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Interaction of Ammonium Sulfide with the Semiconductor Surfaces of AlSb and Related Alloys

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Outline

- Application
- Previous passivation studies
- Experiment
- Results
  - Surface Morphology by SEM
  - Energy Dispersive X-Ray Spectroscopy
  - Electrical characteristics
- Summary

Application: Gamma radiation detection

Advantages

- wide energy bandgap
- high carrier mobilities
- high atomic number

} High resolution, room temperature gamma detection

Problems

- rapid oxidation of aluminum
- high volatility of antimony
- reaction of molten AlSb with most crucible materials

} Growth of bulk AlSb in single crystal form is difficult

Studies of epitaxial Al(As)Sb for radiation detection

High-Resistivity Semi-insulating AlSb on GaAs Substrates Grown by Molecular Beam Epitaxy

E.I. VAUGHAN,[1,3] S. ADDAMANE,[2] D.M. SHIMA,[2] G. BALAKRISHNAN,[2] and A.A. HECHT[1]

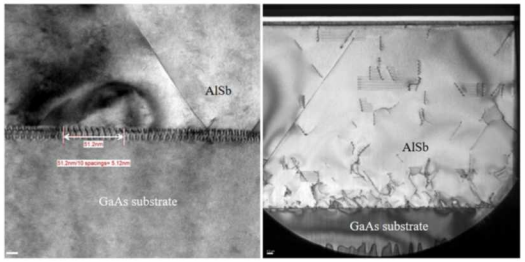
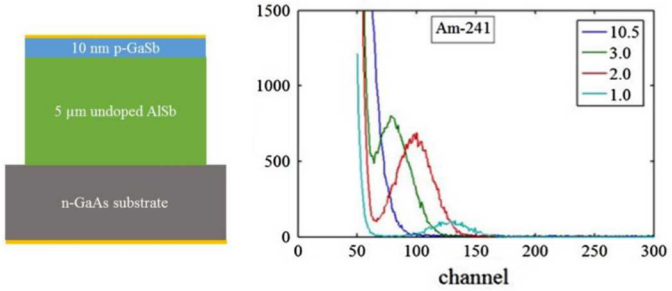


Fig. 1. TEM images of AlSb on GaAs, with higher resolution on left to show lattice dislocation spacing.

E. I. Vaughan, et. al, *J. Electron Mater* **45**, 2025 (2016).



E. I. Vaugha. "Thin film AlSb carrier transport properties and room temperature radiation response." UNM (2016).

Energy-Sensitive GaSb/AlAsSb Separate Absorption and Multiplication Avalanche Photodiodes for X-Ray and Gamma-Ray Detection

Bor-Chau Juang, Andrew Chen, Dingkun Ren, Baolai Liang, David L. Prout, Arion F. Chatziioannou, and Diana L. Huffaker*

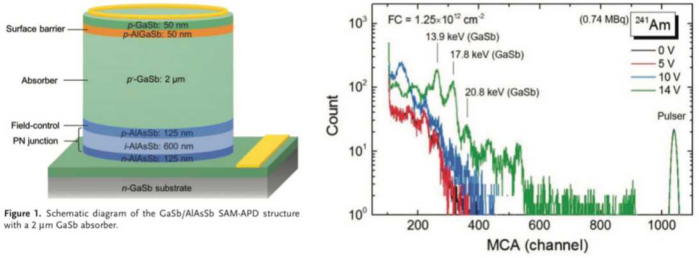


Figure 1. Schematic diagram of the GaSb/AlAsSb SAM-APD structure with a 2 µm GaSb absorber.

B. Juang, et. al, *Adv. Opt. Mater.* 190010 (2019).

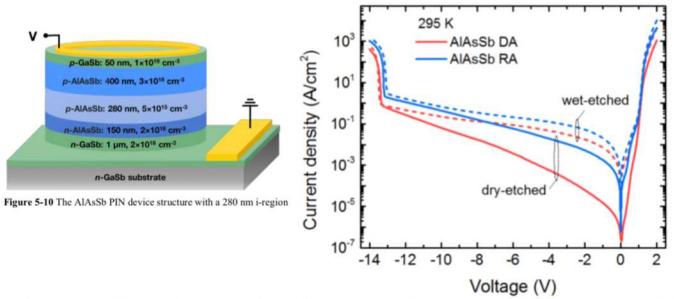
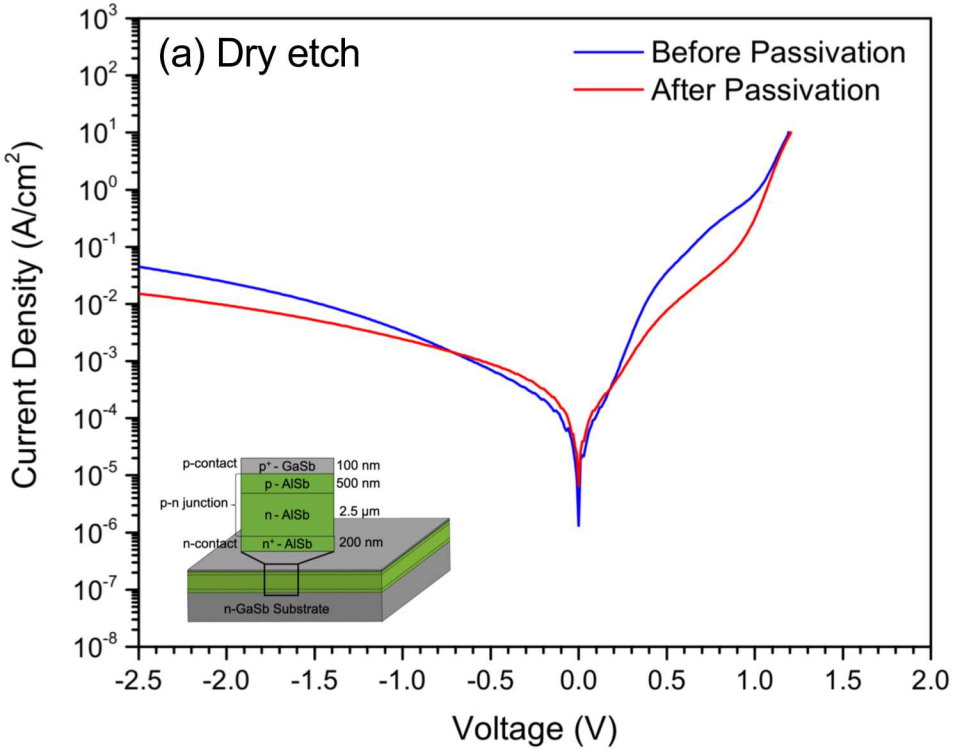
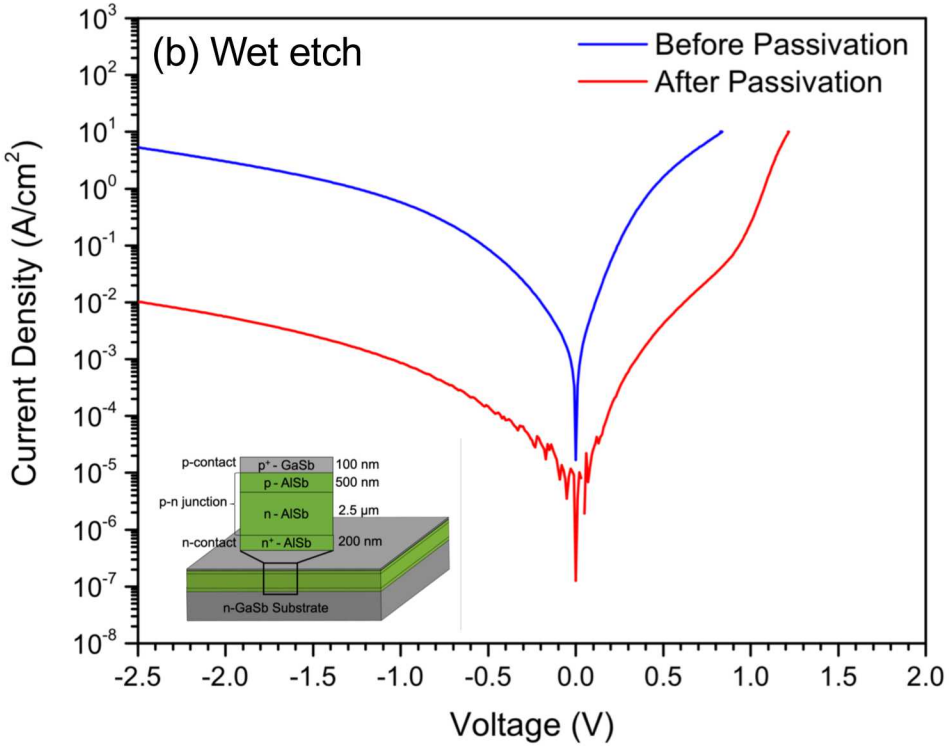


Figure 5-10 The AlAsSb PIN device structure with a 280 nm i-region

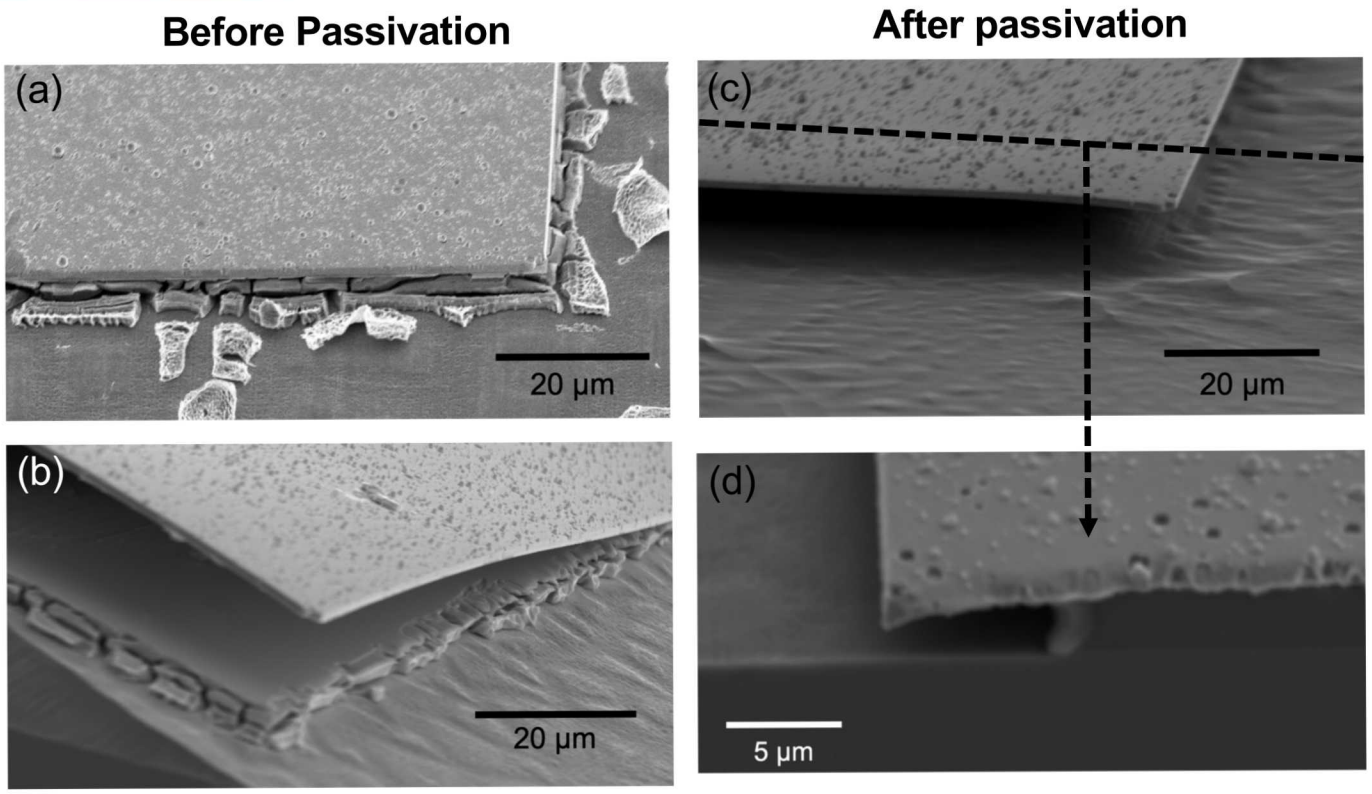
B. Juang. "Development of Antimonide-based Energy-sensitive Radiation Detectors." PhD diss., UCLA, (2018).

p-n AlSb diode passivated with full strength ammonium sulfide





Surface morphology of devices isolated by wet etch



Samples were passivation with 40-44% aqueous ammonium sulfide solution for 5 min at a temperature of 60 °C

GaSb/AlGaAsSb/AlAsSb p-i-n diode with mesas defined by dry etch and passivated with full strength ammonium sulfide

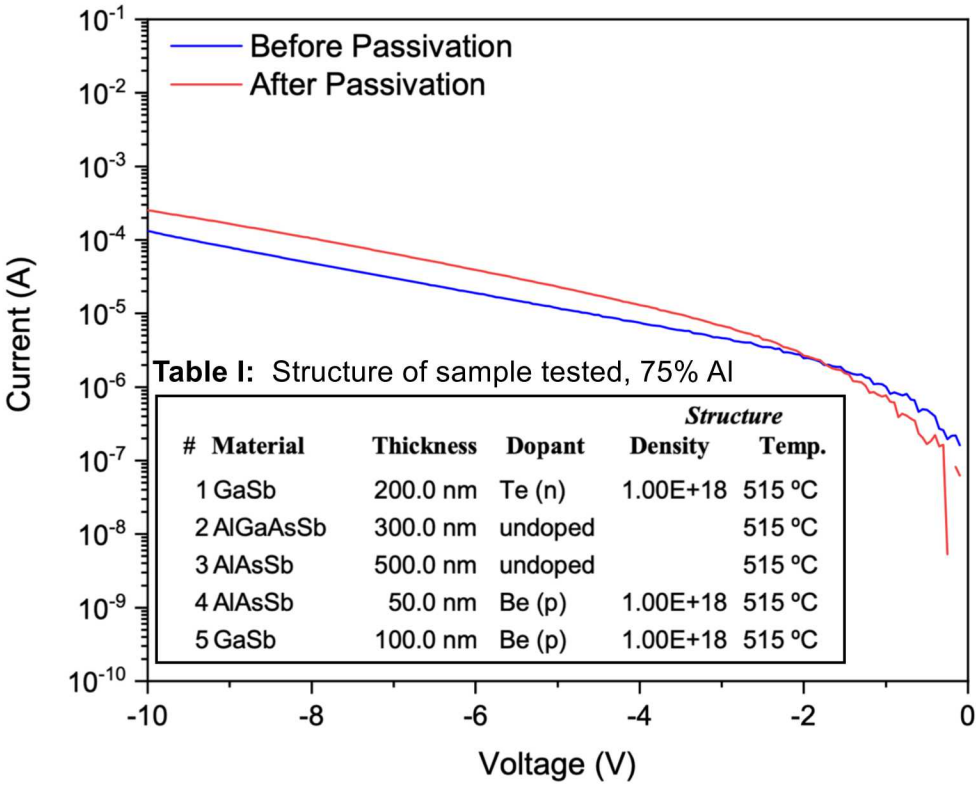
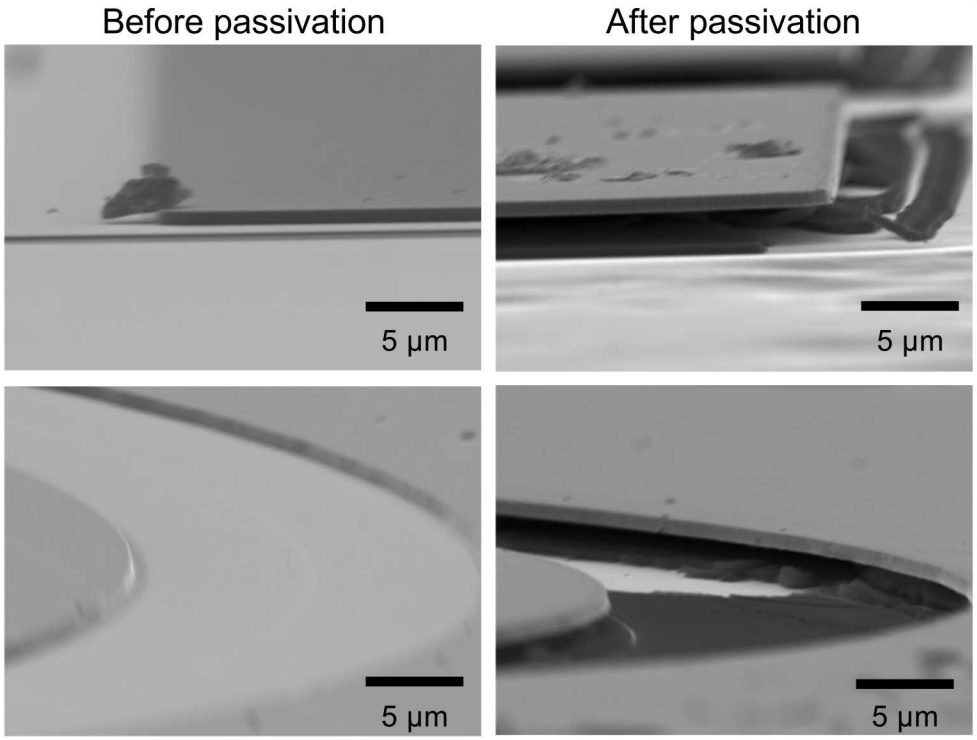


Table I: Structure of sample tested, 75% Al

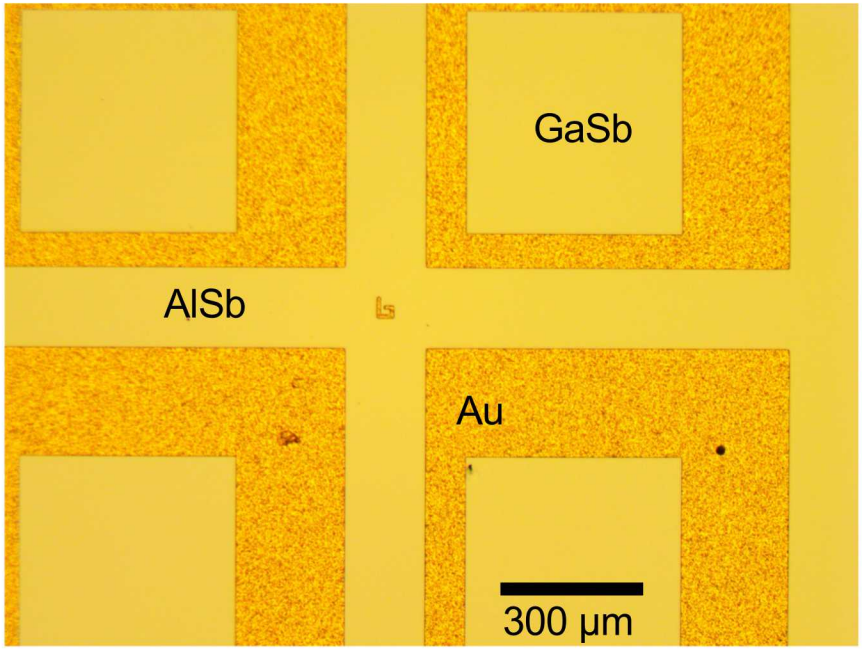
#	Material	Thickness	Dopant	Structure Density	Temp.
1	GaSb	200.0 nm	Te (n)	1.00E+18	515 ºC
2	AlGaAsSb	300.0 nm	undoped		515 ºC
3	AlAsSb	500.0 nm	undoped		515 ºC
4	AlAsSb	50.0 nm	Be (p)	1.00E+18	515 ºC
5	GaSb	100.0 nm	Be (p)	1.00E+18	515 ºC



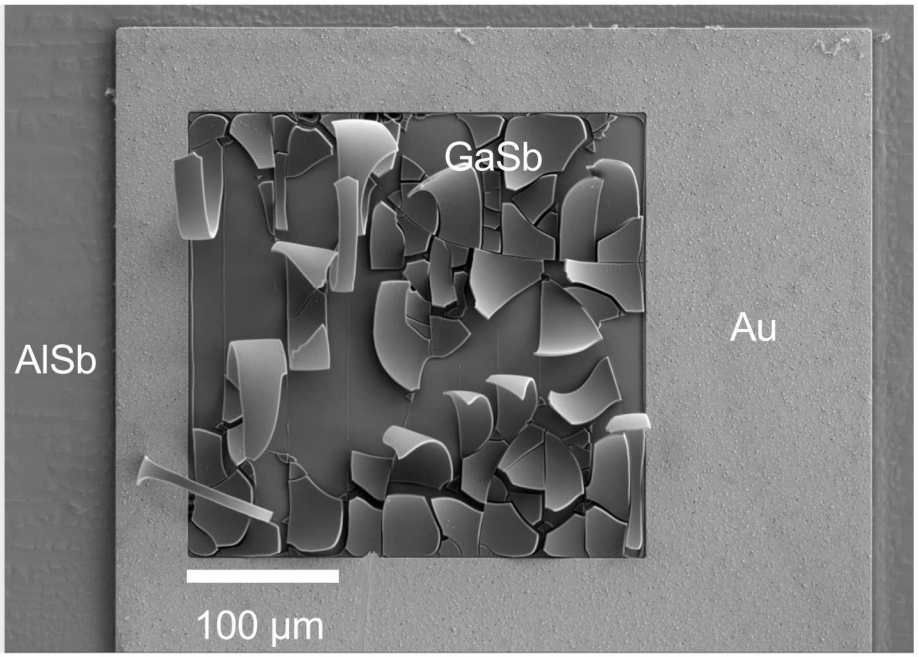
Samples were passivation with 40-44% aqueous ammonium sulfide solution for 5 min at a temperature of 60 °C

Effect of full strength ammonium sulfide on GaSb surfaces

Before passivation



After passivation



Passivation Study with Diluted Ammonium Sulfide at Room Temperature

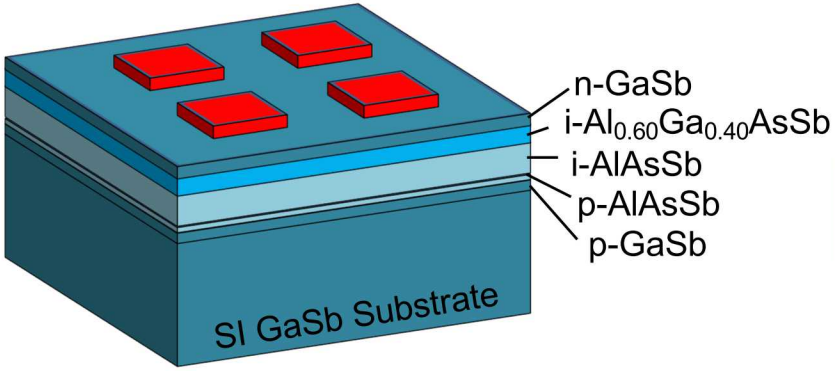
Structure studied

EB6830

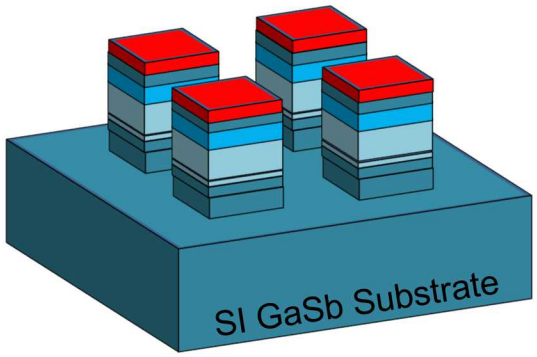
#	Material	Thickness	Dopant	Structure Density	Temp.	SL	Comment
1	GaSb	200.0 nm	Te (n)	1.00E+18	515 ºC		
2	AlGaAsSb	300.0 nm	undoped		515 ºC		nominally 60% Al
3	AlAsSb	500.0 nm	undoped		515 ºC		
4	AlAsSb	50.0 nm	Be (p)	1.00E+18	515 ºC		
5	GaSb	100.0 nm	Be (p)	1.00E+18	515 ºC		

Experiment

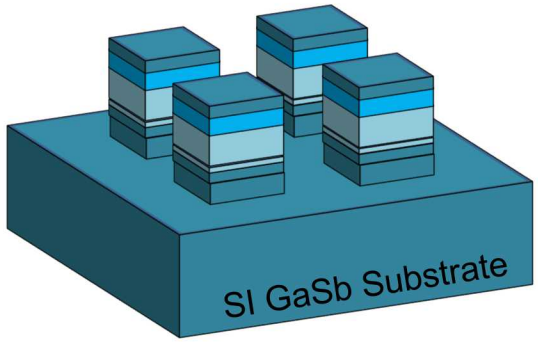
1.- Patterned samples with squares of 50 µm x 50 µm



2.- ICP etch with BCl_3 gas to a depth of ~ 3 µm



3.- Passivation with diluted ammonium sulfide solution for 5 min at room temperature

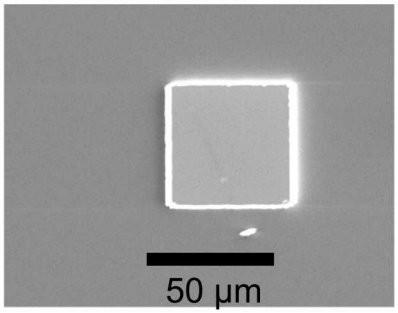


ammonium sulfide with isopropanol
$(NH_4)_2S:C_3H_8O$
ammonium sulfide with water
$(NH_4)_2S:H_2O$

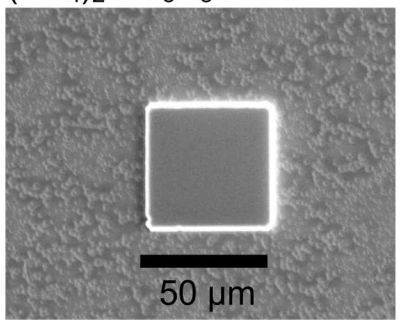
Concentrations:
1:5, 1:10, 1:20

Surface morphology of passivated samples

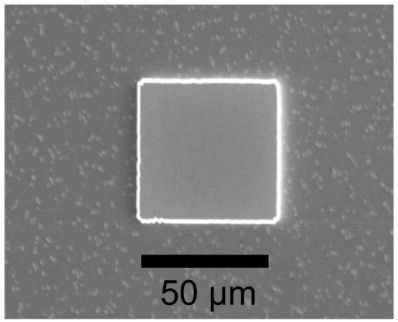
Un - passivated



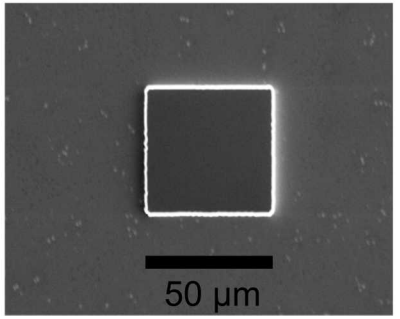
$(NH_4)_2S:C_3H_8O$ 1:5



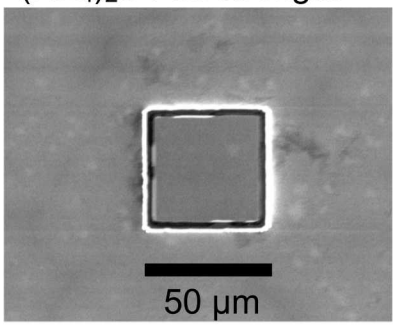
$(NH_4)_2S:C_3H_8O$ 1:10



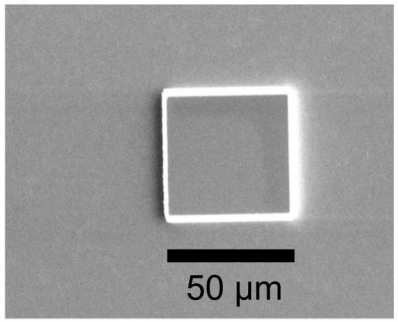
$(NH_4)_2S:C_3H_8O$ 1:20



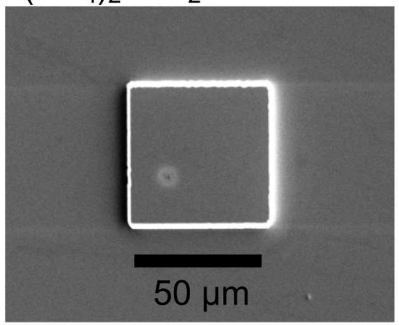
$(NH_4)_2S$ Full strenght



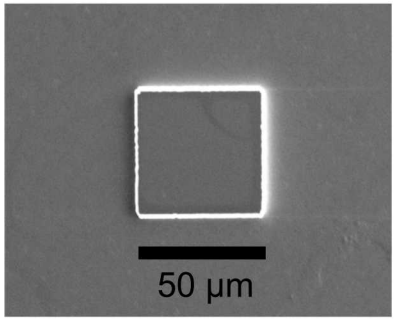
$(NH_4)_2S:H_2O$ 1:5



$(NH_4)_2S: H_2O$ 1:10



$(NH_4)_2S: H_2O$ 1:20



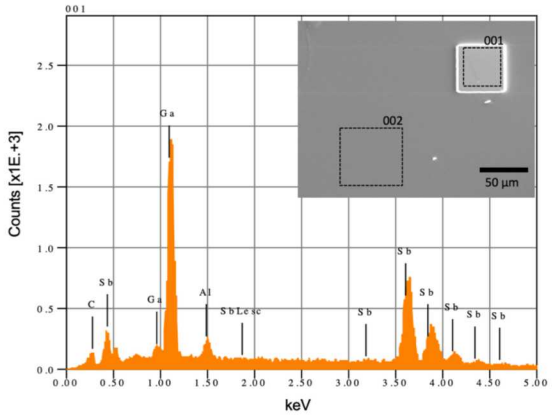
Energy Dispersive x-Ray Spectroscopy (EDS) Analysis

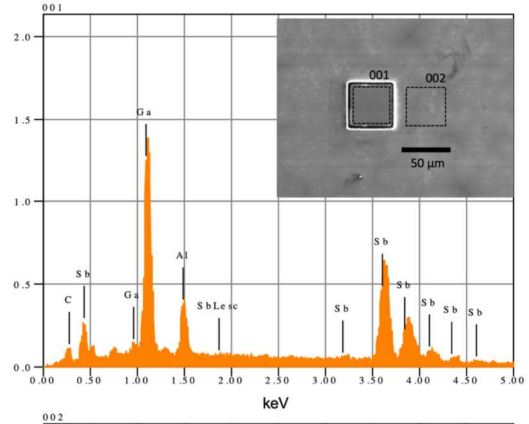
Un - passivated

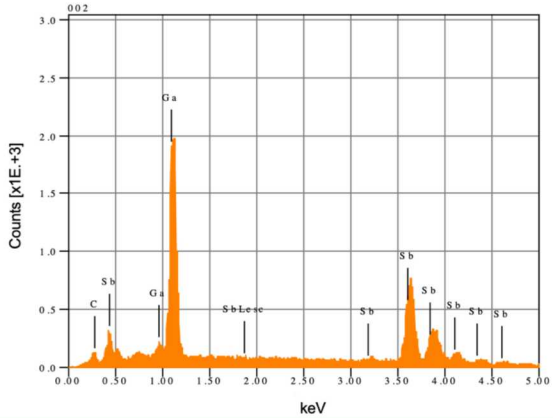
$(NH_4)_2S$ (full strength)- passivated

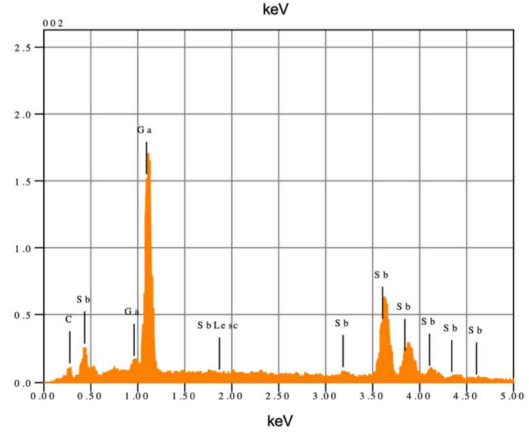
Top of Mesa

Bottom of Mesa

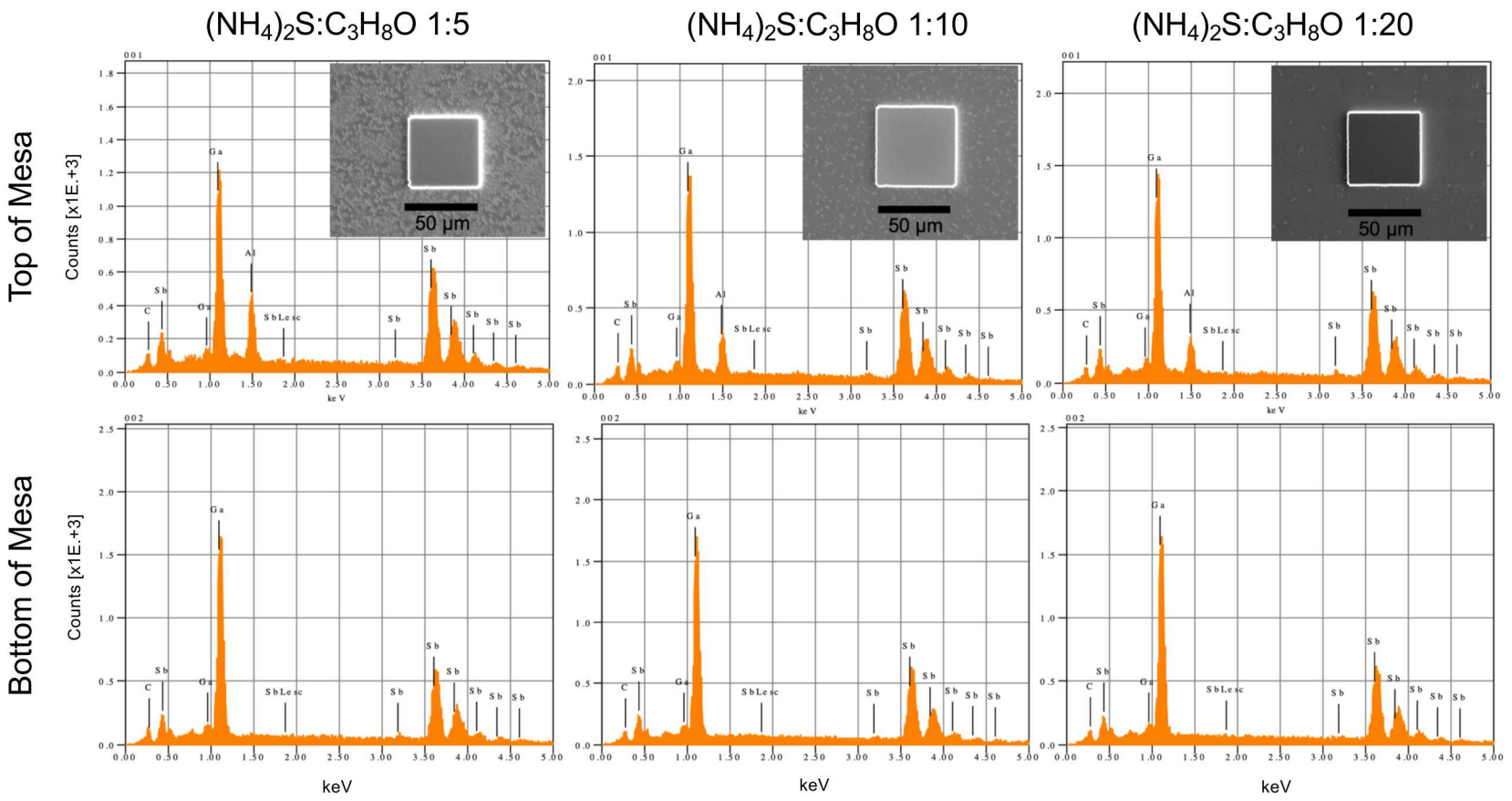








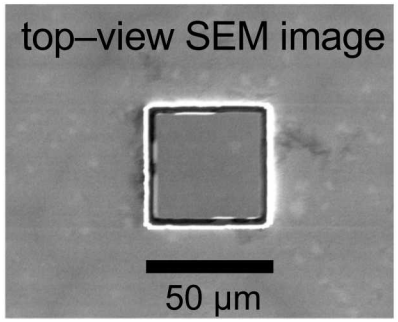
EDS of samples passivated with alcohol diluted ammonium sulfide

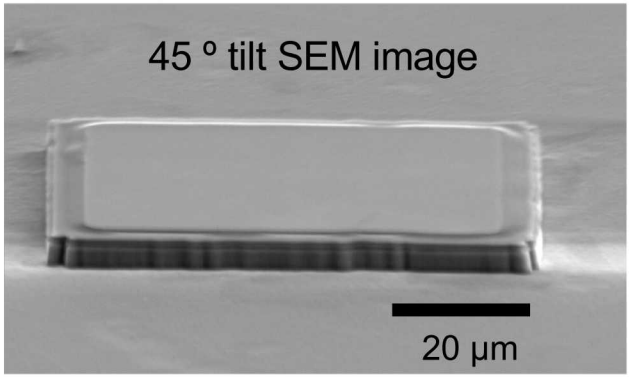


Center for High Technology Materials

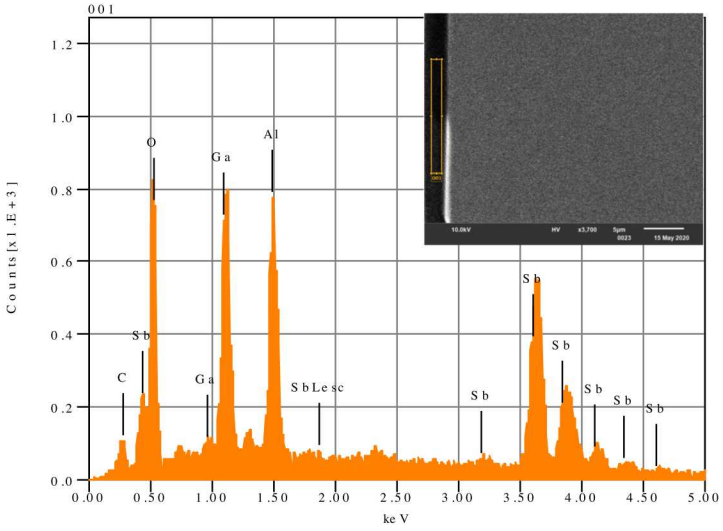
Effect of room temperature full strength $(NH_4)_2S$ passivation on GaSb

$(NH_4)_2S$ (full strength)- passivated





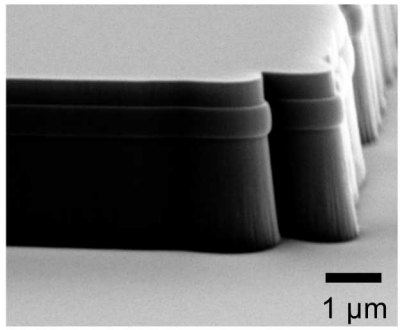
EDS from the edge of the mesa



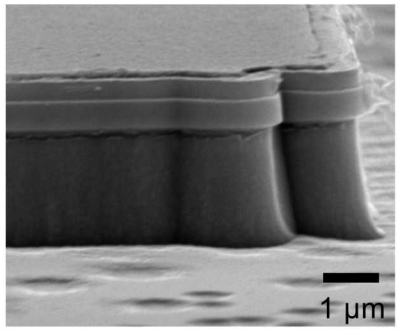
The EDS, besides the typical Al, Ga, and Sb peaks, shows an Oxygen peak which means oxidation. Oxidation is the beginning of etch process.

Morphology of sample's sidewalls

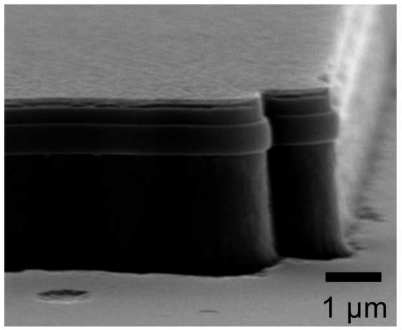
Un-passivated



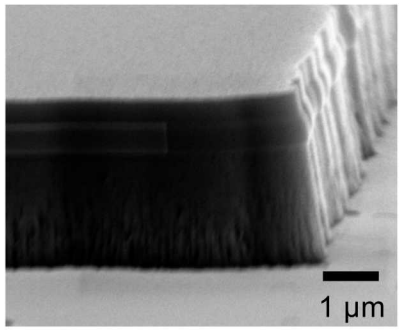
$(NH_4)_2S:C_3H_8O$ 1:5



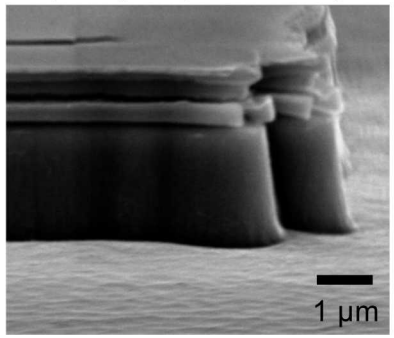
$(NH_4)_2S:C_3H_8O$ 1:10



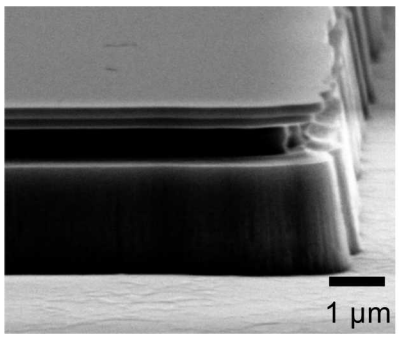
$(NH_4)_2S:C_3H_8O$ 1:20



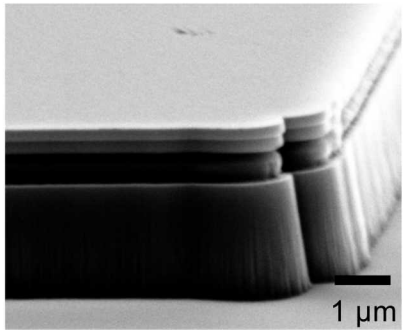
$(NH_4)_2S$ (Undiluted)



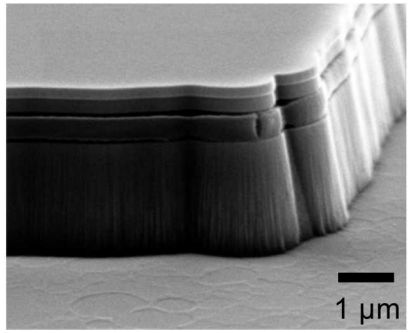
$(NH_4)_2S:H_2O$ 1:5



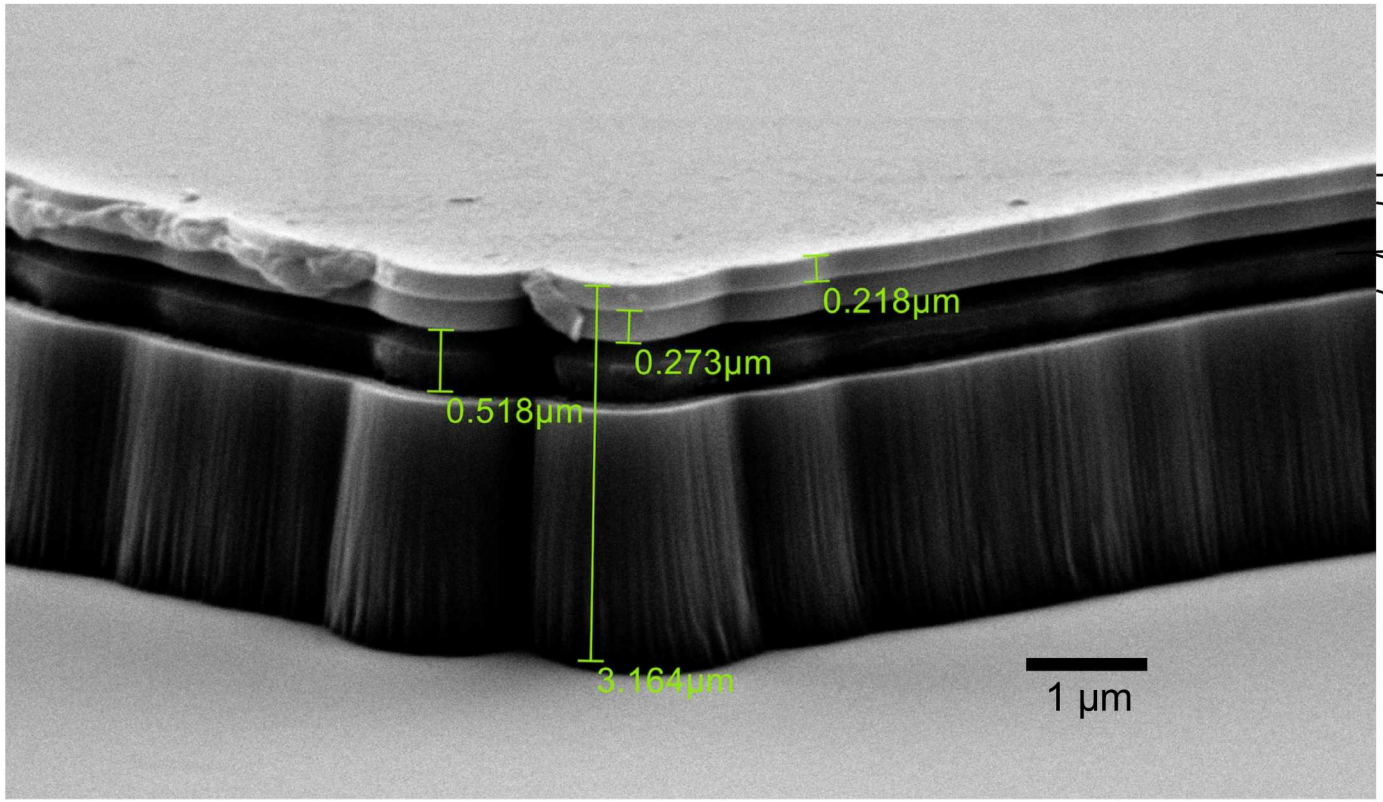
$(NH_4)_2S: H_2O$ 1:10



$(NH_4)_2S: H_2O$ 1:20



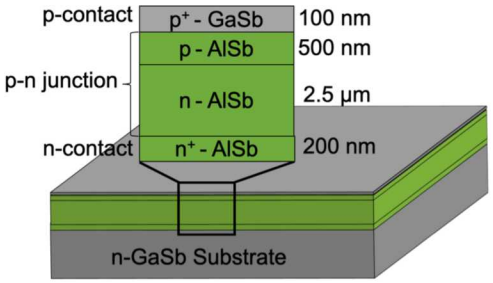
$(NH_4)_2S$: H_2O 1:10



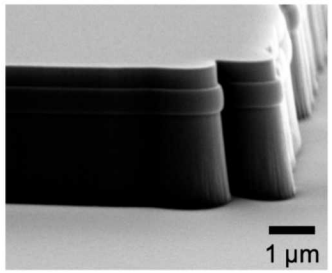
#	Material	Thickness	Dopant
1	GaSb	200.0 nm	Te (n)
2	AlGaAsSb	300.0 nm	undoped
3	AlAsSb	500.0 nm	undoped
4	AlAsSb	50.0 nm	Be (p)
5	GaSb	100.0 nm	Be (p)

Best passivation for an AlSb diode

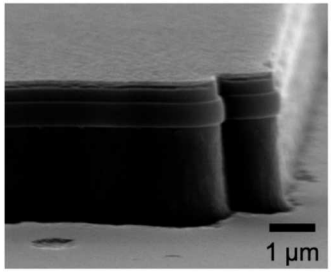
AlSb diode structure



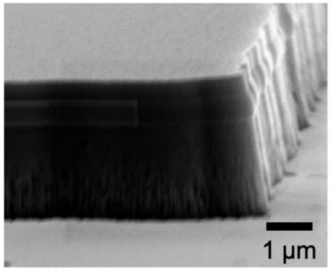
Un-passivated

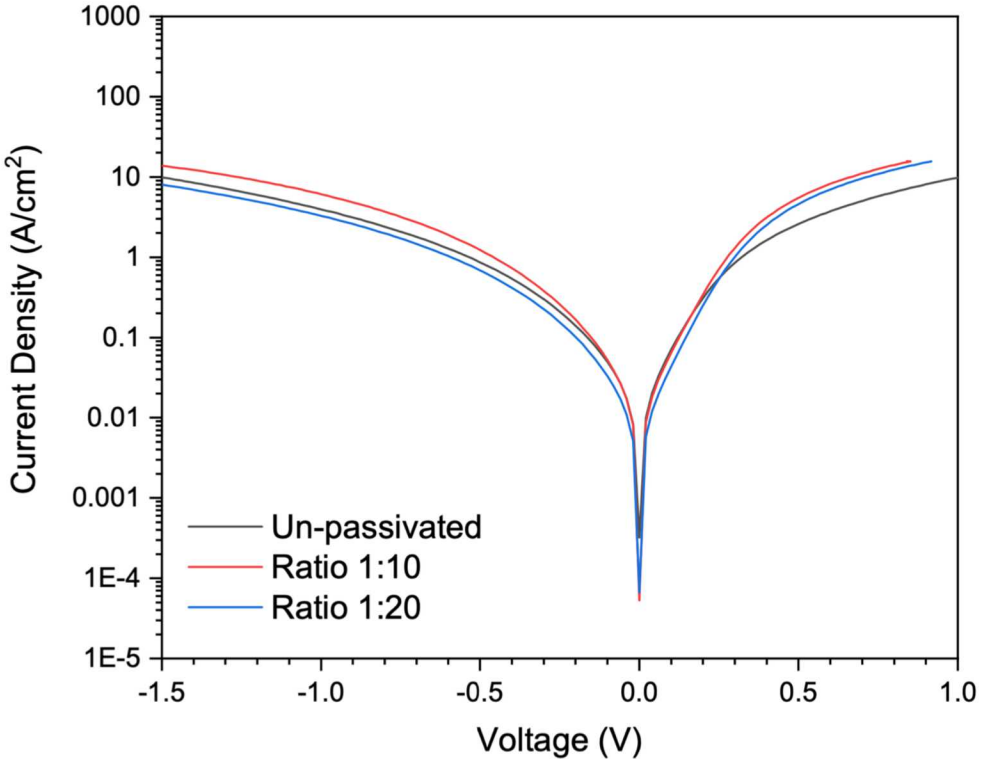


$(NH_4)_2S:C_3H_8O$ 1:10



$(NH_4)_2S:C_3H_8O$ 1:20

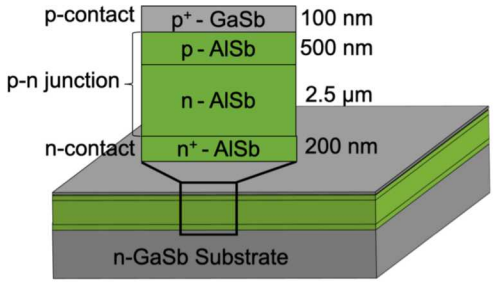


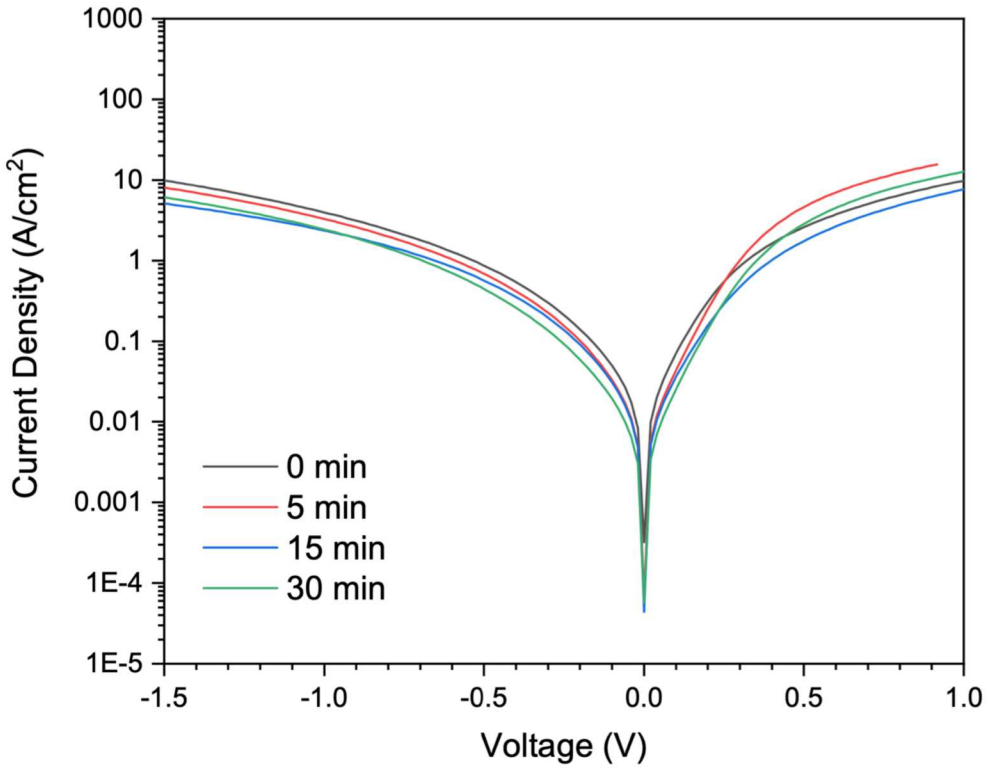


Current-Voltage characteristics of AlSb diodes passivated at different ammonium sulfide concentrations

Effect of time in the solution

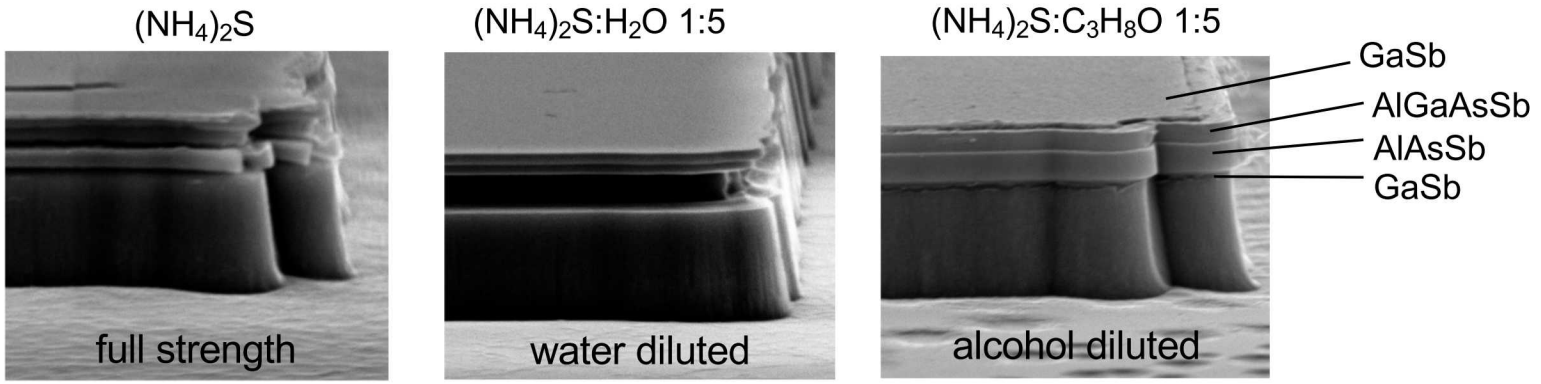
AlSb diode structure





Current-Voltage characteristics of AlSb diodes passivated with $(NH_4)_2S:C_3H_8O$ 1:20 for different times

Summary



- Passivation with **full strength ammonium** sulfide at **room temperature** is **less aggressive** than when at 60 ºC.
- Passivation with **water diluted** ammonium sulfide is the **best option** when structure is mostly **GaSb**.
- Passivation with **alcohol diluted** ammonium sulfide is the **best option** when structure has **AlSb alloys**.

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