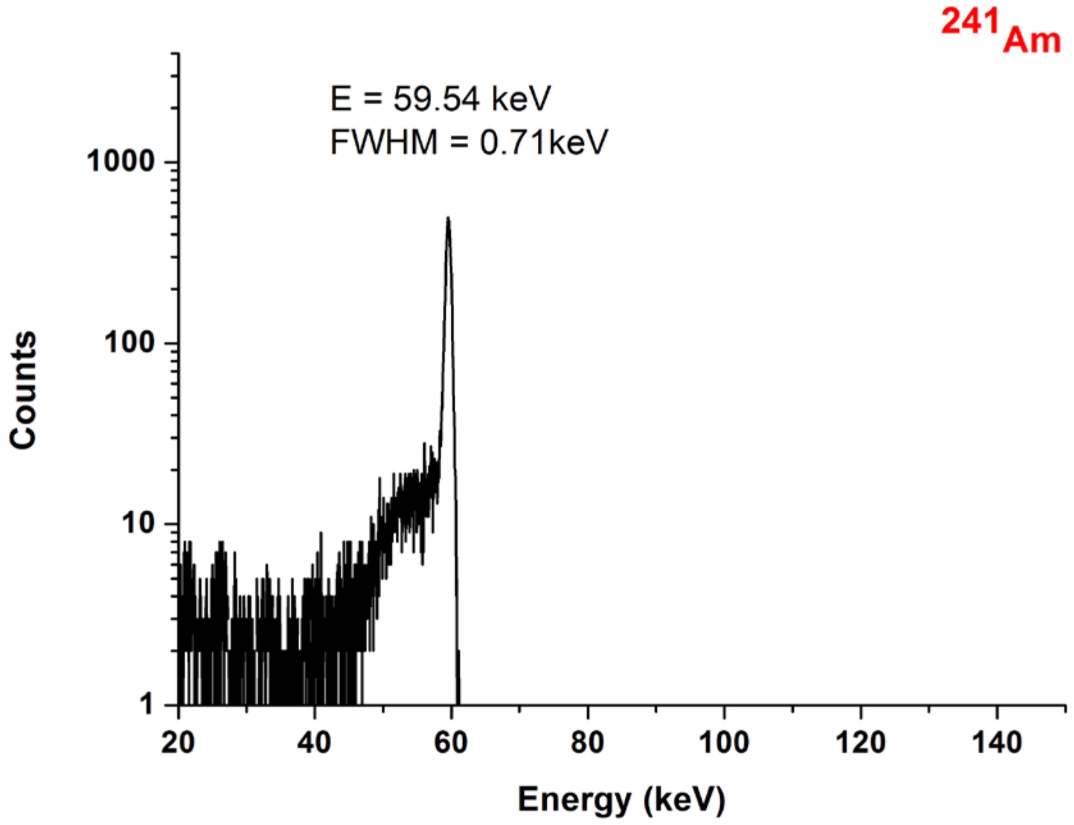
Seg.2

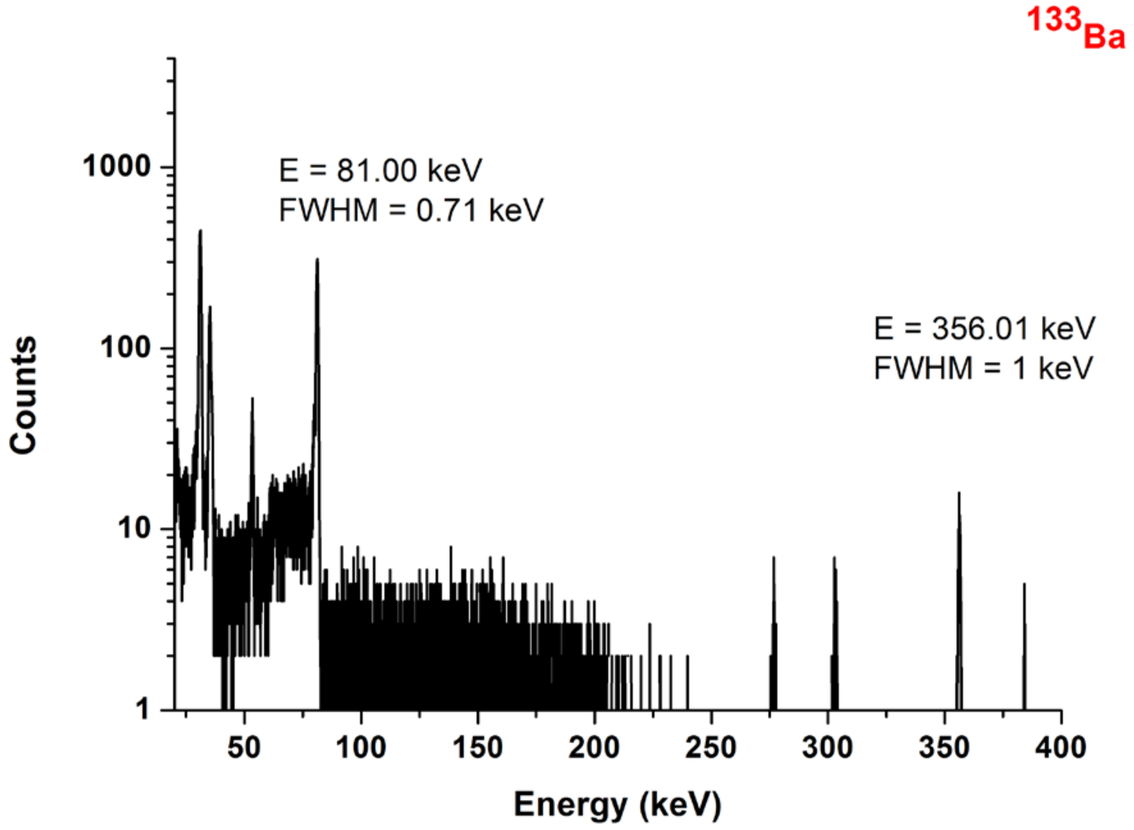


- detector fully depleted
- good energy resolution

Test of small HPGe prototype: detector configuration

Segment **gap 0.2mm**





Good energy resolution in all the energy range up to 400KeV

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Summary

- We have shown that PLM is a good technology to perform contacts in HPGe detectors.
- With this technology we have substituted Li with Sb for the n^+ contact.
- We have verified that the PLM technology can be scaled up to a larger surface.
- The photolithography technology permits to segment the HPGe detector
- We have verified that the chemical passivation between the segments has high electrical resistance

Work in progress

- Development bigger HPGe detectors: PLM Sb contact deposition, photolithograpy segmentation, etc.

- Optimization of the gap between segments

- Development of p^+ and n^+ contacts on HPGe with other materials by PLM

Multidisciplinary Team

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Thanks for the attention !!

ENSAR2 has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654002

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4rd Position Sensitive Germanium Detectors (PSeGe)

Segmentation of PLM contacts in HPGe detectors

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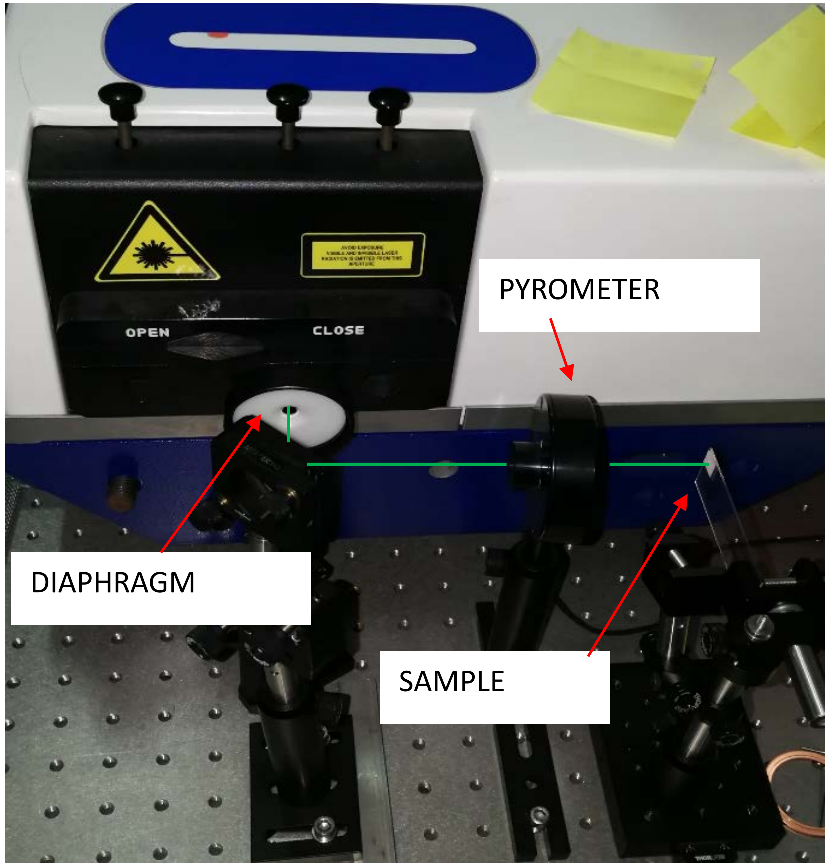
KrF Excimer lasers
coherent COMpex 201

λ=248nm;
τ=25 ns;
$spot\ size = 5.1x5.1$mm;
Rate = 10Hz
Fluence = 400 mJ/cm^2



Pulsed Laser @ LNL-INFN
Nd:YAG (Quantel YG980)
λ=355 nm (third harmonic generator)
τ=7 ns; Ø=6,5 mm; Rate = 10Hz
Radiant power ~1500 mW
Fluence ~300-400 mJ/cm^2