

A new fabrication route for Double Sided Strip HPGe Detectors

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HPGe semiconductor interfaces

Traditional contacts:	thin	thermally stable
<i>p</i> : Boron by ion implantation	✓	✓
<i>n</i> : Lithium by thermal diffusion	✗	✗

HPGe semiconductor interfaces

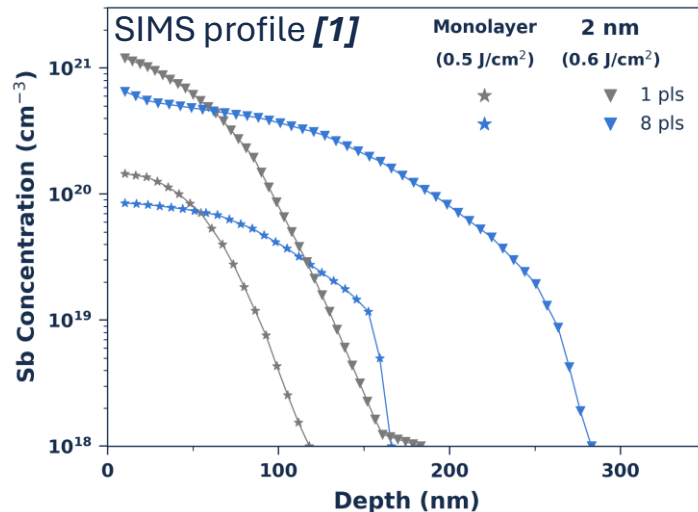
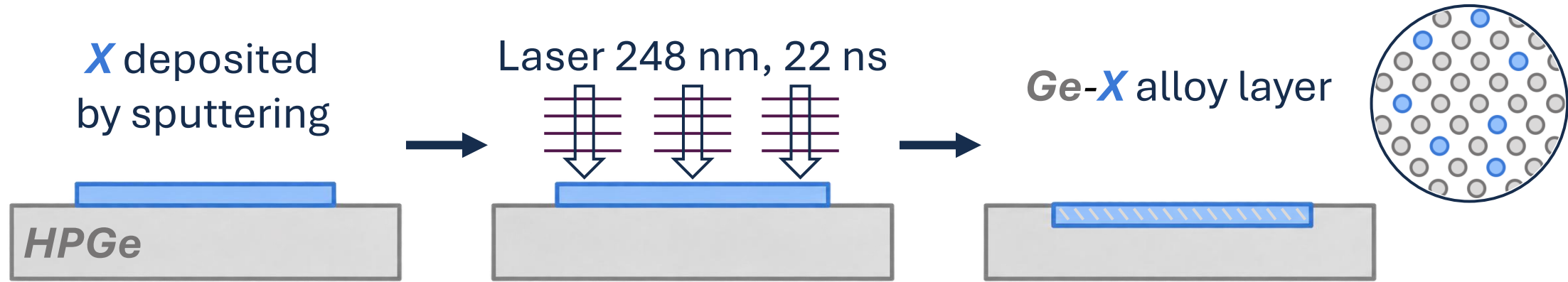
	thin	thermally stable
Traditional contacts:		
<i>p</i> : Boron by ion implantation	✓	✓
<i>n</i> : Lithium by thermal diffusion	✗	✗
Alternatives:		
Amorphous Germanium contacts	✓	✗

HPGe semiconductor interfaces

Traditional contacts:	thin	thermally stable	
<i>p</i> : Boron by ion implantation	✓	✓	
<i>n</i> : Lithium by thermal diffusion	✗	✗	DEAD LAYERS- INACTIVE VOLUMES
Alternatives:	<i>n-contacts show limitations</i>		NOT EASY TO SEGMENT
Amorphous Germanium contacts	✓	✗	NOT ANNEALABLE/ REDUCTION IN EFFICIENCY

Thin and stable contacts: PLM technique

PLM: Pulsed Laser Melting



active concentration:
 $\sim 10^{20}$ at/cm³

melt depth:
 ~ 100 -500 nm

- **THIN**
- **HIGHLY DOPED**
- **THERMALLY STABLE**
- **NO BULK CONTAMINATION**
[2][3]

[1] Carraro et al., Appl. Surf. Sci. 509, 145229 (2020)

[2] Boldrini et al., J. Phys. D: Appl. Phys. 52, 035104 (2019).

[3] Bertoldo S. et al., The European Physical Journal A 57, 177 (2021)

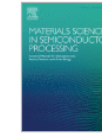
Thin and stable contacts: PLM technique

*Not only for **n**-contacts but also for **p**-contacts*



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

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F. Nicolasi ^{a b}, D.R. Napoli ^a, E. Napolitani ^{a b}, D. De Salvador ^{a b}

Thin-thermally stable semiconductor contacts

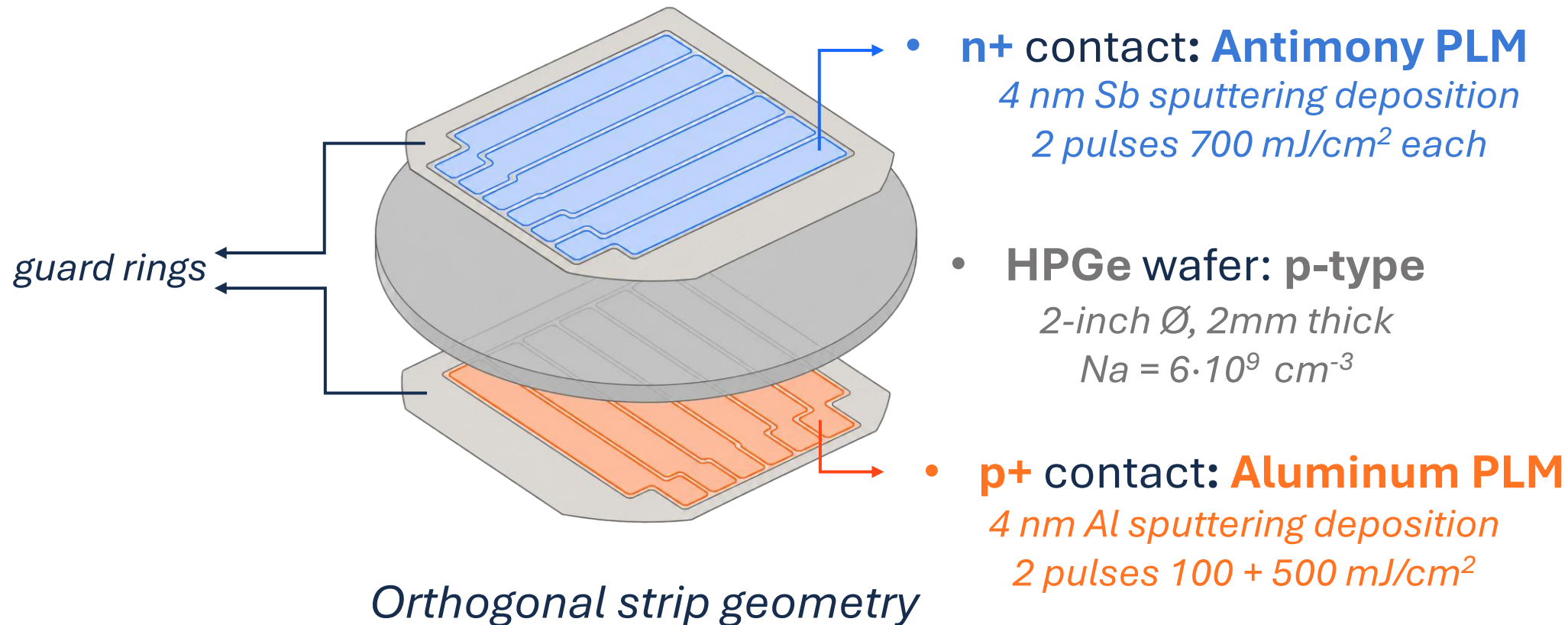
FULLY ANNEALABLE

EASILY SEGMENTABLE

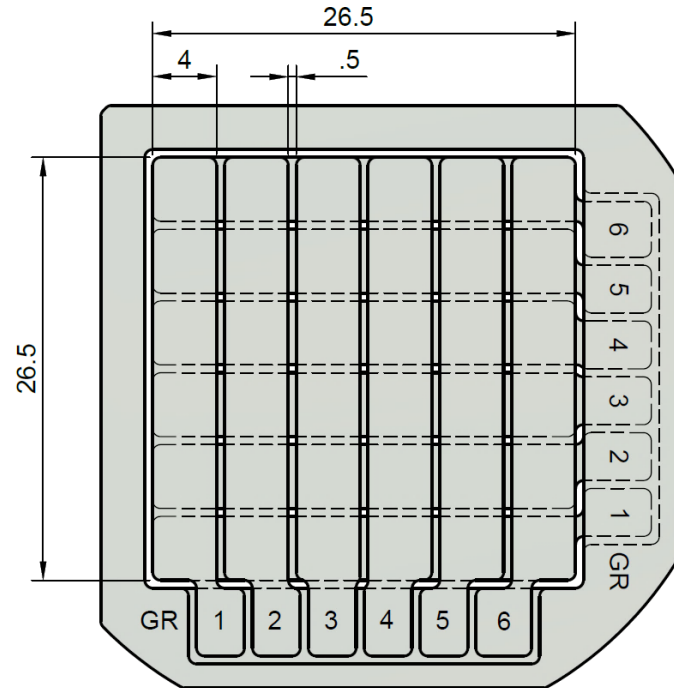
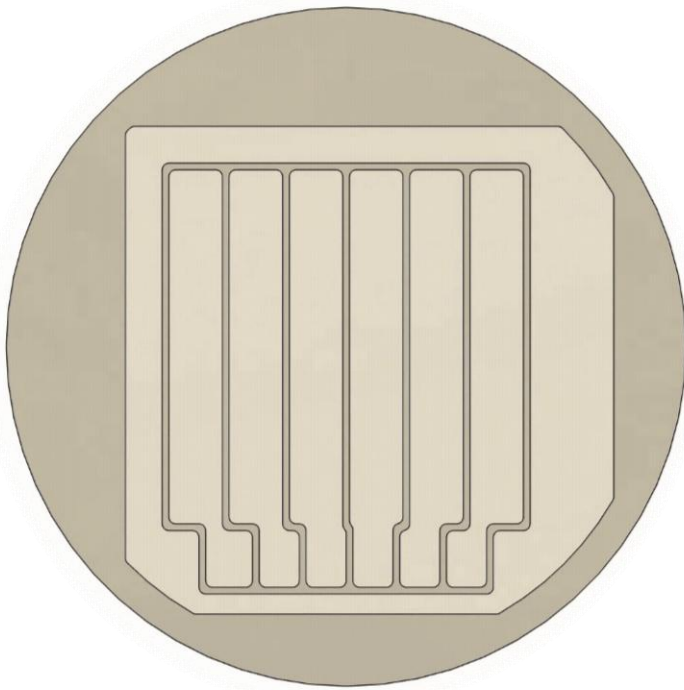
SIMPLE, FAST, AND COST-EFFECTIVE

Our purpose: a full DSSD-PLM device

DSSD: Double Sides Strip Detector



Our purpose: a full PLM device



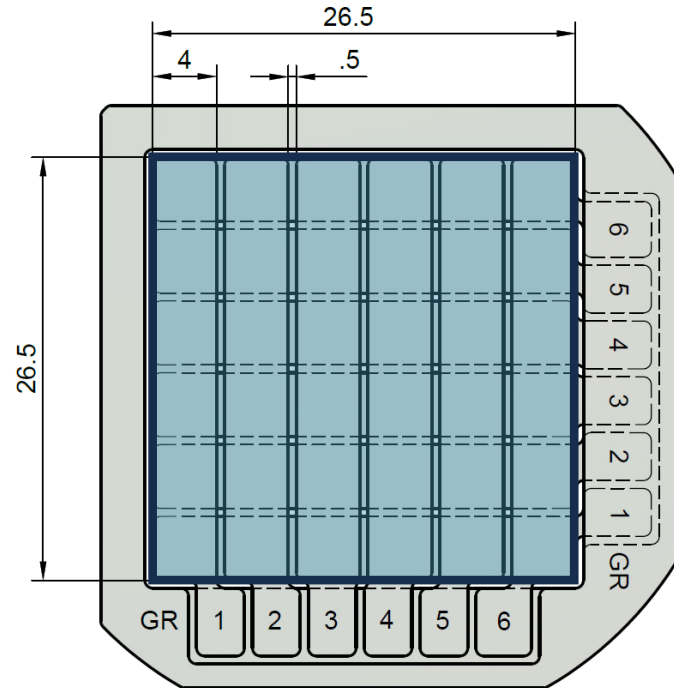
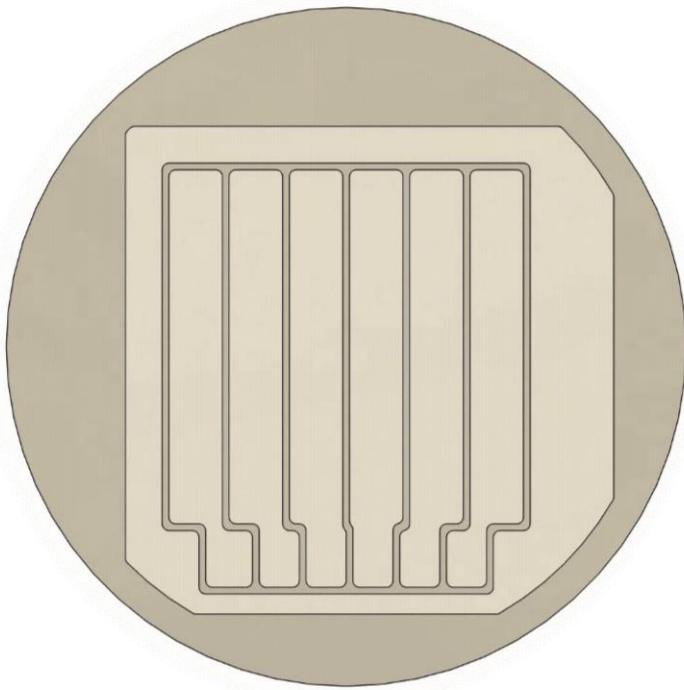
6 strips per side

6 readout electrodes per side

guard rings for edge-field control

0.5 mm gap

Our purpose: a full PLM device



6 strips per side

6 readout electrodes per side

guard rings for edge-field control

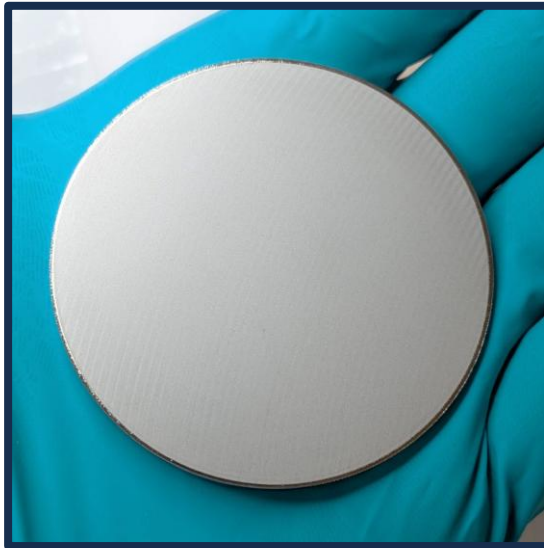
0.5 mm gap

ACTIVE AREA:

36 VOXELS $4 \times 4 \times 2 \text{ mm}^3$

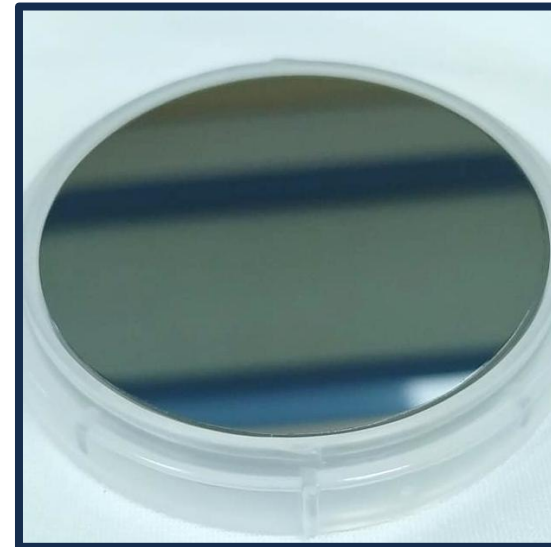
Fabrication Steps: CMP

CMP: Chemical Mechanical Planarization



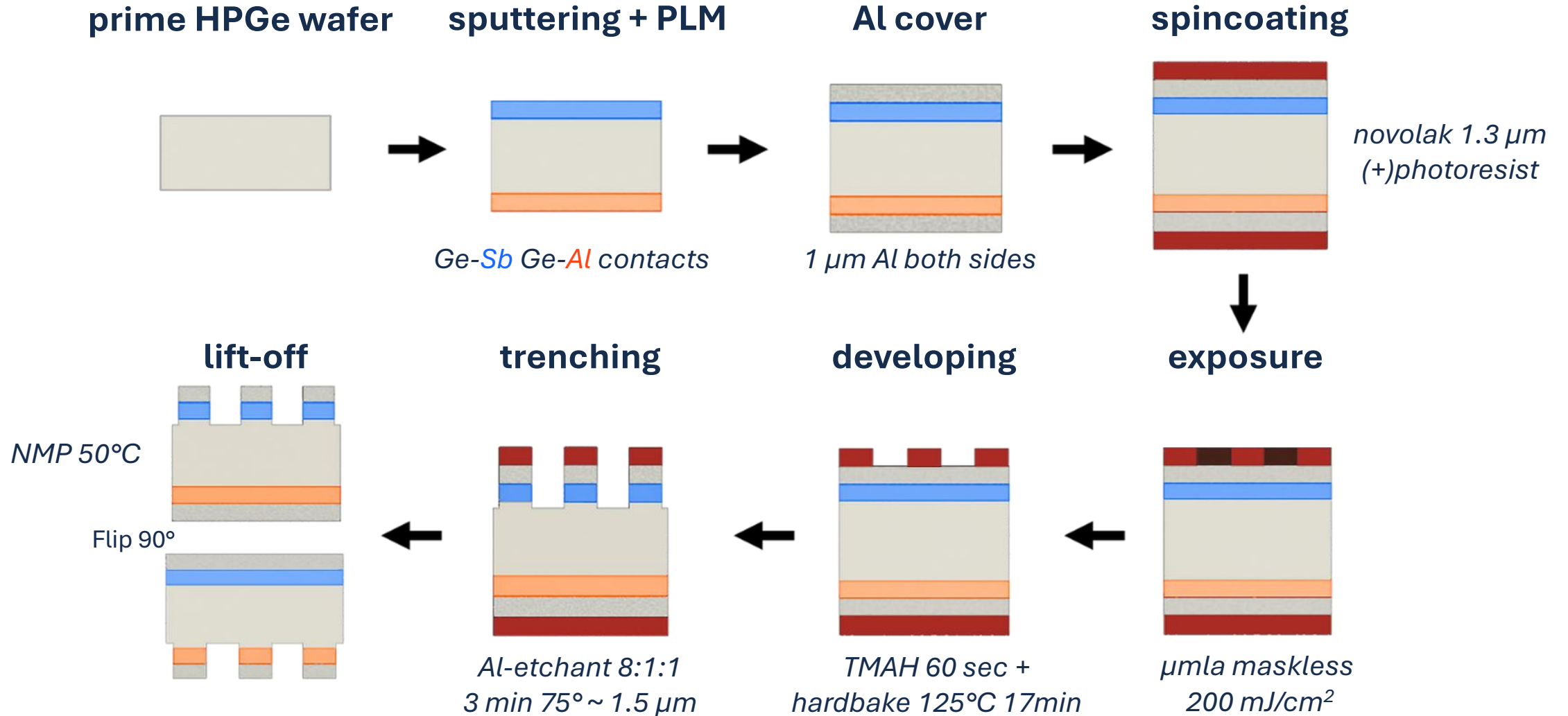
Local RMS $S_q \approx 0.4 \mu\text{m}$
 μm -waviness $\rightarrow$ **blade damage**
 $2.13 \pm 0.03 \text{ mm}$

H_2O_2 (1%wt) +
pH 12 (KOH) +
Colloidal SiO_2 $\varnothing 30 \text{ nm}$
polyurethane pad
 $\Rightarrow$
Both faces

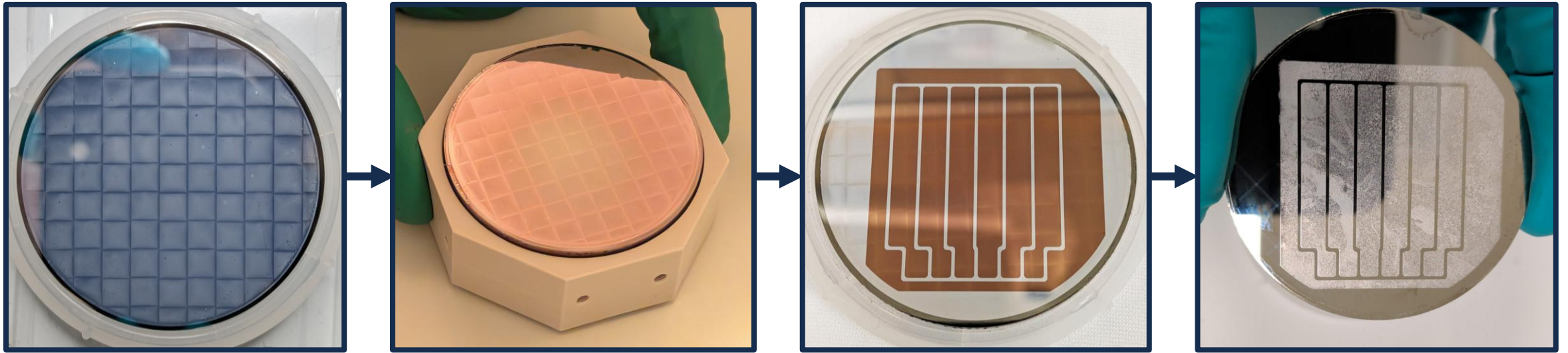


Local RMS $S_q \approx 0.1 \text{ nm}$
Mirror-like surfaces
 $2.00 \pm 0.03 \text{ mm}$

Fabrication Steps

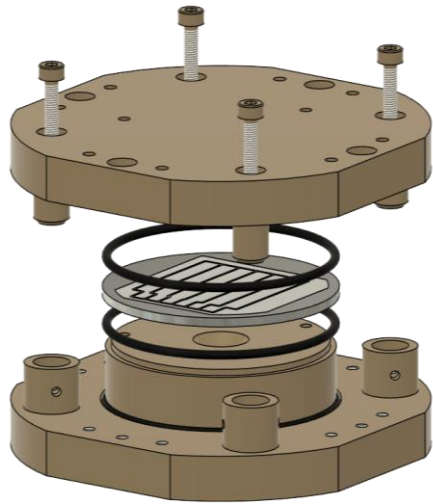


Fabrication Steps: some milestones



Cryostat assembly

lateral
passivation

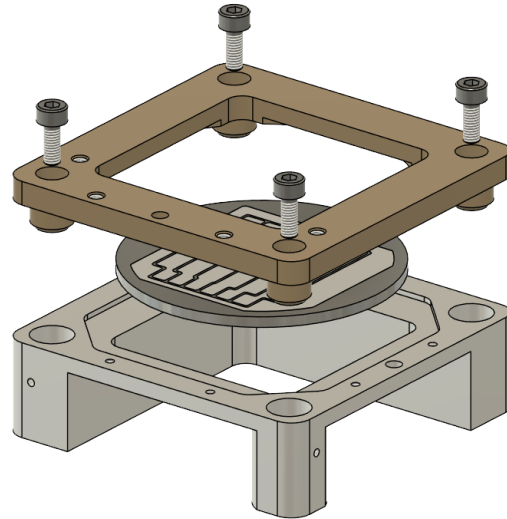


$\text{HNO}_3\text{:HF}$ 3:1

3 min, $\Delta r \sim 80 \mu\text{m}$

Quenching **MeOH**:
HPGe-OMe

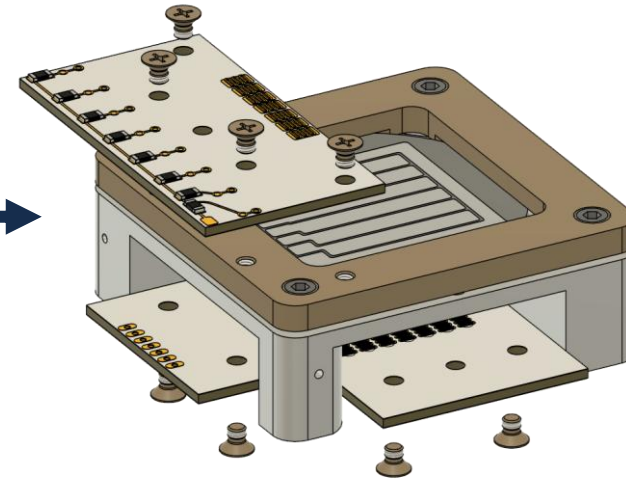
holder
assembly



$\text{Al/Al}_2\text{O}_3$ base for
thermal coupling

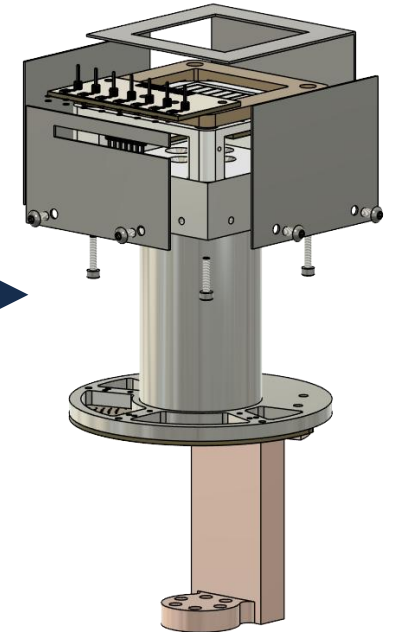
PEEK top-holder for HV-
side electrical insulation

PCB
assembly



**Pogo-pin electrical
contacts**

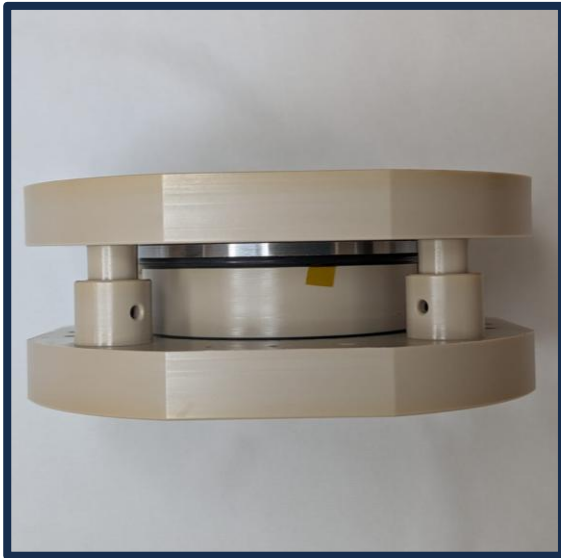
cryostat
integration
and wiring



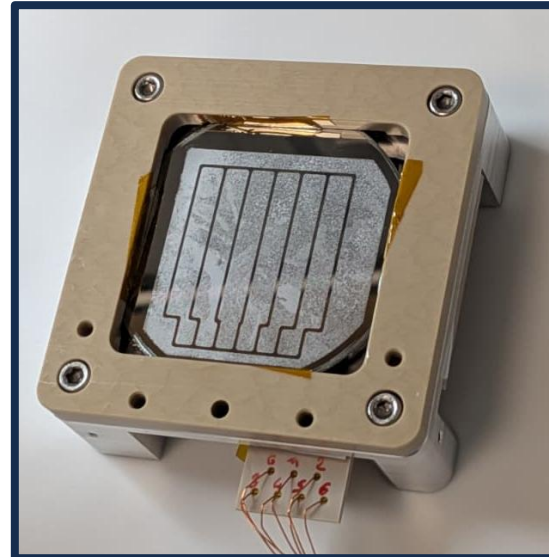
$10^{-6}\text{-}10^{-7}\text{ mbar}$
 LN_2 cooling 77K

Cryostat assembly

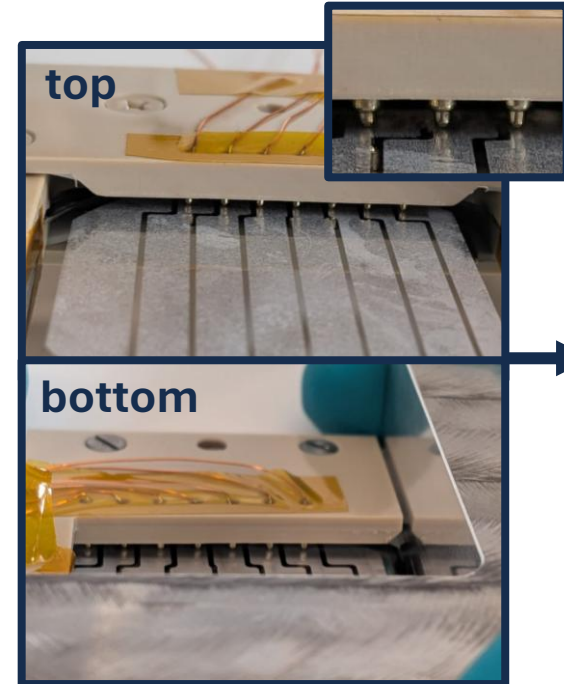
lateral
passivation



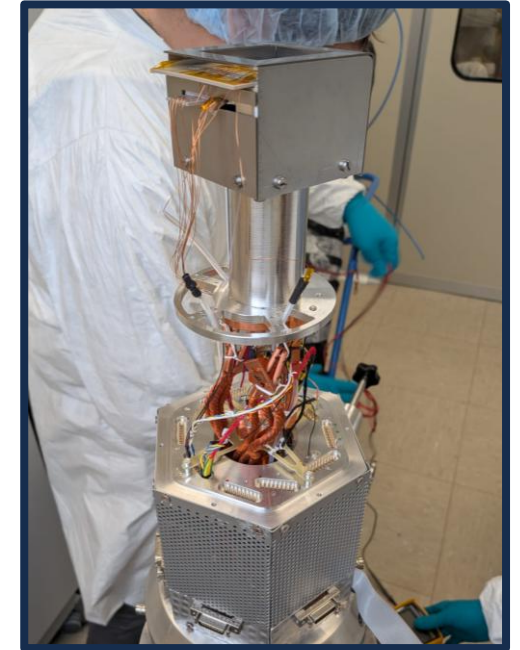
holder
assembly



PCB
assembly

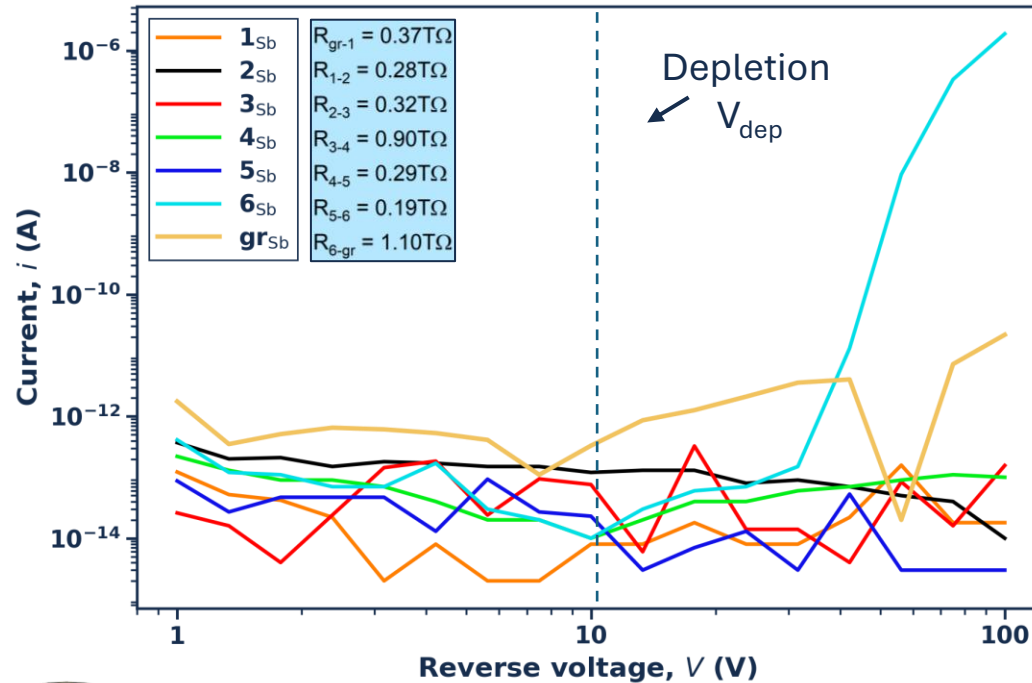


cryostat
integration
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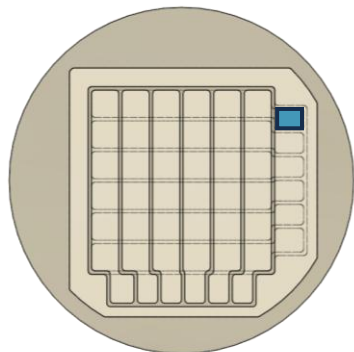
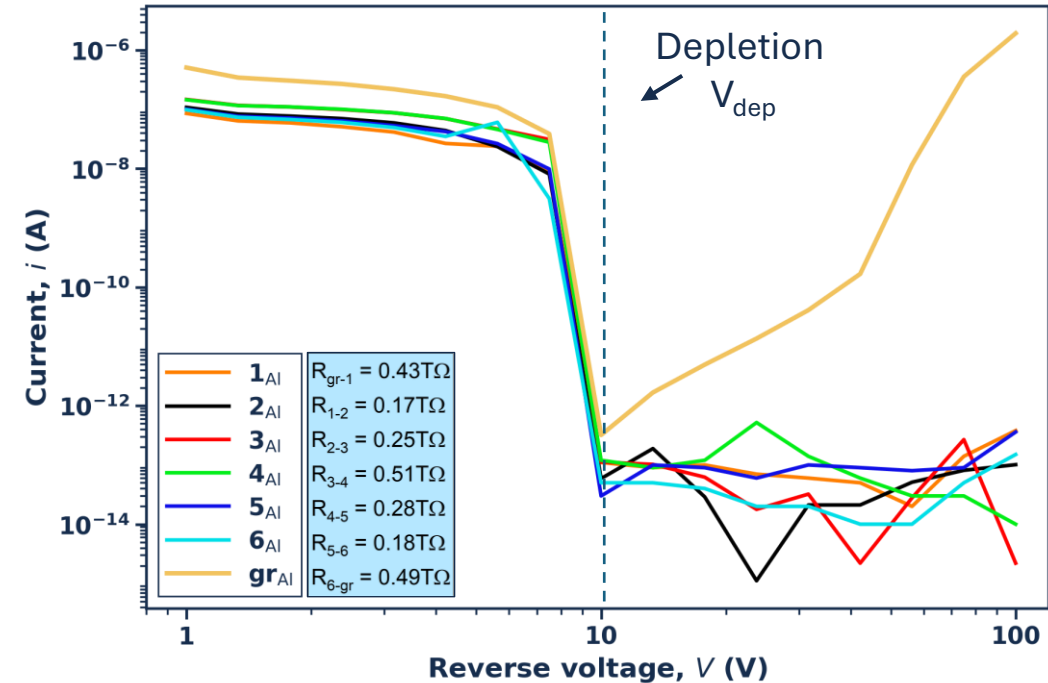


Characterization: segments I-V curves

Sb-PLM junction



Al-PLM contact



No breakdown before depletion $\sim 10V$

First breakdown $6_{Sb}-gr_{Al} \approx 30-40 V$

High effective resistance

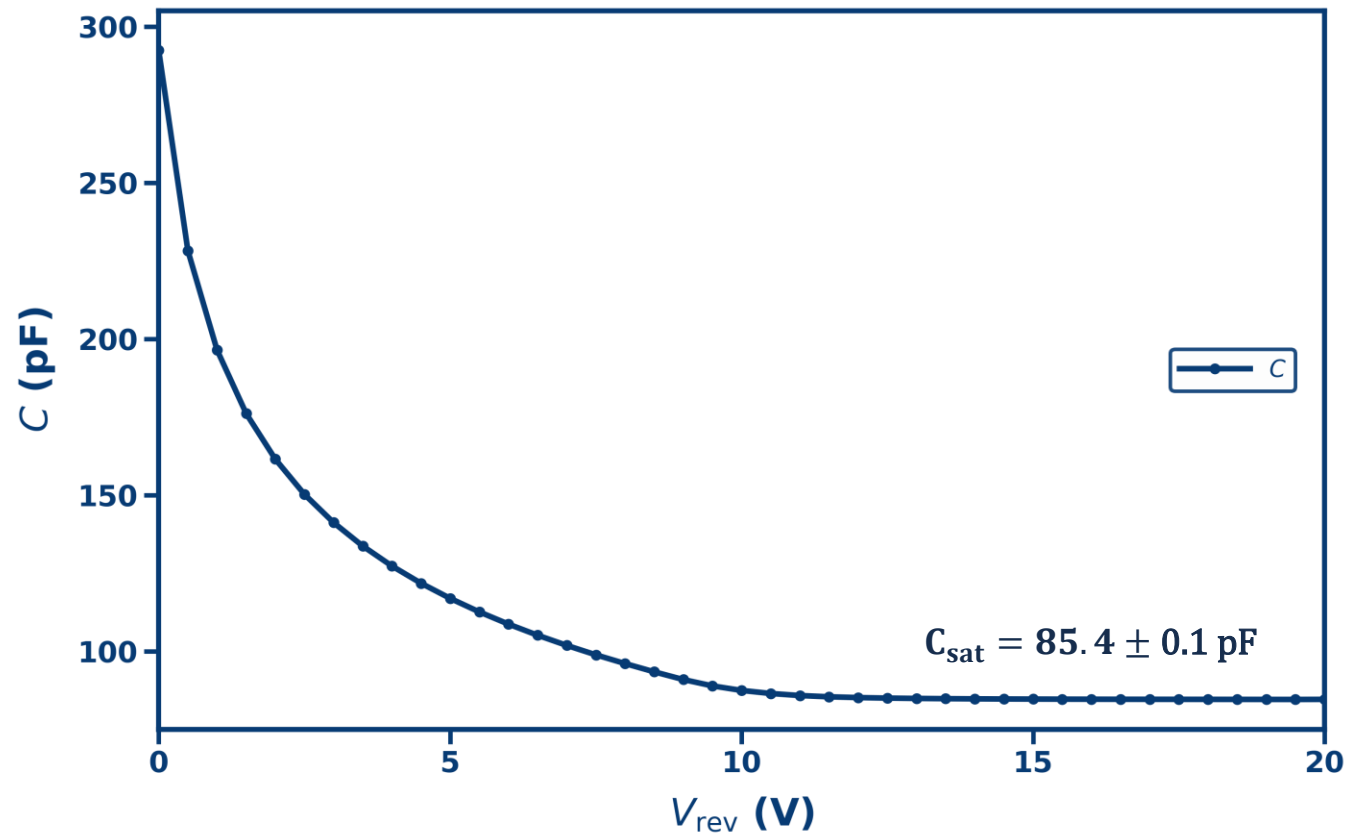


Fully working segmented diode

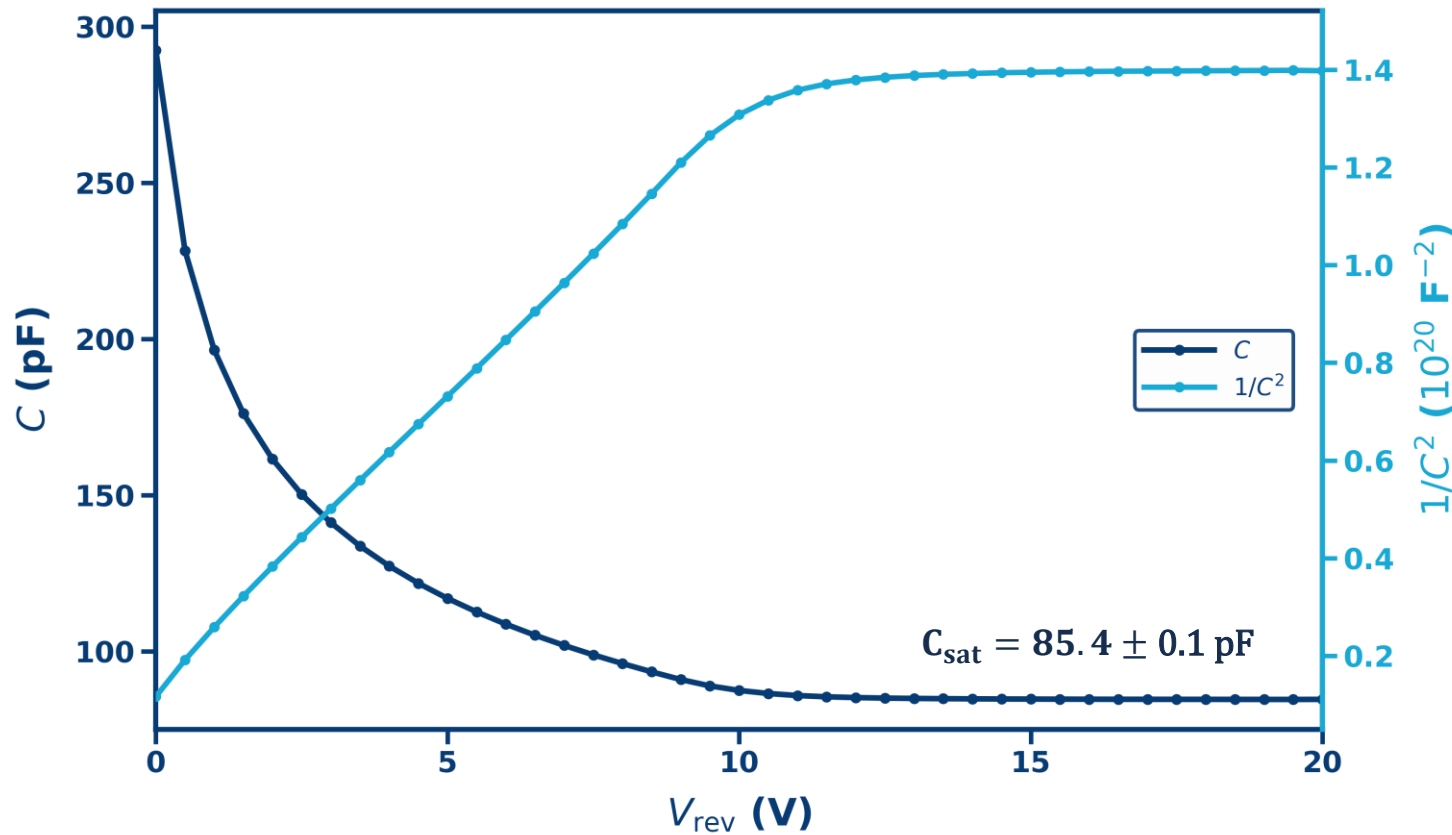
Operational $3-4 \times V_{dep}$ overdepletion

Well isolated strips

Characterization: C-V curve



Characterization: C-V curve

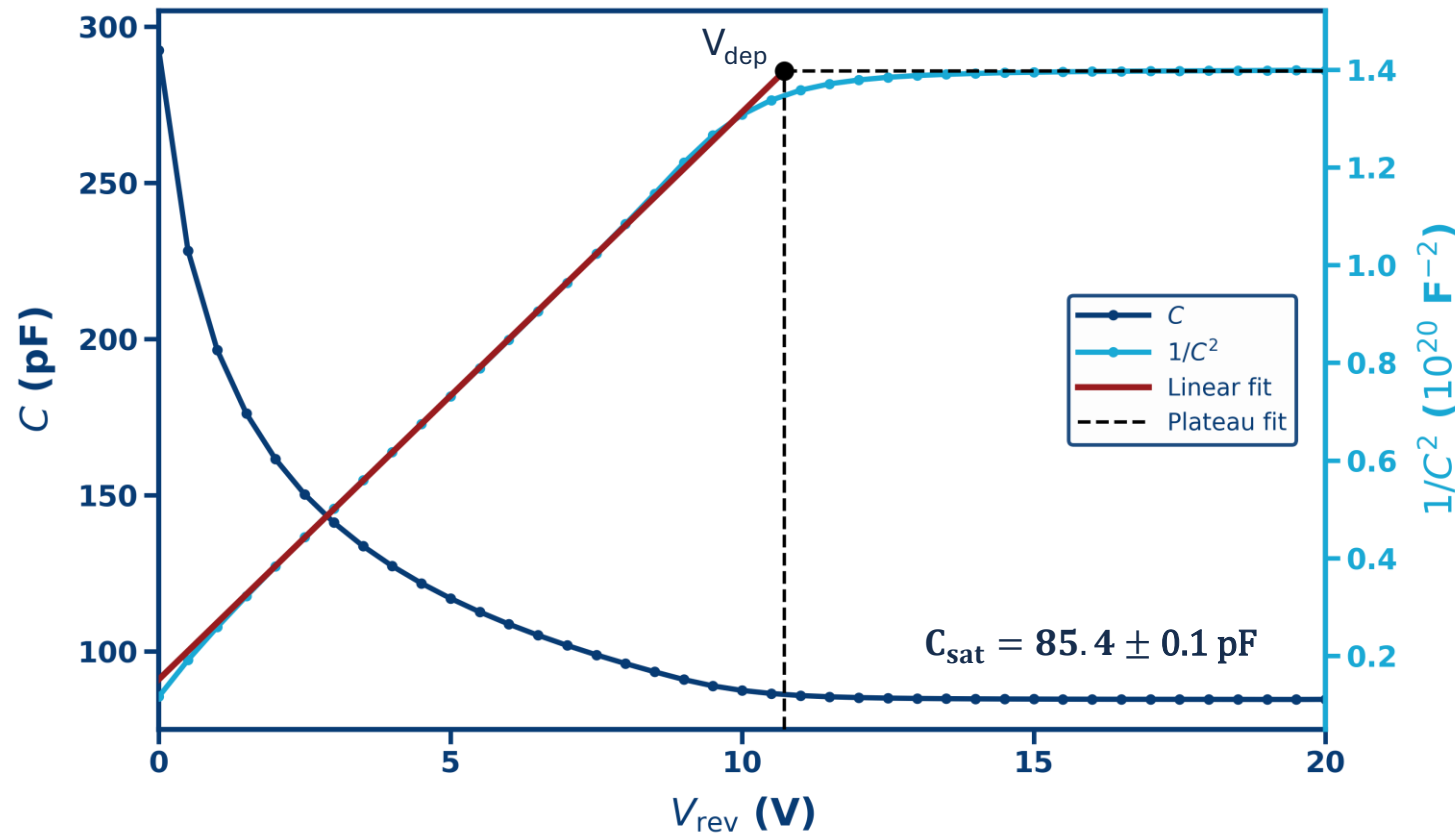


$$C = \sqrt{\frac{q\epsilon_{Ge}A^2N_{eff}}{2(V_{rev} + V_{bi})}} = A \frac{\epsilon_{Ge}}{x}$$

↓

$$\frac{1}{C^2} = \frac{2}{q\epsilon_{Ge}A^2N_{eff}} (V_{rev} + V_{bi})$$

Characterization: C-V curve



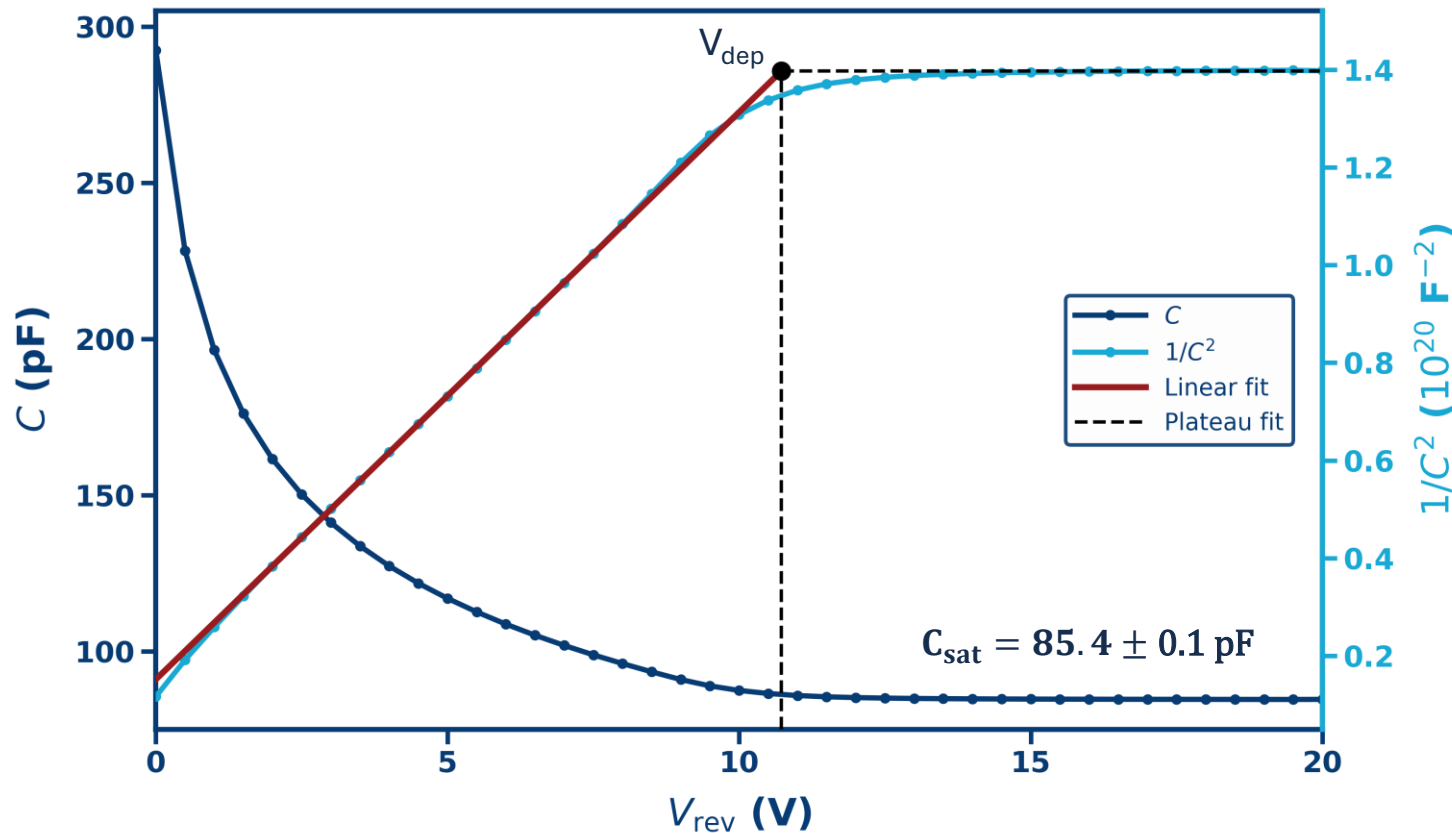
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$$N_{eff} = 5.2 \pm 0.1 \cdot 10^9 \text{ cm}^{-3}$$

$$V_{dep} = 10.5 \pm 0.2 \text{ V}$$

Characterization: C-V curve



$$C = \sqrt{\frac{q\epsilon_{Ge}A^2N_{eff}}{2(V_{rev} + V_{bi})}} = A \frac{\epsilon_{Ge}}{x}$$

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$$N_{eff} = 5.2 \pm 0.1 \cdot 10^9 \text{ cm}^{-3}$$

$$V_{dep} = 10.5 \pm 0.2 \text{ V}$$

$$C_{sat} \approx C_{ideal} = 90 \text{ pF}$$

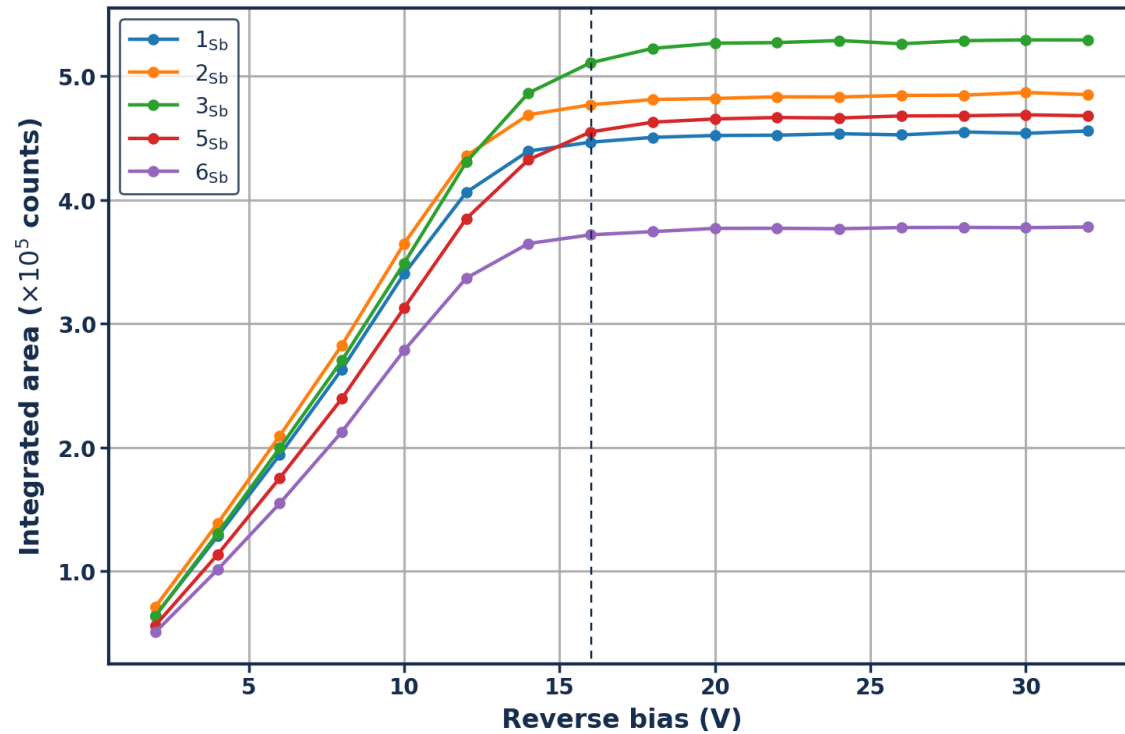
$$N_{eff} \approx N_{prod} = 6 \cdot 10^9$$

Fully depleted volume

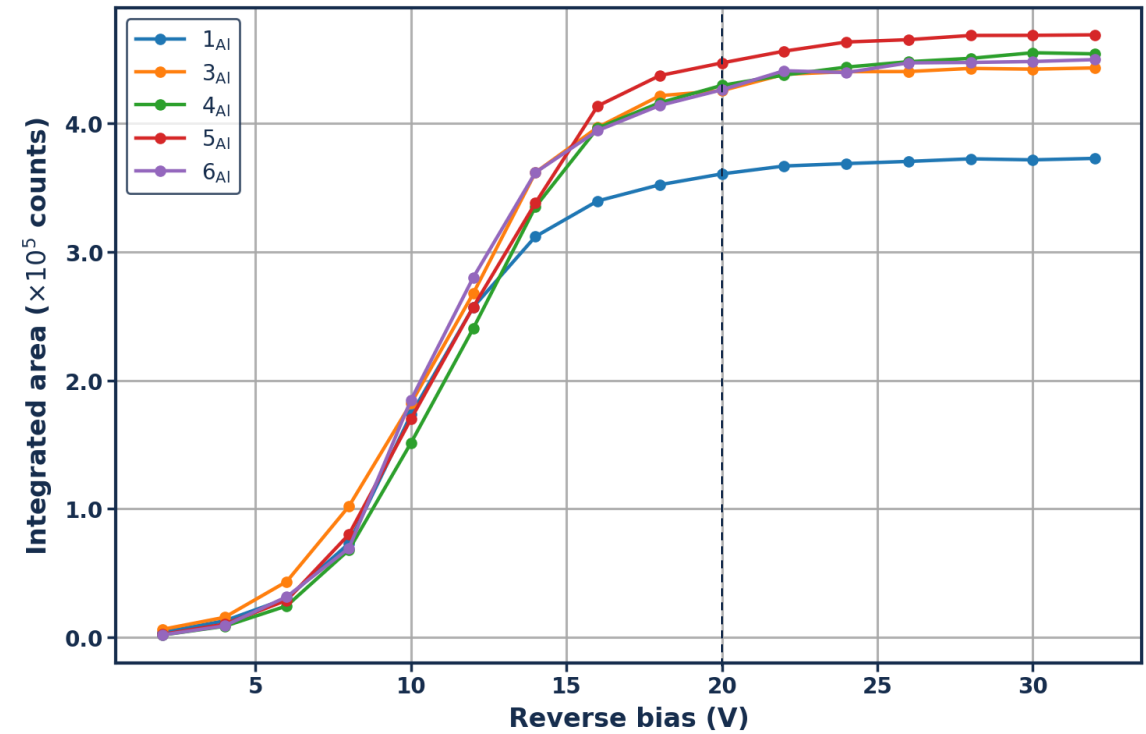
No bulk contamination

^{241}Am 60KeV integrated peak vs V

Sb strips (n-junction)



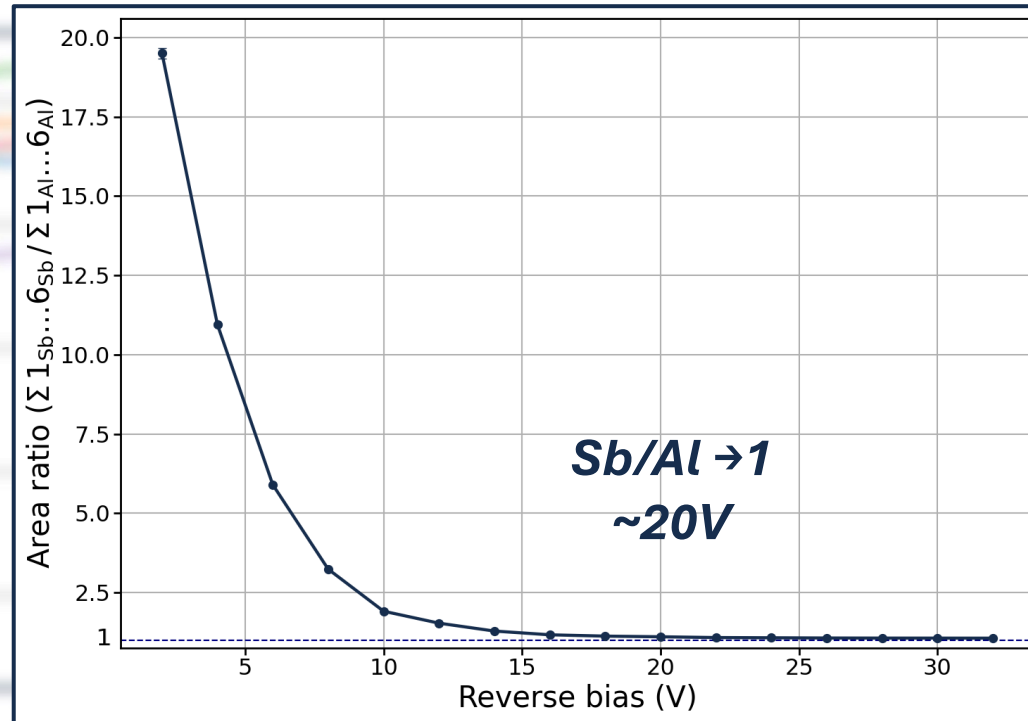
Al strips (p-contact)



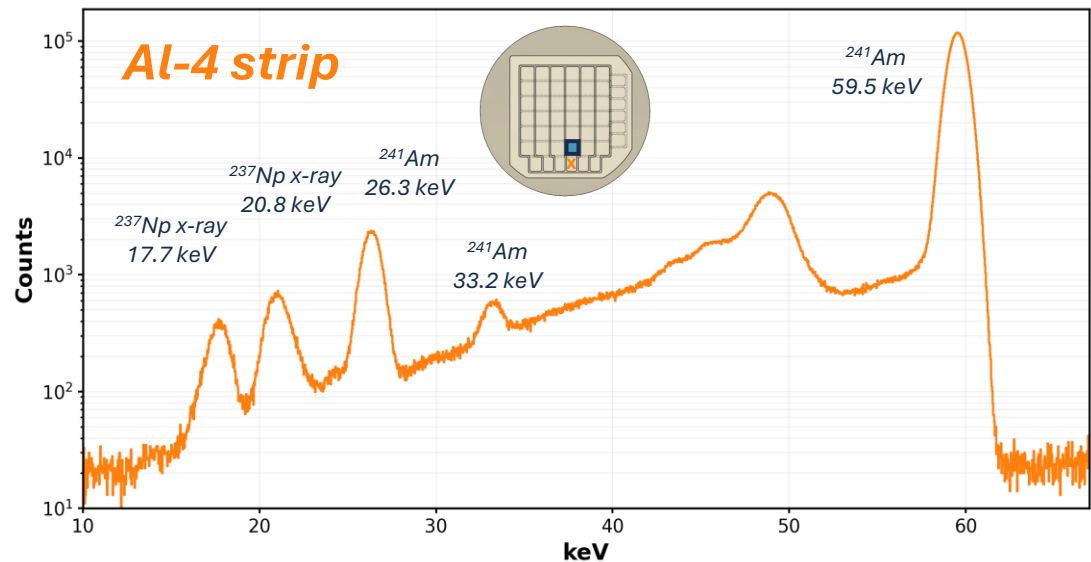
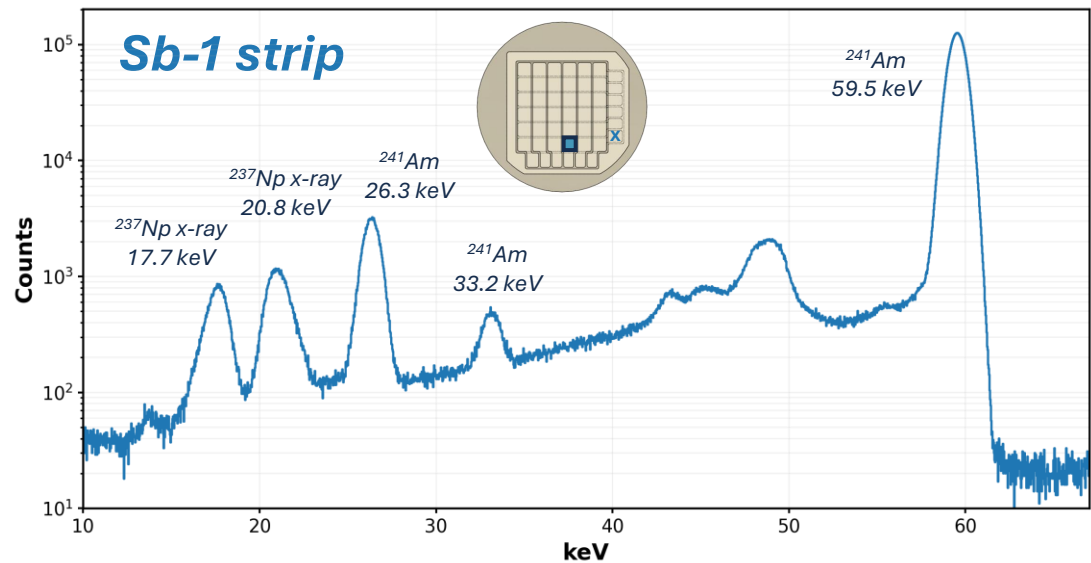
^{241}Am 60KeV integrated peak vs V

Sb strips (n-junction)

Al strips (p-contact)



Detector mode: resolution



^{241}Am : 59.54 keV - Analog acquisition
mean over all contacts

Side	^{241}Am FWHM [keV]
Sb	0.71 ± 0.2
Al	0.84 ± 0.2

^{241}Am : 59.54 keV | ^{137}Cs : 661.66 keV - Digital acquisition

Channel	^{241}Am FWHM [keV]	^{137}Cs FWHM [keV]
1 _{Sb}	0.854 ± 0.002	1.65 ± 0.03
2 _{Sb}	0.881 ± 0.002	1.58 ± 0.03
3 _{Sb}	0.879 ± 0.002	1.63 ± 0.02
4 _{Sb}	N.D.	N.D.
5 _{Sb}	0.874 ± 0.002	1.64 ± 0.04
6 _{Sb}	0.879 ± 0.002	1.70 ± 0.03
1 _{Al}	0.883 ± 0.002	1.957 ± 0.008
2 _{Al}	N.D.	N.D.
3 _{Al}	0.878 ± 0.002	1.944 ± 0.009
4 _{Al}	0.897 ± 0.002	1.983 ± 0.009
5 _{Al}	0.919 ± 0.002	1.998 ± 0.007
6 _{Al}	0.907 ± 0.002	1.953 ± 0.007
GR _{Al}	1.550 ± 0.008	2.75 ± 0.01

Conclusion

- **Successful fabrication of a fully PLM-based double-sided strip HPGe detector**, using Sb for the n-type contacts and Al for the p-type contacts.
- **Complete fabrication protocol**, including CMP, PLM contact formation, photolithographic segmentation, surface passivation and cryogenic mounting, **preserving the bulk impurity concentration**
- Electrical characterization confirmed **stable operation well into the over-depletion regime and good interstrip isolation**
- Good spectroscopic performance was demonstrated with both ^{241}Am and ^{137}Cs , reaching FWHM values of about **0.85–0.9 keV at 59.5 keV** and about **1.6–1.9 keV at 662 keV**.

- *Re-test the detector with complete spectroscopic measurements and pulse shape analysis*
- *Test innovative drop-shaped flex-PCB contacts for soft electrical contact*
- *Measure the **Maxwell capacitance matrix** of the complete electrode system and correlate it with the energy resolution*
- *Exploit the **Sb-PLM n-type contact** as an ohmic contact for n-type **HPGe** detectors **with a boron-implanted junction***
- ***Scale up to thicker planar detectors:** first 15 mm, then 20 mm, with larger lateral dimensions*

Thanks for your attention

Davide De Salvador

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Daniel Napoli

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Francesco Recchia

