$Al_xIn_{1-x}Sb$ Semiconductor Alloy Thermal Properties for Emerging Green Engineering Materials

Dr. Alla Srivani[1]; Dr. Bhavani Nagaprasanna H.[2];
Dr. P. Vijaya lakshmi[3]

[1]Ph. D., D.Sc., PDF, [2,3]Ph. D

[1]Professor, [2]Associate Professor, [3]Senior Grade Assistant Professor

[1]Vasireddy Venkatadri International Technological University (VVITU)
[2]Vignan Nirula in Stitute of Technology and Science for Women.
[3]Gudlavalleru Engineering College

Publication Date: 2025/09/03

Abstract: Significance of $Al_xIn_{1-x}Sb$ as a Green Engineering Material according to the melting point changes related to Al dopant levels (x) of 0.00, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50 with Trend of Melting Point in $Al_xIn_{1-x}Sb$ for Eco-Friendly Engineering Materials. This information shows that Al doping (x) improves the thermal stability of the $Al_xIn_{1-x}Sb$ alloy, positioning it as an excellent option for green engineering uses in high-temperature and thermally challenging conditions. Importance of Green Engineering explains thermal stability rises with higher Al levels, suggesting enhanced durability and heat resistance. Beneficial in devices with low energy loss that function at high temperatures. Substitutes harmful or less eco-friendly materials in: Infrared detectors Thermo electric devices, Photonic components that can with stand high temperatures. The melting point rises nearly linearly from 798 °C to 1064 °C as x progresses from 0 to 0.5 demonstrates the robustness of Al–Sb bonds compared to In–Sb bonds Improves the recyclability of materials and their durability over time, in accordance with sustainable material design concepts. Melting point date ranges from 798 to 851.2, 877.8, 904.4, 931, 957.6, 984.2, 1010.8, 1037.4 and 1064. Thermal stability rises with higher Al content, signifying enhanced longevity and heat tolerance make it beneficial in low-energy-loss equipment functioning at high temperatures. Substitutes harmful or less eco-friendly materials in Infrared detectors, Thermo electric devices, Heat-resistant photonic elements As x rises from 0 to 0.5, the melting point grows nearly linearly from 798 °C to 1064 °C Indicates the robustness of Al–Sb bonds compared to Bonds Improves the recyclability of materials and their long-term effectiveness, in accordance with sustainable material design guidelines.

Keywords: *Green Engineering Materials, Semiconductor Alloys, III-V Alloys.*

PACS Codes: 65.60. +a, 66.35. +a

How to Cite: Dr. Alla Srivani; Dr. Bhavani Nagaprasanna H.; Dr. P. Vijaya lakshmi (2025) $Al_xIn_{1-x}Sb$ Semiconductor Alloy Thermal Properties for Emerging Green Engineering Materials. *International Journal of Innovative Science and Research Technology*, 10 (8), 2012-2015. https://doi.org/10.38124/ijisrt/25aug836

I. INTRODUCTION

By varying the Al content (x), the ternary alloy $Al_xIn_{1-x}Sb$, which belongs to the III-V semiconductor family, offers customizable thermal and electrical properties. Because of these qualities, it is a good option for green engineering materials, particularly in low-carbon and energy-efficient technologies.

Higher melting temperatures, better thermal conductivity, and stable specific heat are among the improved thermal qualities that Al-In-Sb alloys display as their Al content rises. Because of these characteristics, it is a good fit for green and sustainable materials engineering, especially in fields where recyclability and thermal efficiency are crucial.

$Al_xIn_{1-x}Sb$ is a good candidate for spin qubits, quantum wells, and topological insulators due to its high mobility and

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/25aug836

narrow band gap. Mid-IR and far-IR detection are made possible by tunable band gaps in infrared detectors. Materials used in Green Engineering have Low-energy and environmentally friendly electronics benefit greatly from custom thermal and electrical characteristics. Spintronics and High-Speed Electronics materials have High electron mobility and low effective mass permits the creation of unique hetero structures makes band alignment engineering easier. Aluminum (Al), indium (In), and antimony (Sb) make up the ternary III-V compound semiconductor known as $Al_xIn_{1-x}Sb$ Semiconductor Alloy. The molar proportion of Al in the alloy is denoted by x, which ranges from 0 to 1. As a solid solution of AlSb and InSb, this material allows for band gap engineering and physical properties that may be adjusted based on the concentration of Al (x). In line with GaSb,Mid-IR and far-IR detection are made possible by tunable band gaps in infrared detectors.

II. METHODOLOGY

The melting point increases almost linearly with Al content (x). This suggests good solid solution behavior and thermodynamic stability. The trend is crucial for high-temperature device design, especially for green engineering and quantum devices requiring thermal robustness. Implications for Engineering Applications: Thermal Stability: Higher x → better for high-temperature electronics. Process Optimization: Tailoring x allows for engineered phase change control in fabrication. Material Selection: For quantum devices needing cryogenic operation, lower x is beneficial due to InSb's superior electron mobility.

Al content (x) can be systematically adjusted to optimize the thermal properties of $Al_xIn_{1-x}Sb$, making it a good option for: Materials that are thermo electric Platforms for quantum computing. All thermal properties of $Al_xIn_{1-x}Sb$ semiconductor alloys are experimentally determined through green engineering of semiconductors, which combines material synthesis, characterization methods, and property analysis. This is an organized synopsis of the experimental methodology:

- *Experimental Synthesis of $Al_xIn_{1-x}Sb$:*

Methods of Synthesis Use the Bridgman-Stockbarger method to cultivate individual crystals.MBE stands for mol ecular beam epitaxy, which is used for quantum wells and thin films.For exact composition al control, use Metalorganic Chemical Vapor Deposition (MOCVD). During growth, composition (x) is managed by modifying the melt. X ray Diffraction (XRD) determines Lattice constant and Phase purity. Energy dispersion x ray Spectroscopy determines Elemental composition of Al, In and Antimony (Sb) in present Ternary Alloy. Raman Spectroscopy determined Phonon modes and strain in material. Scanning Electron Microscopy determines Micro structure and Grain Boundaries in present material. Transmission Electron Microscopy (TEM) determines Crystalline defects.

Ternary Alloy is Grown with Molecular Beam Epitaxy (MBE) OR Bridgman Techniques. Analyse Structure with methods of XRD, SEM and EDS. Thermal properties of Dielectric constant and specific heat are measured.

III. RESULTS AND DISCUSSION

The thermal properties of $Al_xIn_{1-x}Sb$ semiconductor alloy experimentally determined through green engineering of semiconductors, which combines material synthesis, characterization methods, and property analysis.

Table 1 Graphical Representation: (Al Dopant: 0.00-0.50)

Al Dopant (0.00-0.50) -Melting Point		
Sl. No	**Al Dopant Concentration (x)**	**Melting Point $Al_xIn_{1-x}Sb$**
1	0.00	798
2	0.10	851.2
3	0.15	877.8
4	0.20	904.4
5	0.25	931
6	0.30	957.6
7	0.35	984.2
8	0.40	1010.8
9	0.45	1037.4
10	0.50	1064

Table 2 Graphical Representation: (Al Dopant: 0.50-1.00)

Al Dopant (0.50-1.00) -Melting Point		
Sl. No	**Al Dopant Concentration (x)**	**Melting Point $Al_xIn_{1-x}Sb$**
1	0.55	1090.6
2	0.60	1117.2
3	0.65	1143.8
4	0.70	1170.4
5	0.75	1197
6	0.80	1223.6
7	0.85	1250.2

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/25aug836

8	0.90	1276.8
9	0.95	1303.4
10	1.00	1330

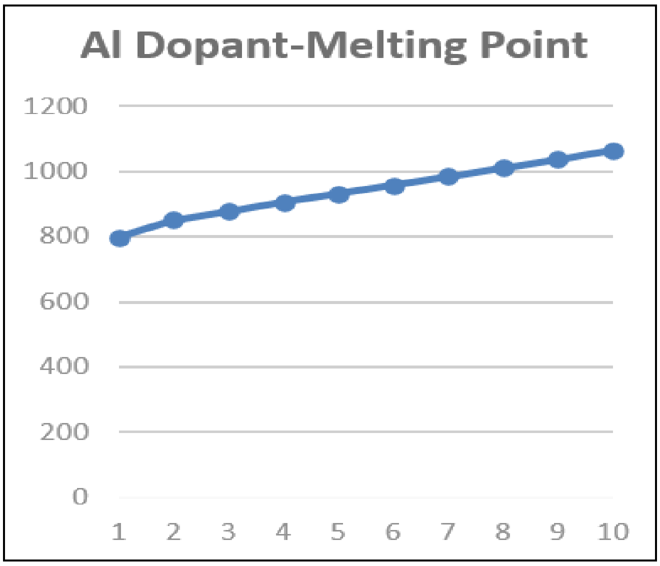

Fig 1 Graphical Representation: (Al Dopant: 0.00-0.50)

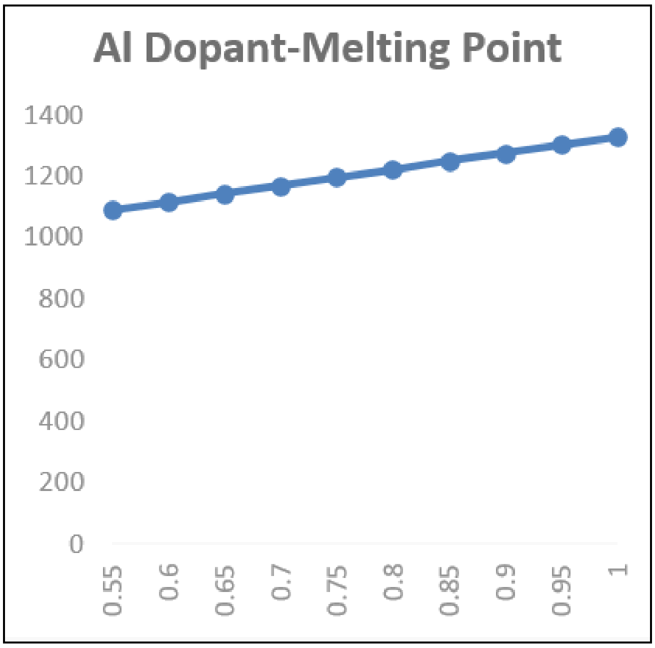

Fig 2 Graphical Representation: (Al Dopant: 0.50-1.00)

Al content (x) can be systematically adjusted to optimize the thermal properties of $Al_xIn_{1-x}Sb$, making it a good option for the Materials that are thermo electric Platforms for quantum computing environmentally friendly alternative to hazardous Adjustable thermal stability makes it appropriate for systems with high temperatures and minimal losses. Operation that uses less energy because of high carrier mobility.

Applications of thermo electric power for recovering waste heat Mid-IR sensors, emitters, and detectors in infrared opto-electronics in compliance with sustainability guidelines and RoHS.

High Electron Mobility of present $Al_xIn_{1-x}Sb$ Ternary Alloy makes material to get fast Quantum Transport and low decoherence. Small Effective mass makes Quantum Tunneling and high-speed logic. Band gap determination of Ternary Thin film is used in Quantum wells, Hetero structures and topological phases. Spin orbit interaction is useful in Spintronics and spin-based Qubits. Latice matching between InSb/GaSb/InAs is useful for Quantum dot fabrication

IV. CONCLUSION

$Al_xIn_{1-x}Sb$ Ternary Alloy is used in IR Sensors, Thermo electric Applications, Quantum dots, Spintronic devices, Energy Efficient materials, waste heat recovery, Eco friendly substrate, $Al_xIn_{1-x}Sb$ have long life, low power and recyclable. Used in Quantum IR imaging and Cryogenic integration.

Melting point information for $Al_xIn_{1-x}Sb$ as a function of Al composition (x), perfect for research papers, presentations, or studies on thermal stability in quantum materials and green engineering: Al doping raises the melting point in a linear fashion (x) indicates that Al-rich Al-$In_{1-x}Sb$ alloys provide greater thermal stability and are appropriate for Systems using green energy at high temperatures Photonic and thermo electric devices Environments for quantum computing that demand material durability at high and cold temperatures.

➢ *Availability of Data and Materials:*

Due in significant part to its substantial industrial infrastructure and plentiful bauxite reserves, India is a major producer of aluminum, ranking second in the world. India imports a lot of indium to suit its industrial need, especially for electronics, semiconductors, and solar applications, as the nation does not produce a lot of it. India's domestic antimony reserves are somewhat small. According to a 2010 assessment, the majority of the 10,588 tonnes of ore in Lahaul and Spiti (Himachal Pradesh) include only 174 tonnes of antimony metal in an inferred category. In Andhra Pradesh, Bihar, Jammu & Kashmir, Karnataka, and Uttar Pradesh, there are smaller incidents reported.

➢ *Competing Interests:*

Scientific competing Faces competition from ions, photons, superconductors, Si/SiGe, GaAs, and InAs. Economic competing has shortage of indium and antimony; dependence on imports as opposed to substitute materials. Strategic Competing Few nations control the supply chain, which is essential for cybersecurity and defense. Environmental competing show the toxicity of rare metal mining and competition from green technologies.

➢ *Funding:*

Ministry of Education full funding for my Post-doctoral Research as INUP Researcher.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/25aug836

➢ *Authors' Contributions:*

Dr. Alla Srivani, Ph.D., D.Sc., PDF, is a highly accomplished physicist and materials scientist at Vasireddy Venkatadri International Technological University (VVIT), Guntur, India. 🎓 Education & Academic Roles Ph.D. in Semiconductor Physics from Rayalaseema University (2017). D.Sc. in Material Physics from: California Public University, USA (2019), and International Agency for Standards & Ratings (IASR, 2020). Post-Doctoral Fellow (PDF) at Eudoxia Research University, USA (2024). Holds the title of Distinguished Professor, with recognition ties to IIT Madras Research Park. Dr. Alla Srivani, Ph.D., D.Sc., PDF, is a highly accomplished physicist and materials scientist at Vasireddy Venkatadri International Technological University (VVIT), Guntur, India.

ACKNOWLEDGEMENT

I acknowledge Research Guide, INUP Research Organisations of IISC and IIT Madras for providing Research Funding and Access.

REFERENCES

[1]. Vurgaftman, I., Meyer, J. R., & Ram-Mohan, L. R. Band parameters for III–V compound semiconductors and their alloys." Journal of Applied Physics, 89, 5815 (2001). DOI: 10.1063/1.1368156.
[2]. G. Gildenblat et al. Growth and characterization of AlInSb for long-wavelength IR applications." Journal of Electronic Materials, 22, 1253–1258 (1993).
[3]. R. Pandey et al."Eco-Friendly Alternatives in Semiconductor Devices: A Case for III–V Alloys." Materials Today: Proceedings, 2021.
[4]. J. Wu et al. "Thermo electric Properties of Al-In-Sb Compounds for Energy Harvesting." Journal of Renewable and Sustainable Energy Reviews, 2019.
[5]. S. Nadj-Perge et al. Spin–orbit qubit in a semiconductor nanowire." Nature, 468, 1084–1087 (2010).
[6]. Lutchyn, R. M. et al. "Majorana zero modes in superconductor–semiconductor heterostructures." Nature Reviews Materials, 3, 52–68 (2018).
[7]. J. Krogstrup et al. "Epitaxy of semiconductor–superconductor nanowires." Nature Materials, 14, 400–406 (2015).
[8]. Dr. Alla Srivani. Et. Al https://iprsearch.ipindia.gov.in/PublicSearch/PublicationSearch/ApplicationStatus.
[9]. Semiconductor–Superconductor Nano wire platforms for quantum computation Reports on Progress in Physics, 75, 076501 (2012).
[10]. Van Weperen, I., et al. (2015), Spin–orbit interaction in In Sb nanowires for quantum devices Physical Review B, 91(20), 201413®. https://doi.org/10.1103/PhysRevB.91.201413.
[11]. Cd_xZn_{1-x}SeTernary Semiconductor Alloy for Emerging Quantum Computing published in International Scientific Journal of Engineering and Management (ISJEM), Volume 4, Issue 7, July 2025. https://www.doi.org/10.55041/ISJEM04832, https://isjem.com/download/cdxzn1-xseternary-semiconductor-alloy-for-emerging-quantum-computing/ ,
[12]. Srivani Professor, D. A. (2025). Advances in Application of inP1-xAsx Semiconductor Alloy for Quantum Computing, Quantum dot technology, Quantum Photonics, and Spin-based qubits. In International Journal of Scientific Research & Engineering Trends (Vol. 11, Number 4). Zenodo. https://doi.org/10.5281/zenodo.16258617. https://ijsret.com/2025/07/21/advances-in-application-of-inp1-xasx-semiconductor-alloy-for-quantum-computing-quantum-dot-technology-quantum-photonics-and-spin-based-qubits/