4th Position Sensitive Germanium Detectors and Application Workshop (PSeGe)

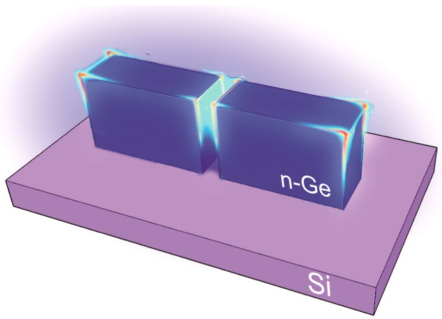
16-19 Semptember 2019 – INFN LNL

n-type high doping of Ge by Sb deposition and pulsed laser melting

Carraro Chiara

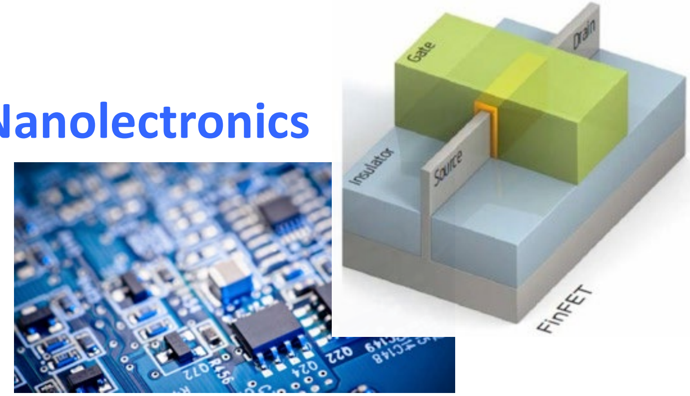
PhD student Physics – Univ. Of Padova

Ge-based devices

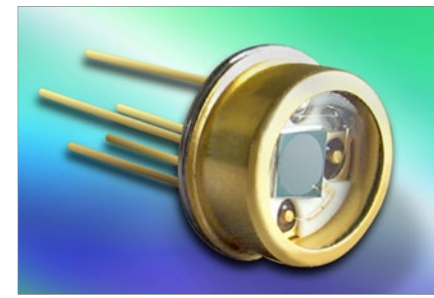


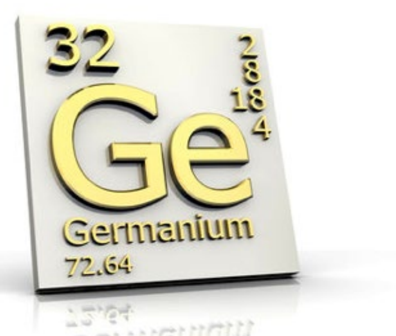
Plasmonic molecular sensors

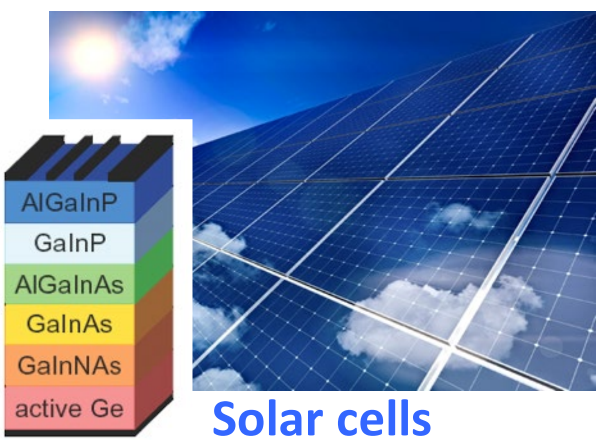
Nanolectronics



Photodetectors

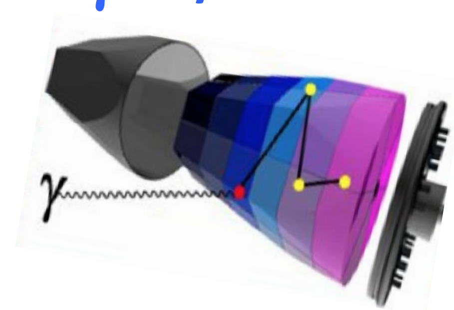


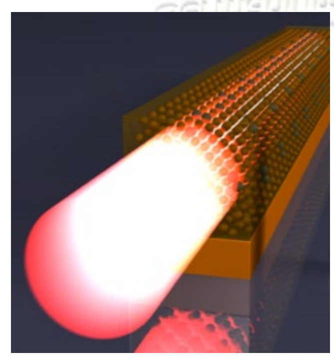




Solar cells

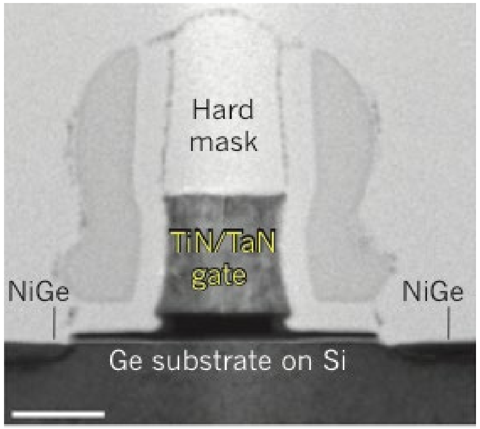
γ-Ray detectors

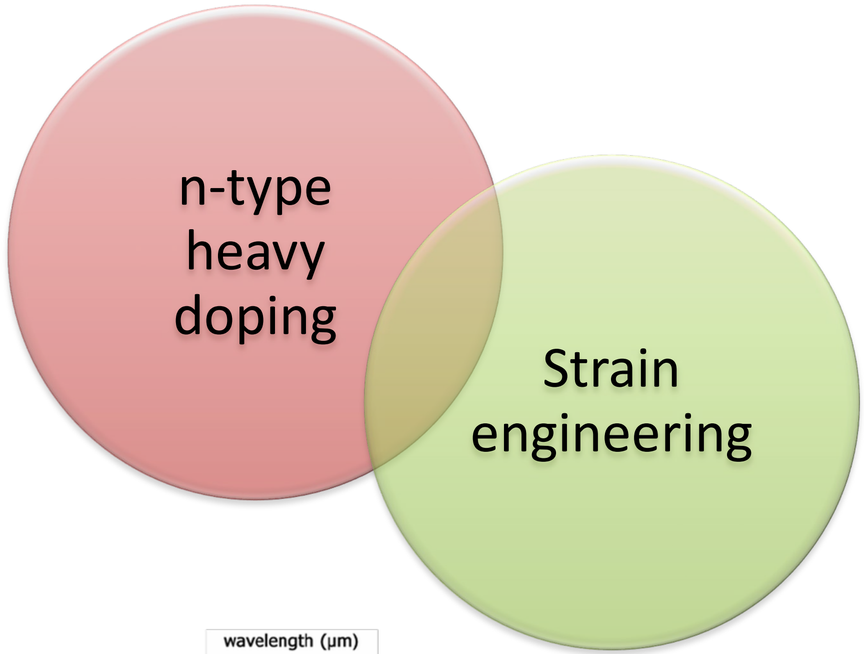


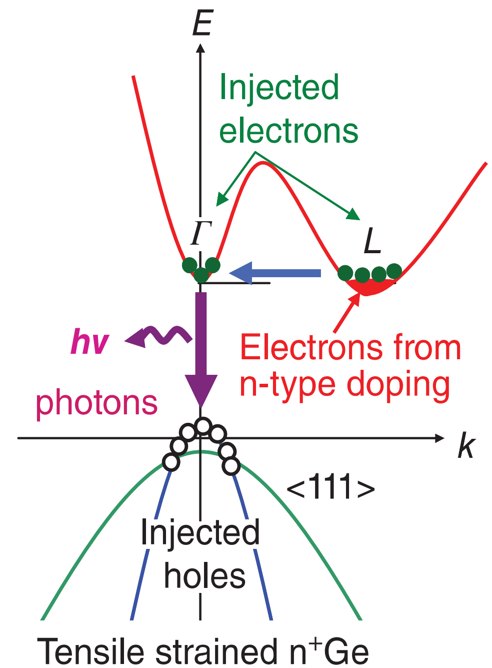


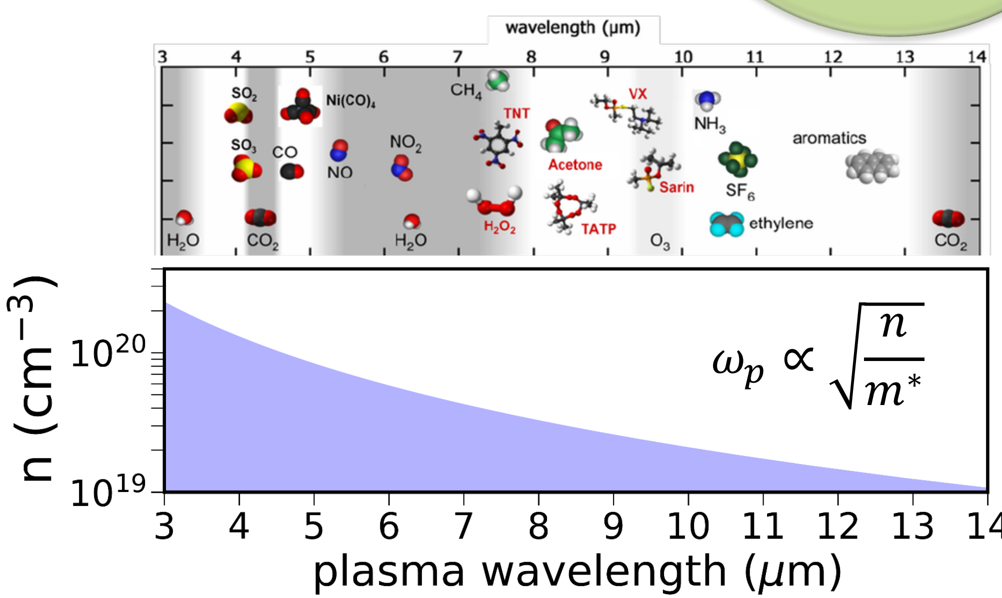
Lasers

Ge hot topics

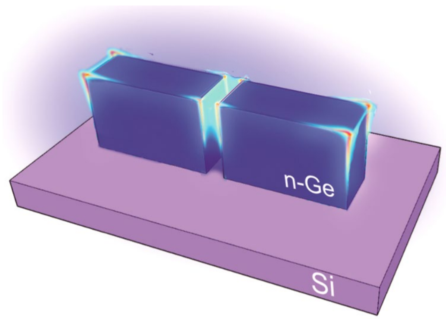






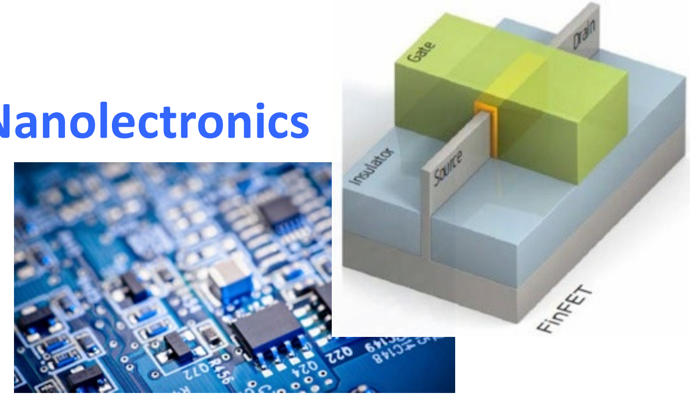


Ge-based devices

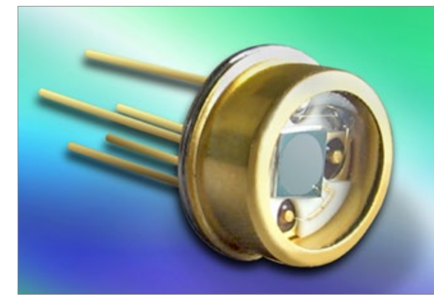


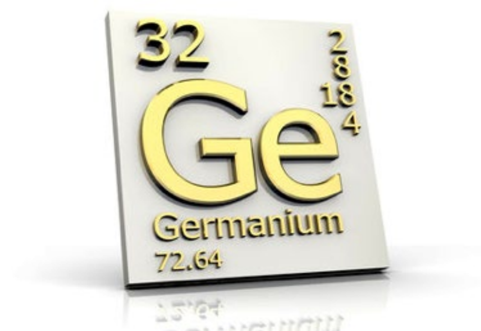
Plasmonic molecular sensors

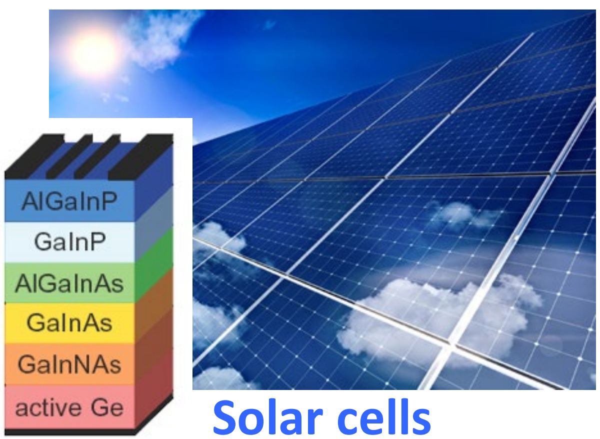
Nanolectronics



Photodetectors

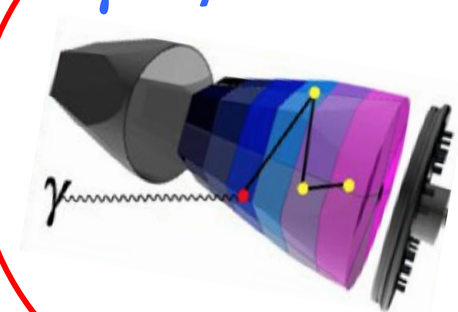


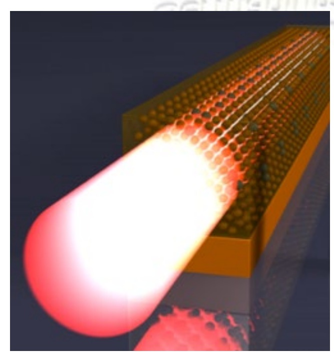




Solar cells

γ-Ray detectors

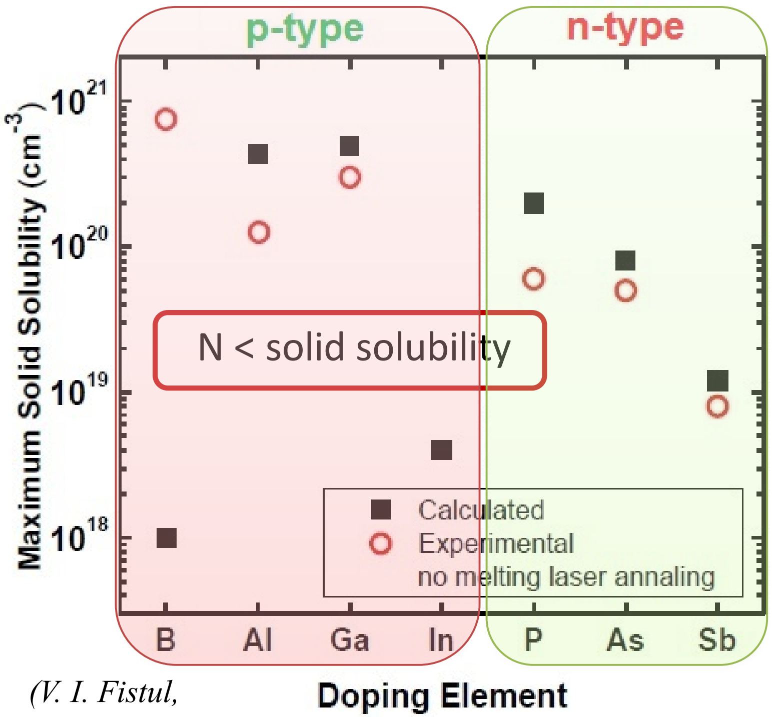




Lasers

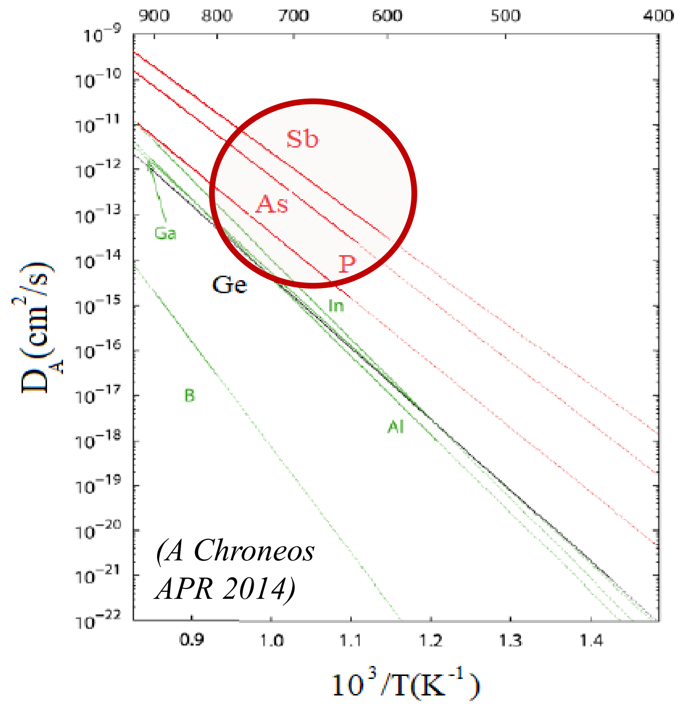
Issues on Ge n-type doping

Low active concentrations

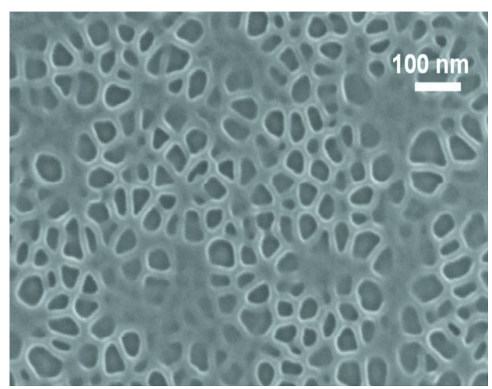


(V. I. Fistul, CRC press 2004)

High Diffusivities



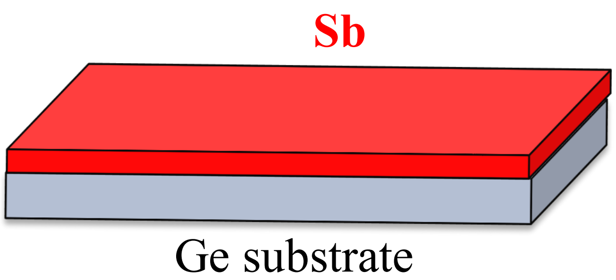
Ion Implantation Damage



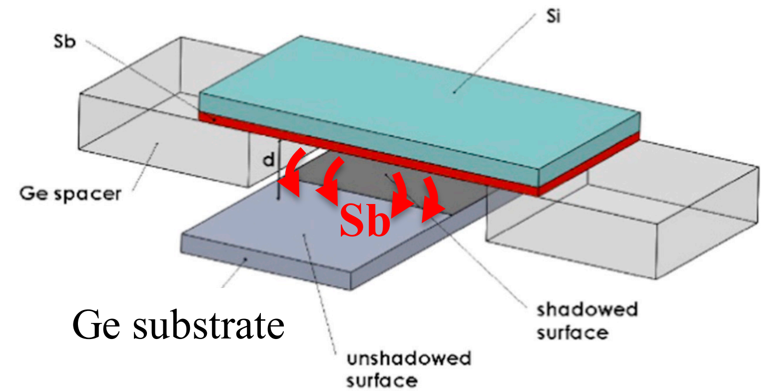
Ge implanted with 50 KeV 6×10^{15} Sb/cm^2 (Bruno JAP 2010)

Sb deposition + PLM

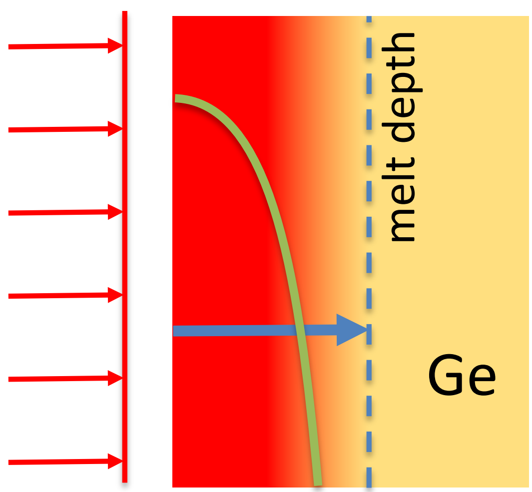
Sb Sputtering (1 – 8 nm)



Sb RTP Evaporation (self-limited monolayer deposition)



(*F. Sgarbossa et al., Appl. Surf. Sci.* ***496*** *(2019)*)

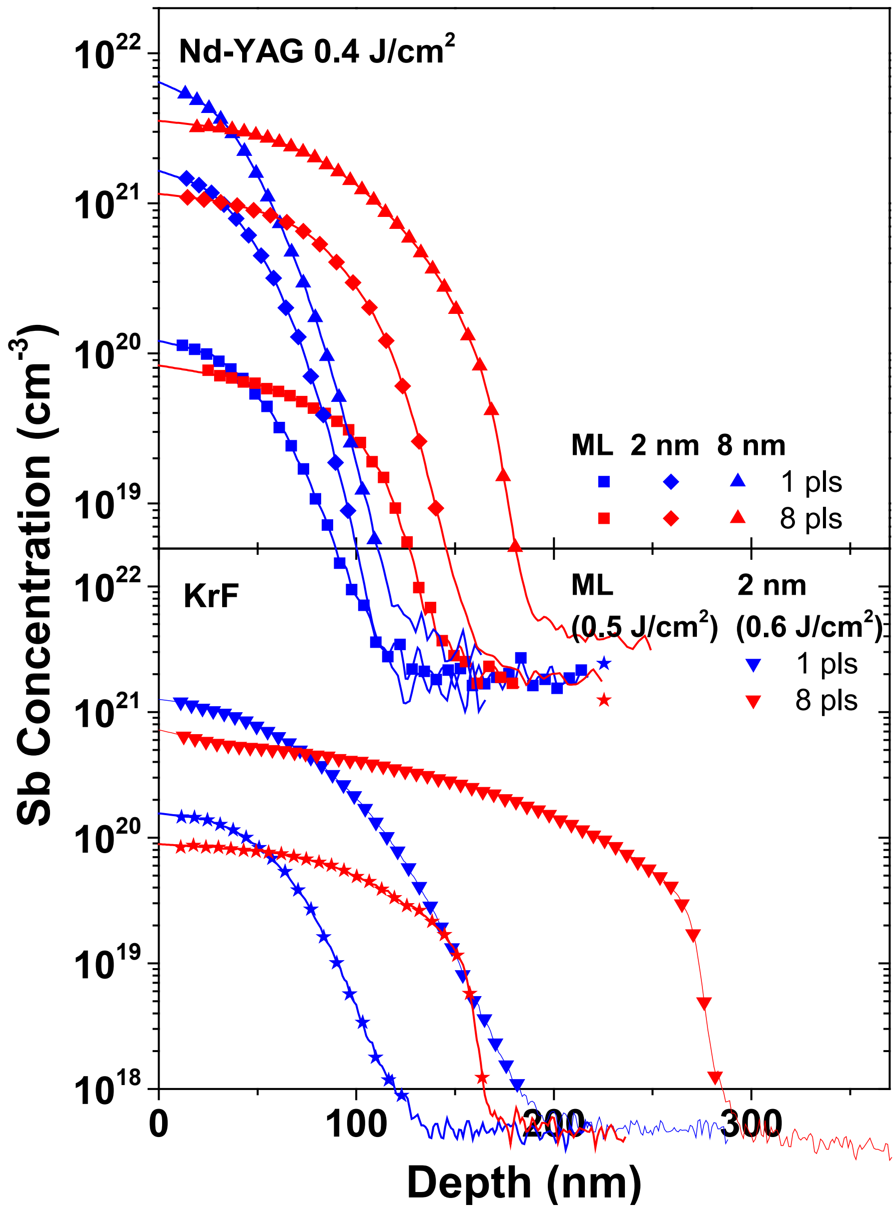


Pulsed Laser Melting

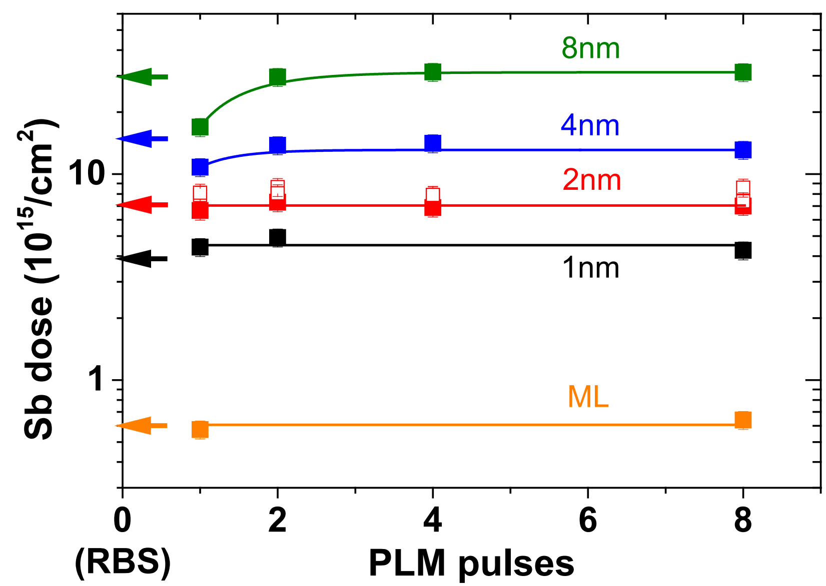
for dopant diffusion, incorporation, and activation

- Nd-YAG λ=355 nm, 7 ns, 400 mJ/cm^2
1 to 8 pulses
- KrF λ=248 nm, 25 ns, 300-700 mJ/cm^2
1 to 8 pulses

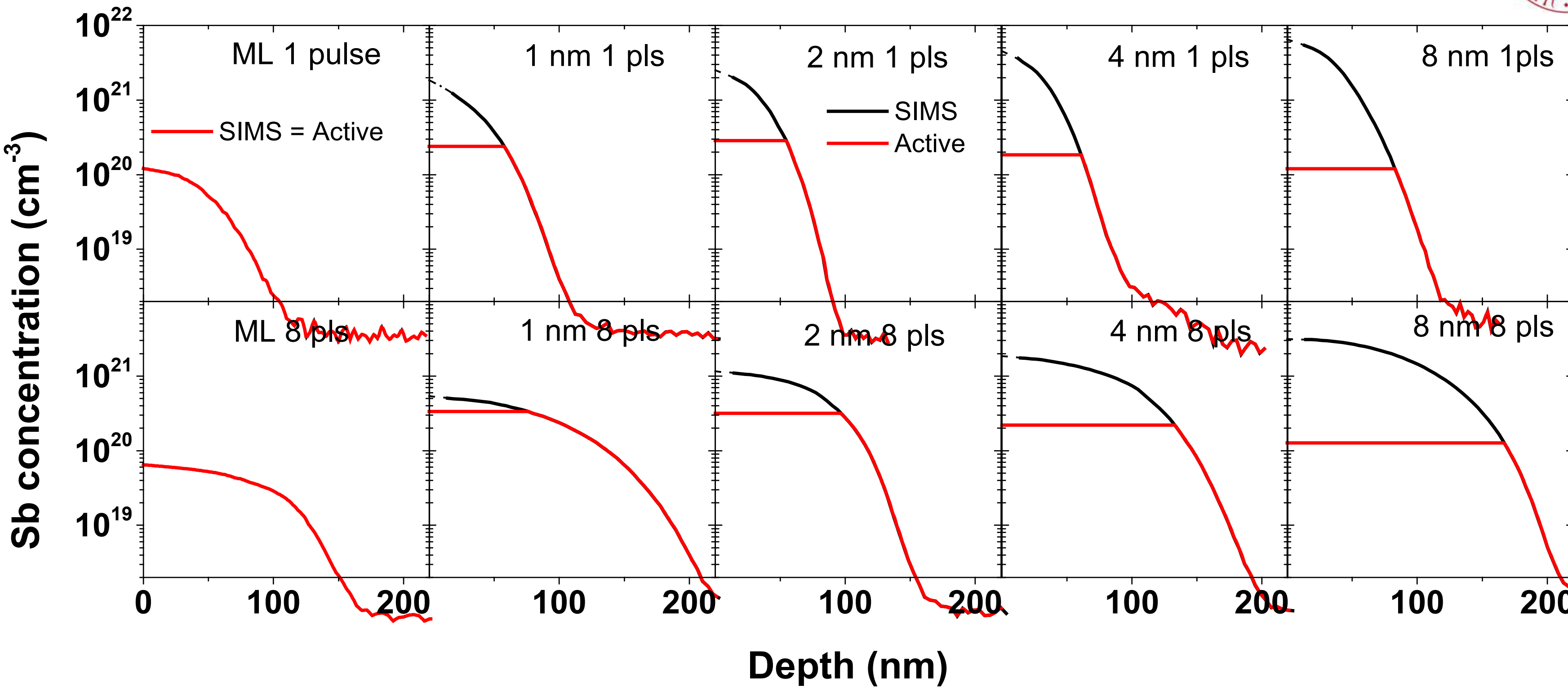
Chemical profile evolution



- Sb incorporation at >10% concentration
- No surface segregation
- No Sb loss
- Diffusion confined in molten layer



Dopant activation

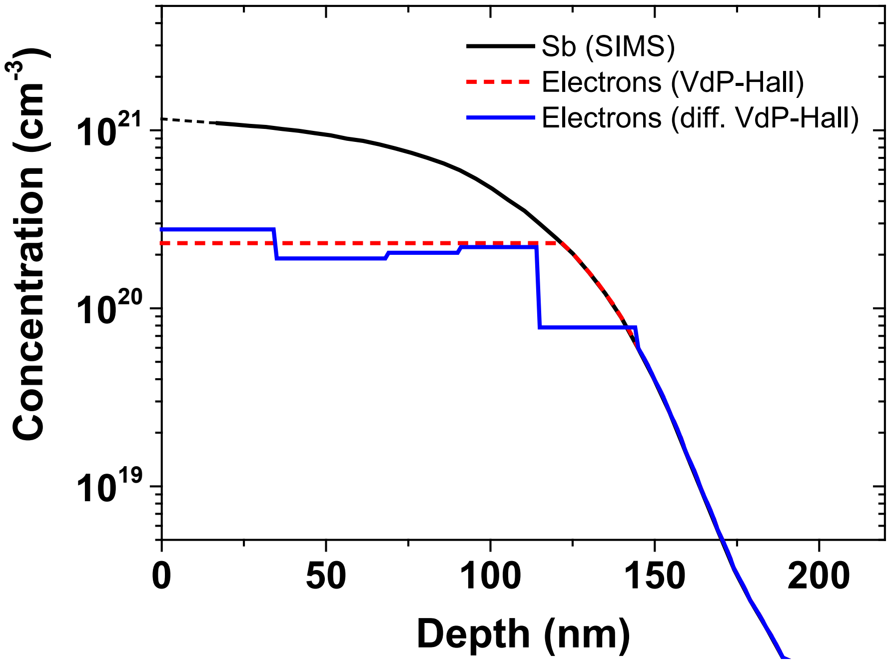


- Van der Pauw – Hall measurements
- Maximum active concentration extracted from measured RHs assuming SIMS profiles fully active below N_{max}
- Hall scattering factor r_H=1

$$RH_s = \frac{\int n(x)\mu^2(x)dx}{e \cdot \left(\int n(x)\mu(x)dx\right)^2}$$

(R. Baron, G. Shifrin, O. Marsh and J. W. Mayer, and J. Menéndez, J. Appl. Phys. ***40****, 3702 (1969))*

Dopant activation

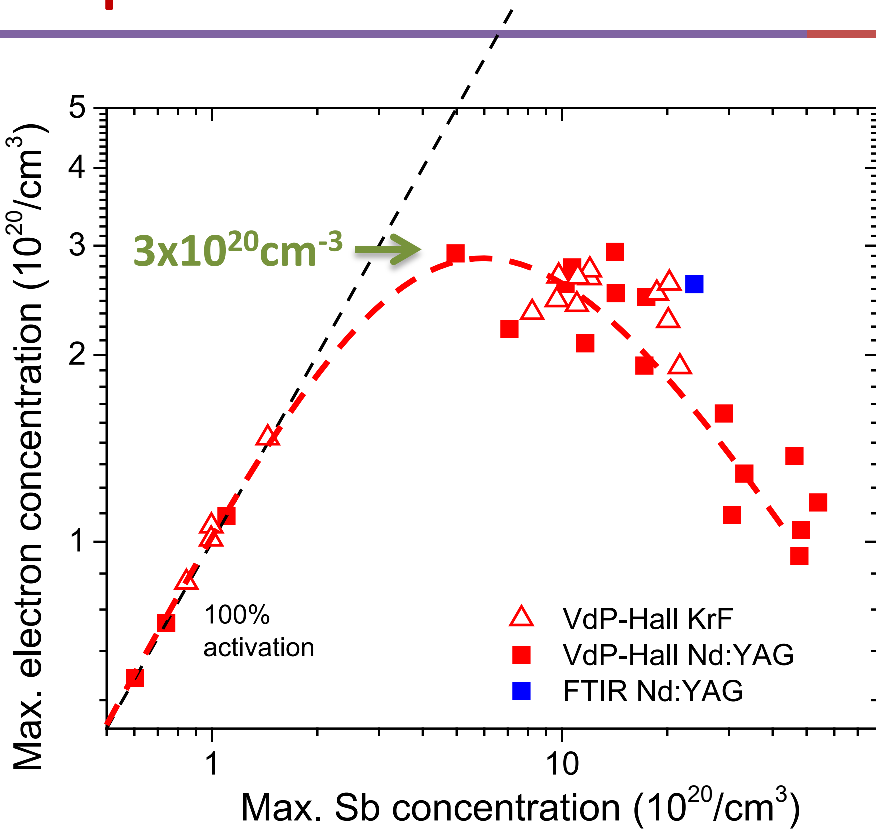


- Alternating VdP-Hall measurements with chemical etching → carrier depth profile
- Differential Van der Pauw – Hall measurements confirm active profile.

$$n(x) = \frac{(\Delta\sigma_S)^2}{q \cdot \Delta x \cdot \Delta(RH_S\sigma_S^2)}$$

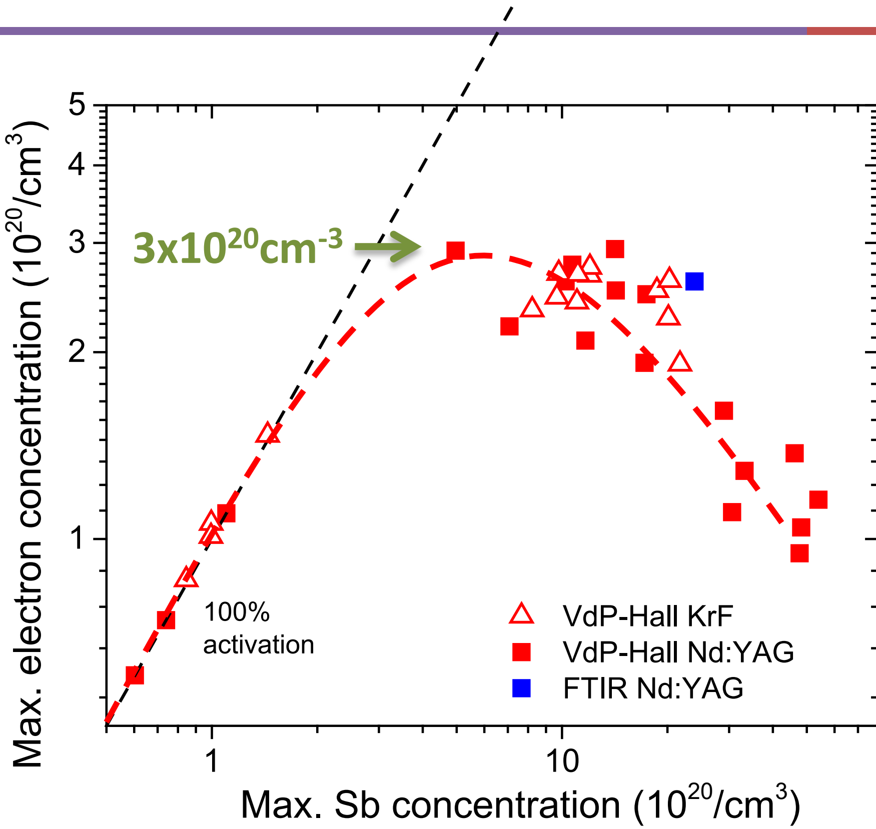
$$\mu_H(x) = \frac{\Delta(RH_S\sigma_S^2)}{\Delta\sigma_S}$$

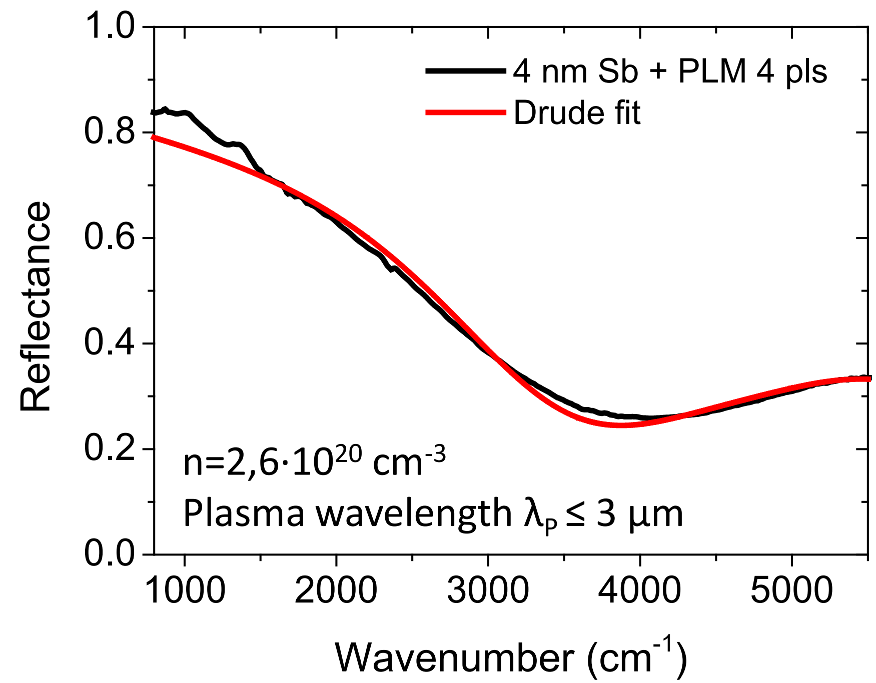
Dopant activation



- Active Sb saturates at $3x10^{20}cm^{-3}$

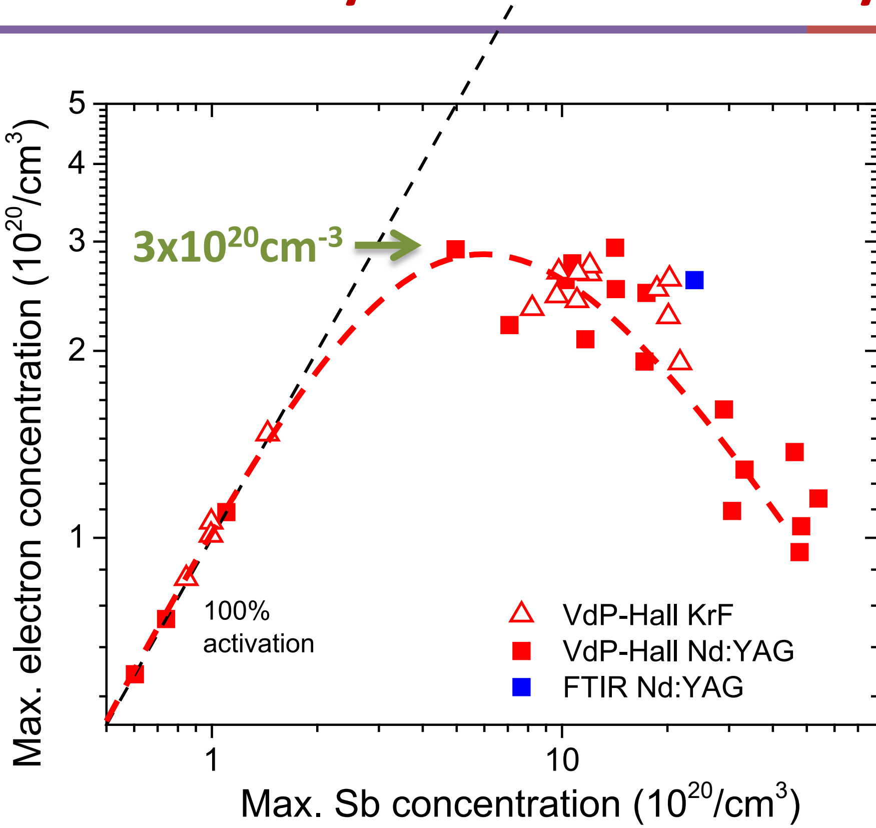
FTIR

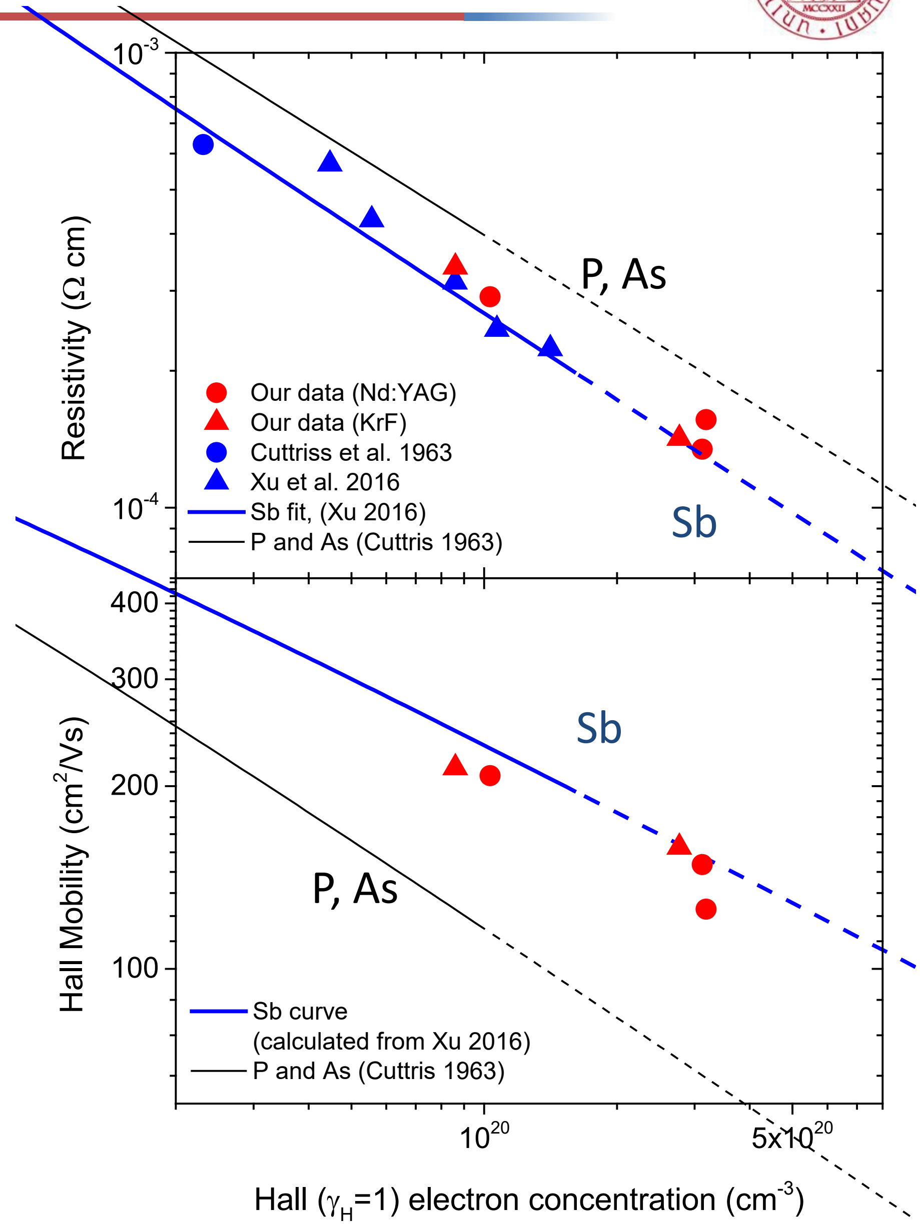




- Active Sb saturates at $3x10^{20}cm^{-3}$
- Plasma wavelength below 3 µm

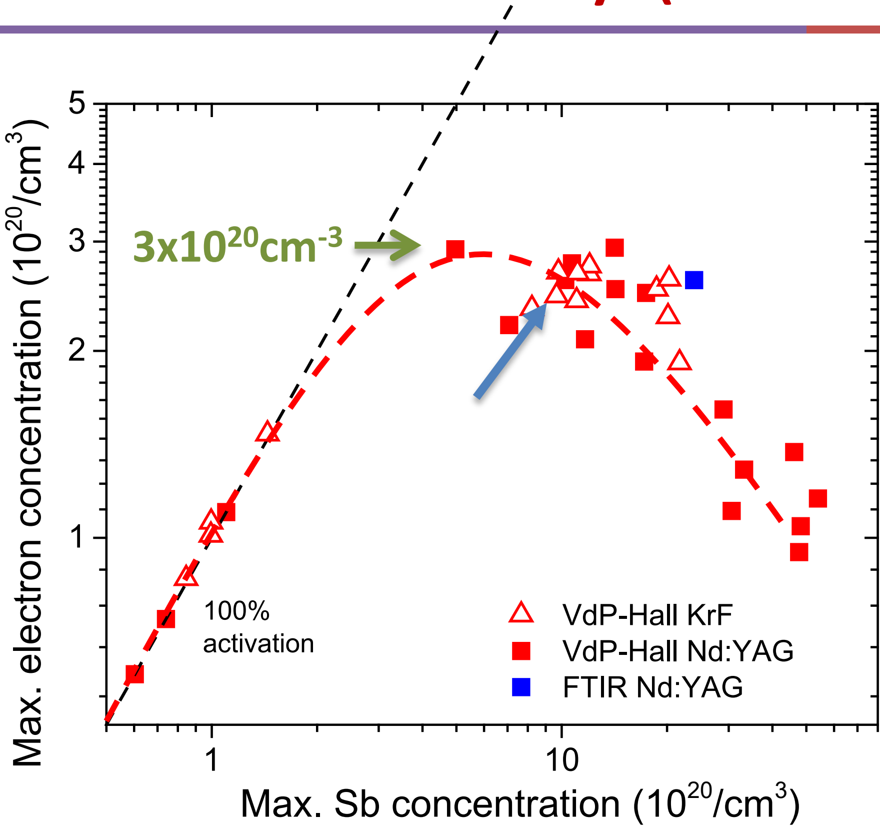
Resistivity and Mobility

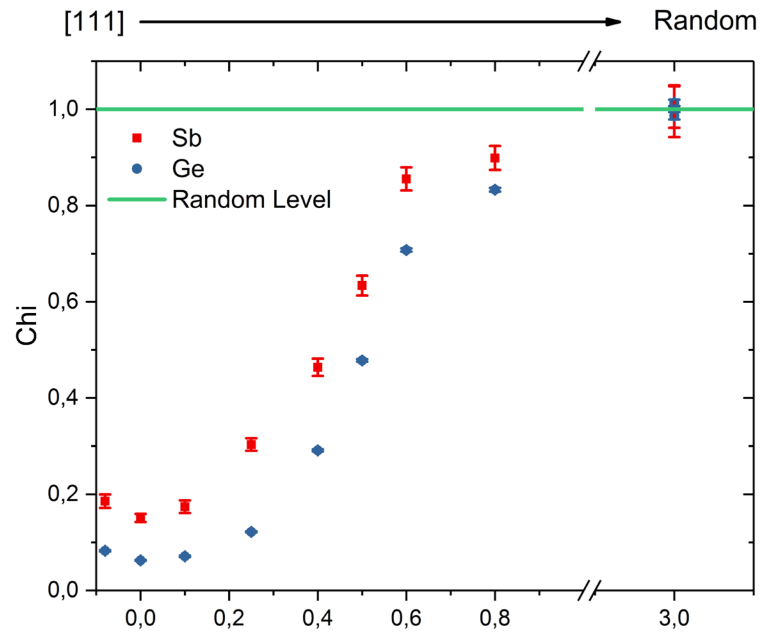


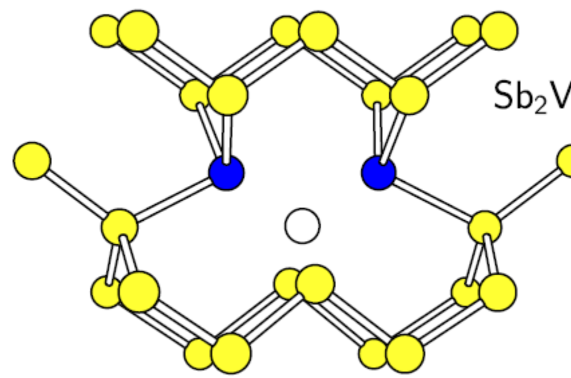


- Active Sb saturates at $3x10^{20}cm^{-3}$
- Plasma wavelength below 3 µm
- Ultralow resistivity
- High mobility

Substitutionality (c-RBS dip)



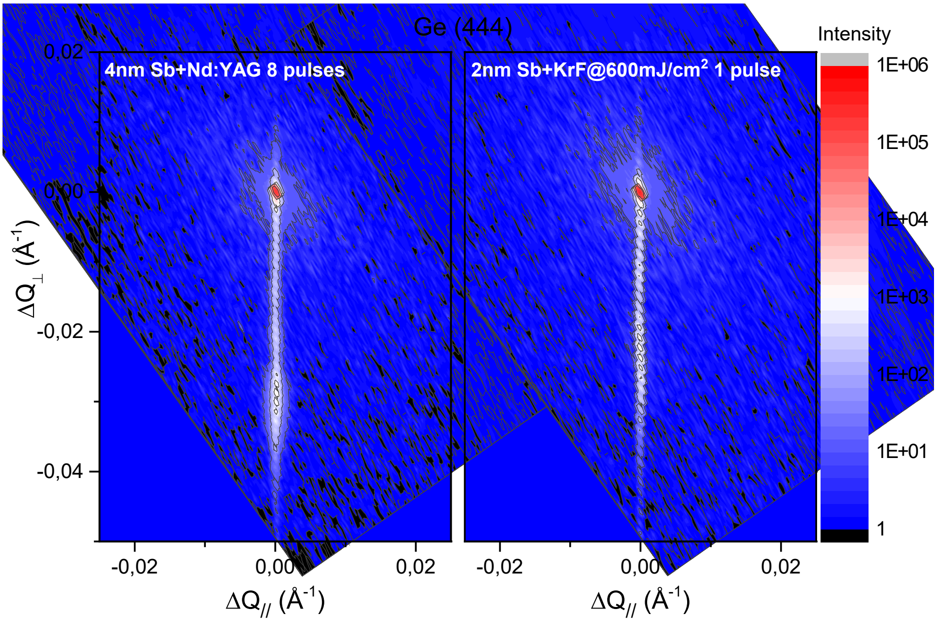




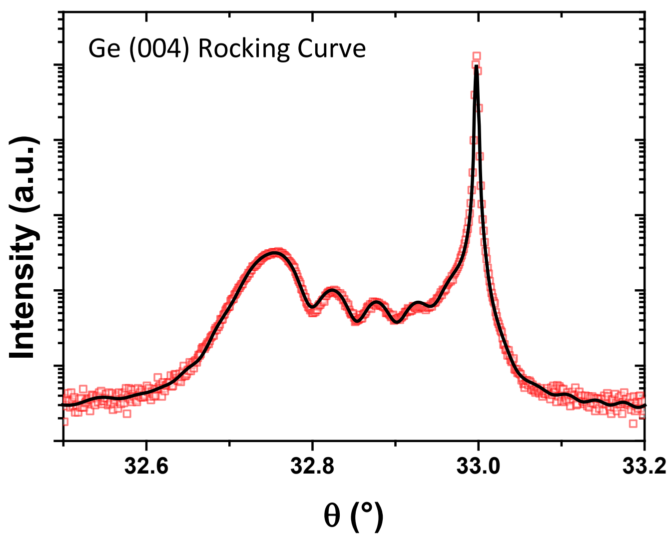
- C-RBS: Sb ~100 % nearly substitutional with small displacements
- After PLM inactive Sb is in the form of very small Sb_nV complexes.

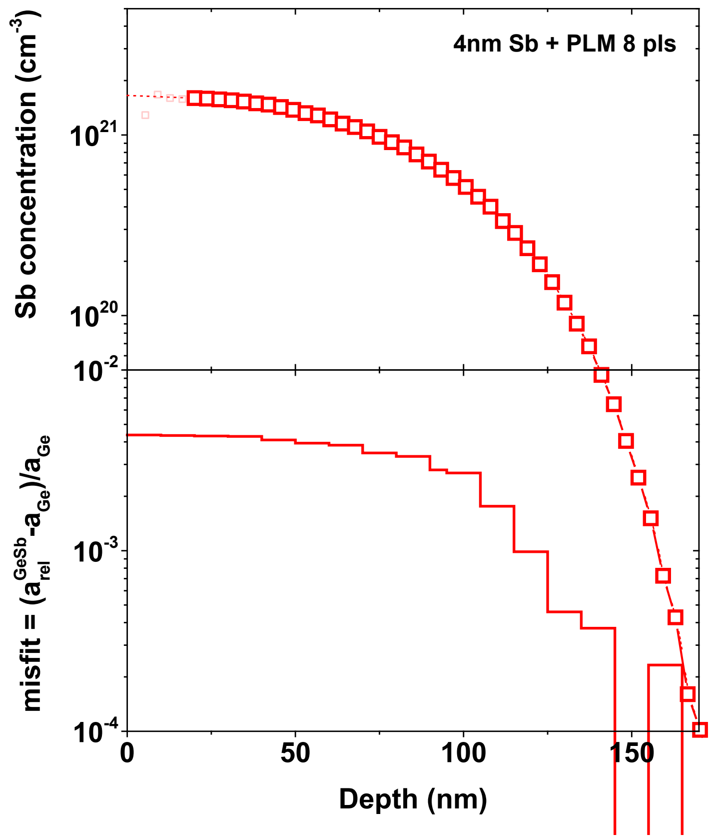
(José Coutinho, et al., J. Mater. Sci. Mater. Electron. 2007)
(A. Chroneos, J. Appl. Phys. 2010)

HRXRD strain depth profiling

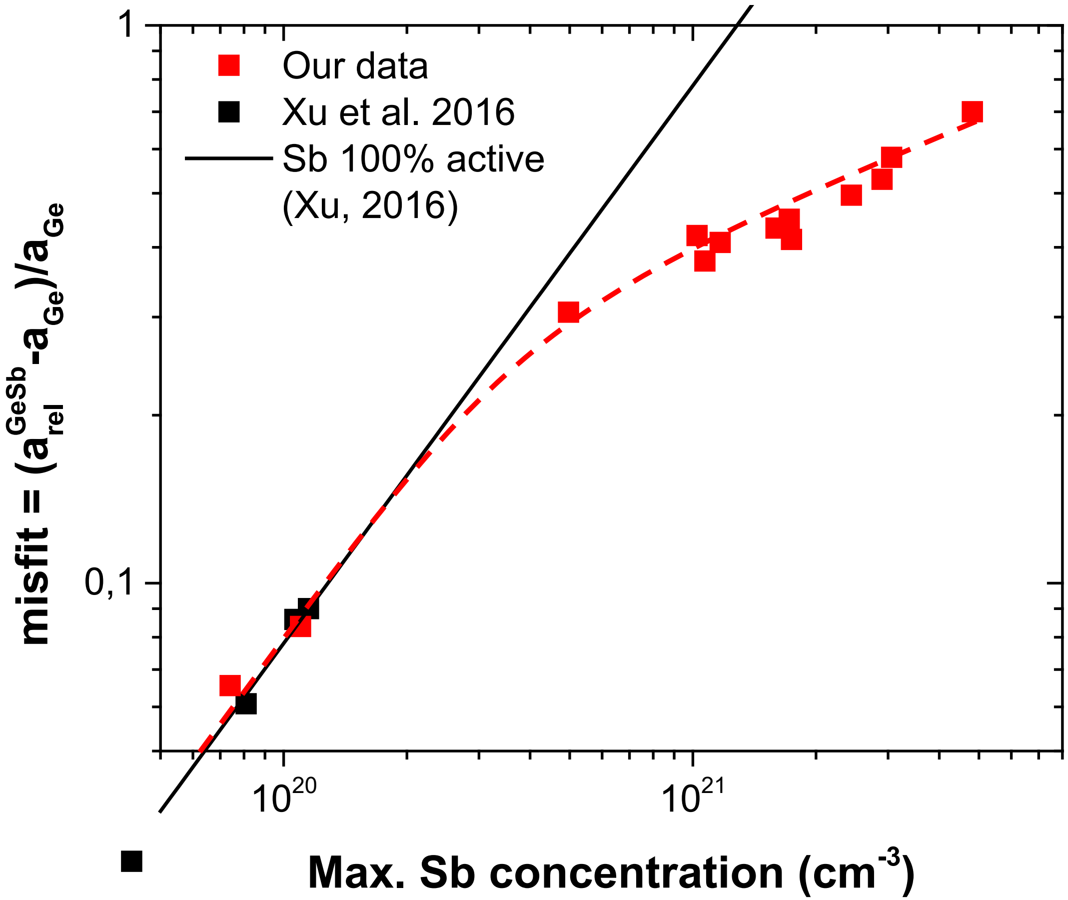


- Excellent cristallinity
- Pseudomorphicity of doped layer
- No sign of extended defects
- Strain depth profiles extracted





HRXRD strain depth profiling



- At low concentrations misfit aligns with literature data for 100% active Sb
- At high concentrations misfit continue to increase up to 0.7%

Conclusions

- The combination of Sb deposition and PLM provides an extremely efficient doping technique.
- Carrier concentration up to $3x10^{20}cm^{-3}$ with record low resistivity and excellent mobility
- No bulk contamination as consequence of PLM

IOP Publishing Journal of Physics D: Applied Physics
J. Phys. D: Appl. Phys. **52** (2019) 035104 (11pp) https://doi.org/10.1088/1361-6463/aae9c0

Characterization and modeling of thermally-induced doping contaminants in high-purity germanium

V Boldrini[1,2,4], G Maggioni[1,2], S Carturan[1,2]
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Eur. Phys. J. A (2018) **54**: 34
DOI 10.1140/epja/i2018-12471-0
THE EUROPEAN PHYSICAL JOURNAL A

Special Article – New Tools and Techniques

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Conclusions

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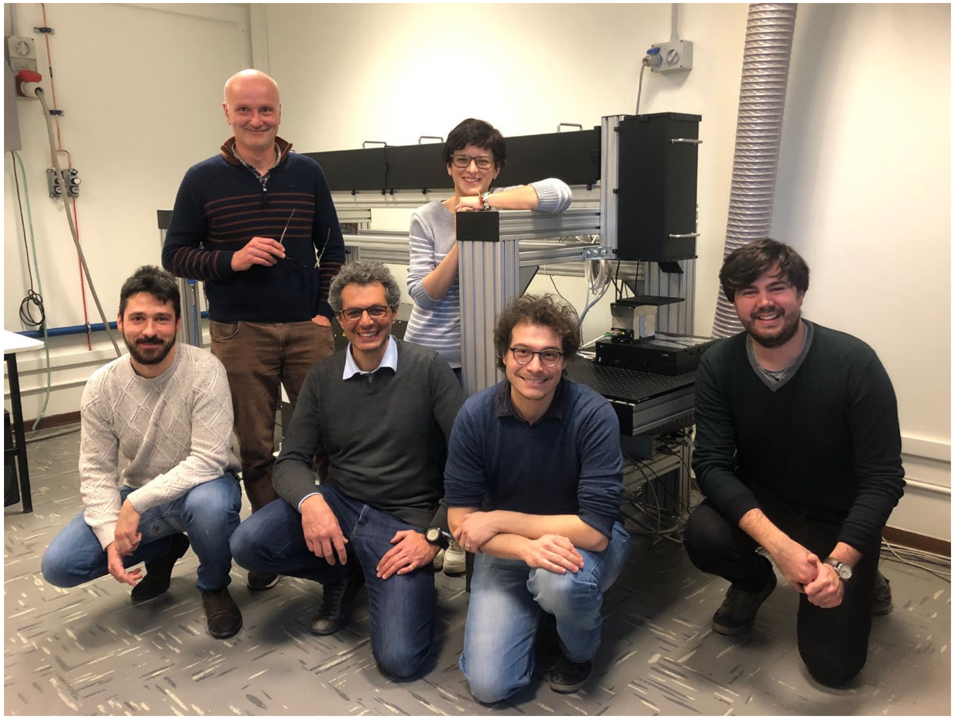
- Carrier concentration up to $3x10^{20}cm^{-3}$ with record low resistivity and excellent mobility
- No bulk contamination as consequence of PLM
- Pseudomorphic layers Ge:Sb layers with no extended defects
- FTIR reports plasma wavelengths below 3 µm in the MIR range useful for gas sensing applications
- Inactive Sb is nearly substitutional with small displacement, compatible with very small Sb_nV clusters.



Thanks for your attention!

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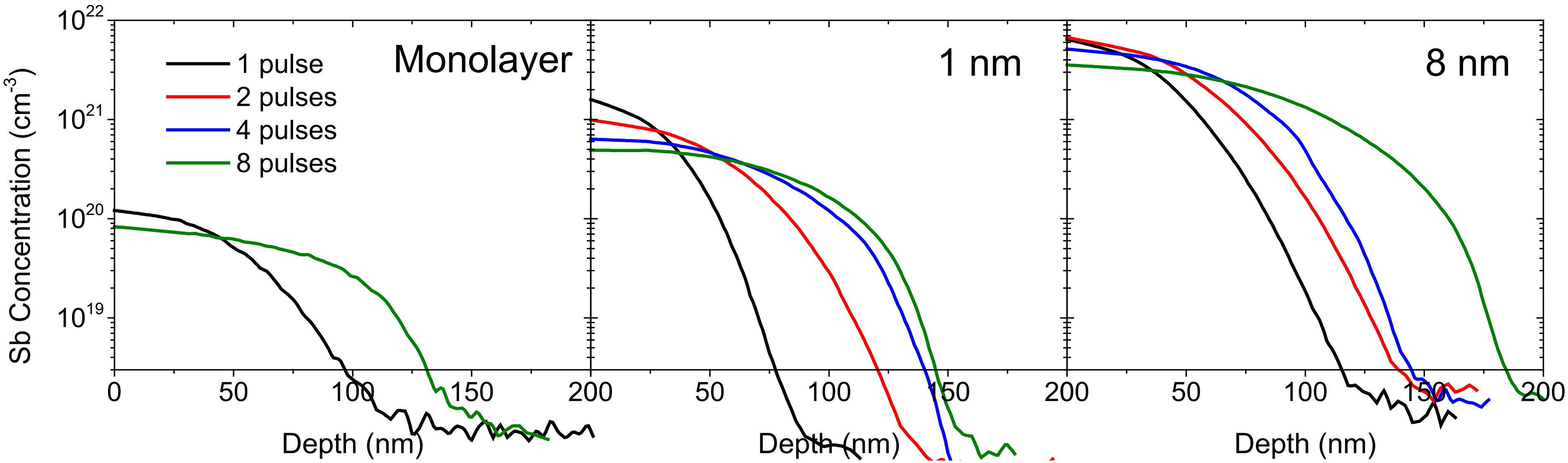
Chemical profile evolution



- Sb incorporation at >10% concentration
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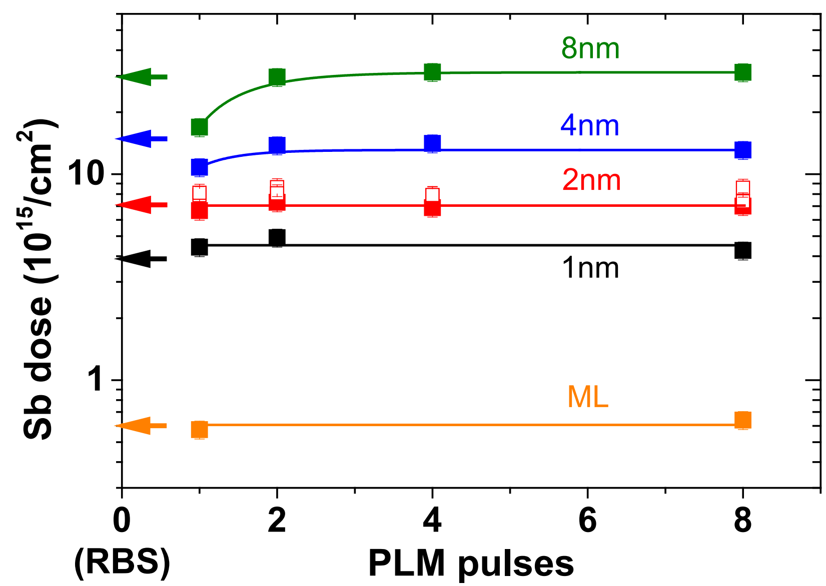
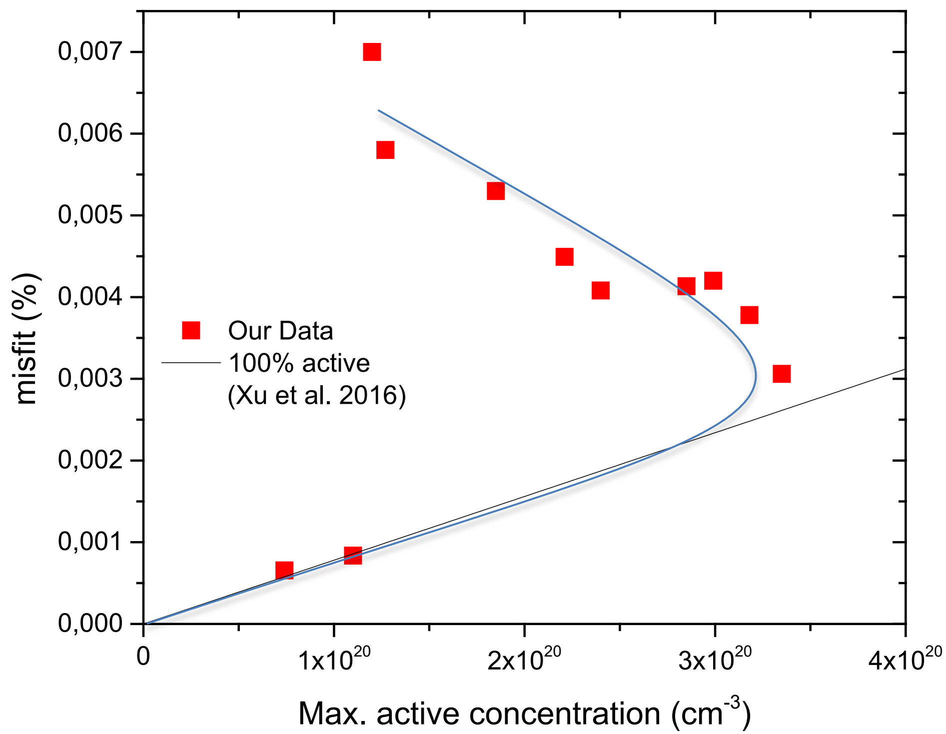
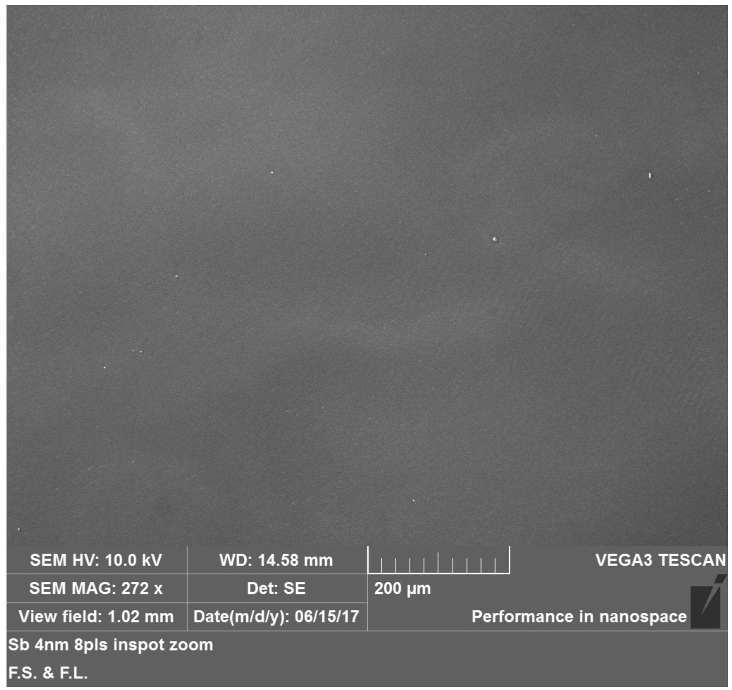
- No Sb loss




0,007
0,006
0,005
0,004
0,003
0,002
0,001
0,000
misfit (%)
Our Data
100% active
(Xu et al. 2016)
0
1x10^20
2x10^20
3x10^20
4x10^20
Max. active concentration (cm^-3)


SEM HV: 10.0 kV
WD: 14.58 mm
VEGA3 TESCAN
SEM MAG: 272 x
Det: SE
200 μm
View field: 1.02 mm
Date(m/d/y): 06/15/17
Performance in nanospace
Sb 4nm 8pls inspot zoom
F.S. & F.L.

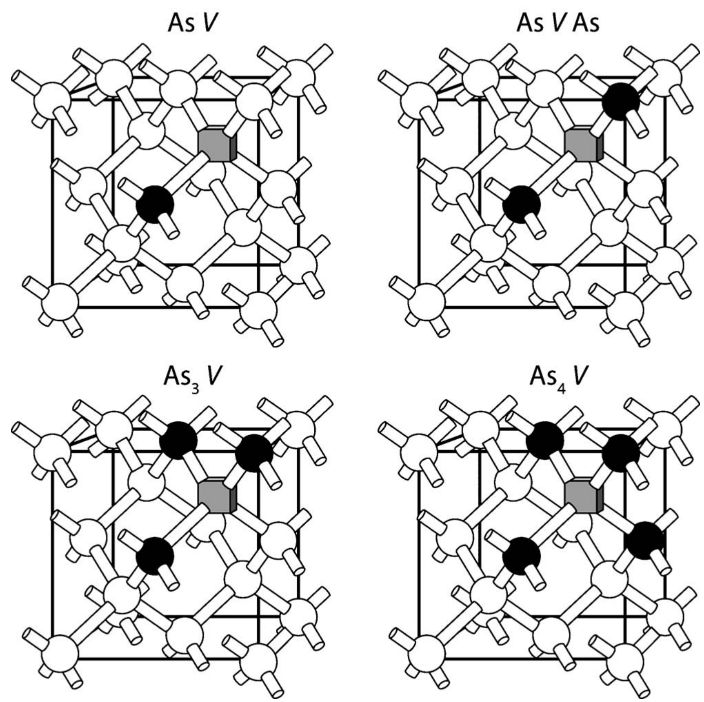
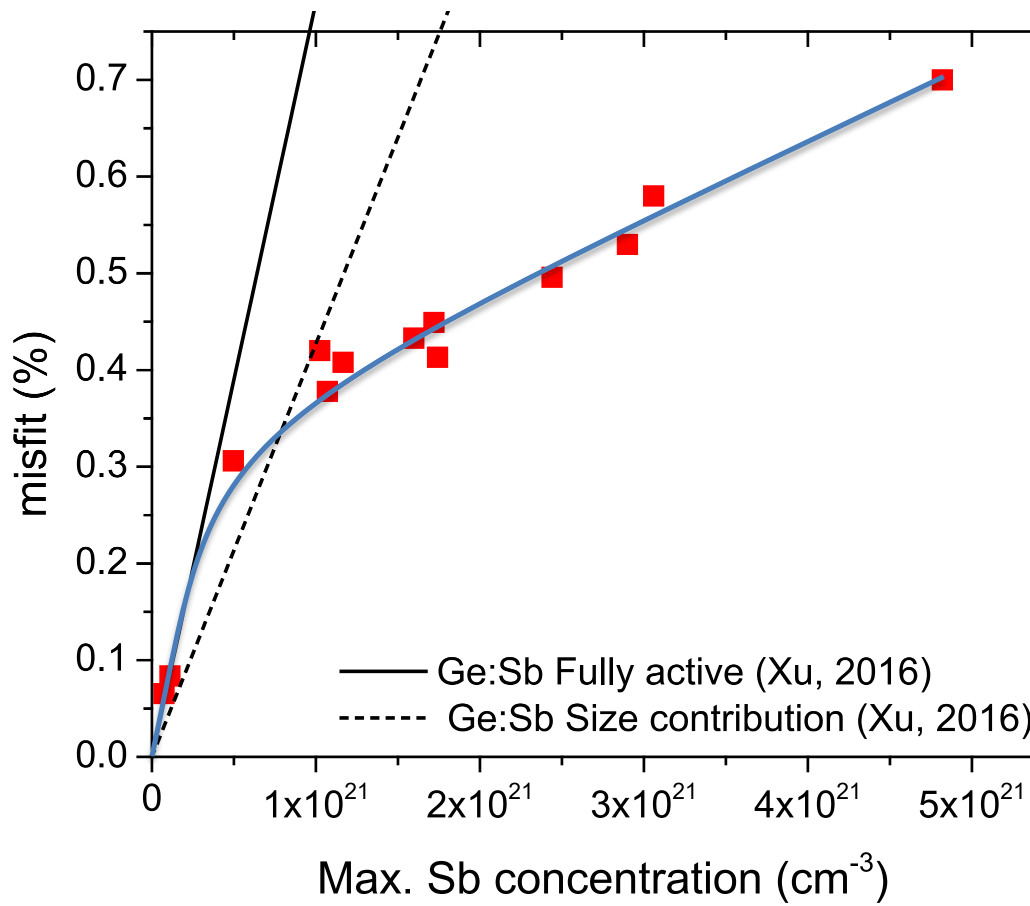


FIG. 1. As_nV configurations in a unit cell of the Ge. White circles represent the Ge atoms, black circles the As atoms, and squares V.

A. Chroneos, R. W. Grimes, B. P. Uberuaga, S. Brotzmann, and H. Bracht, Appl. Phys. Lett. ***91****, 192106 (2007).*

HRXRD



misfit (%)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
1x10^21
2x10^21
3x10^21
4x10^21
5x10^21
Max. Sb concentration (cm^-3)
Ge:Sb Fully active (Xu, 2016)
Ge:Sb Size contribution (Xu, 2016)