Doping of α−$(Al_xGa_{1-x})_2O_3$ using Suboxide Molecular-Beam Epitaxy

Kira Martin [1], Jacob Steele [2], Darrell G. Schlom [2,3,4,5]

[1]Department of Material Science and Engineering, University of Illinois at Urbana-Champaign, [2]Department of Material Science and Engineering, Cornell University, [3]School of Applied Physics and Engineering Physics, Cornell University, [4]Kavli Institute at Cornell for Nanoscale Science, [5]Leibniz-Institut für Kristallzüchtung, Max-Born-Str

Introduction

- Ga_2O_3 has an ultrawide-bandgap and high breakdown field making it a useful material for high power and ultra-high frequency devices [1]
- Alloying Ga_2O_3 with Al_2O_3 extends the bandgap and breakdown field even further

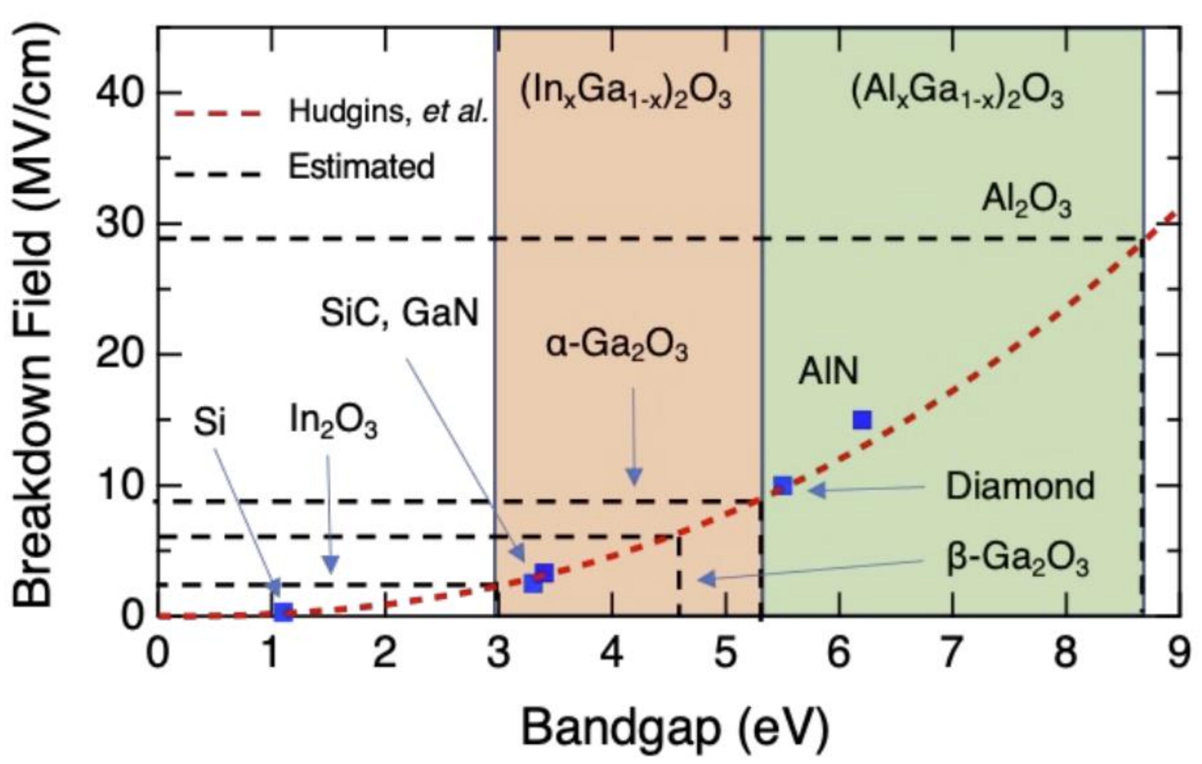


Figure Courtesy of Jon McCandless

- α−$(Al_xGa_{1-x})_2O_3$ has a bandgap ranging from 5.4-8.6 eV which can be tuned based on the Al composition [2]
- If successfully doped, α−$(Al_xGa_{1-x})_2O_3$ would be the highest bandgap and highest breakdown field semiconductor
- Molecular-beam Epitaxy (MBE) has grown the highest quality α−$(Al_xGa_{1-x})_2O_3$ films over the whole range of Al composition, but has slow growth rates, around 0.2 µm/hr, compared to other epitaxial growth methods [3]

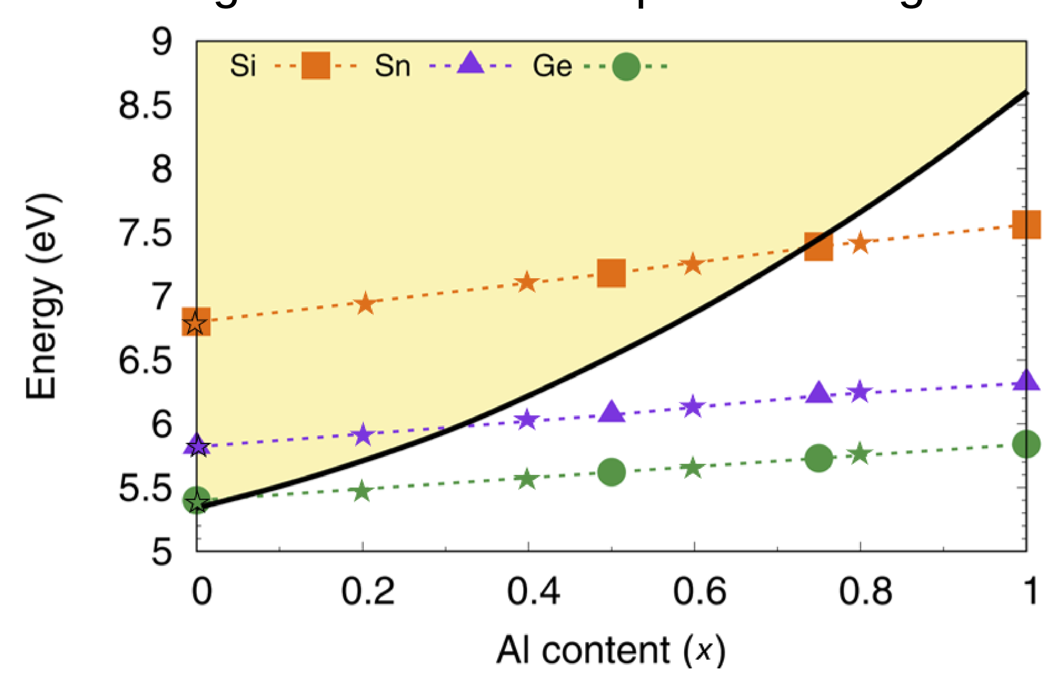
Methods

- All films were grown by *S*-MBE on A-plane Sapphire substrates
- X-ray diffraction (XRD) and X-ray reflectivity (XRR) were used to confirm film composition and thickness of each film
- The two-point resistance of each sample was measured using a multimeter

Methods

S-MBE [4,5]

- Suboxide MBE (*S*-MBE) simplifies the growth reactions of for III-O materials, including Ga_2O_3, growth allowing for increased growth rates while maintaining high film quality
- Observed Changes:
  - Increases growth rate
  - Allows for linear composition control
  - Increases accessible growth regime
  - Can grow whole Al composition range



Appl. Phys. Lett.. 2022;121(4). doi:10.1063/5.0096394

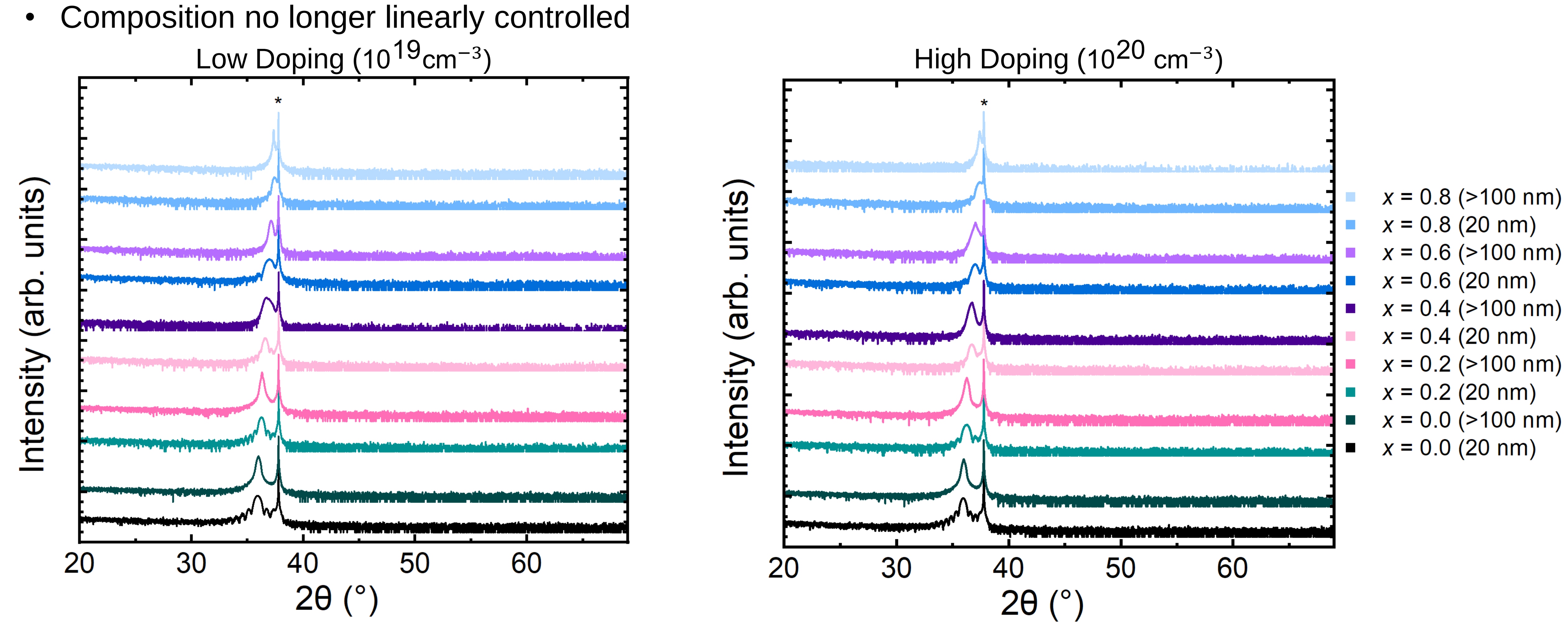
MOCATAXY [6]

- Metal-oxide-catalyzed epitaxy (MOCATAXY) utilizes a catalytic element to increase the growth rate through metal-exchange catalysis
- Sn and In catalyze Ga_2O_3 growth
- Potential Benefits:
  - Increases growth rate
  - Improves surface morphology
  - Stabilizes previously unstable phases
  - May enhance crystalline quality

- Previous computational work has predicted the Al composition at which dopants transition from shallow to deep donors in α−$(Al_xGa_{1-x})_2O_3$ [7]
- The planned growth series will vary
  - Dopant (Sn [8], Ge [9], Si [10])
  - Doping level (10^{19}, 10^{20} cm^{-3})
  - Film Composition (0, 20, 40, 60, 80% Al)
  - Thickness (~20, ≥100 nm)

Results

- Films were not conductive enough to measure a resistance with a multimeter
  - Unclear if dopants are being incorporated into film during growth
- MOCATAXY was observed during growths with Sn
  - Growth rate increased
  - Composition no longer linearly controlled



Conclusions

- Sn doping resulted in insulating films at all tested conditions
- MOCATAXY observed during growths with Sn
- Further work is necessary to understand doping of α−$(Al_xGa_{1-x})_2O_3$ by *S*-MBE

Future Work

- Complete doping series for Si and Ge
- SIMS analysis to investigate incorporation of dopants in film
- High temperature hall measurements will be done on nonconductive films to see if donor activation will occur at nonstandard conditions
- Hall measurements to determine electron mobility and sheet carrier concentration of any conductive samples
- Ion implantation on undoped samples

Acknowledgments

I would like to thank my mentor Jacob Steele and Professor Darrell G. Schlom for their support and guidance in this project. This research was funded by the National Science Foundation (NSF) Platform for the Accelerated Realization, analysis, and Discovery of Interface Materials (PARADIM) under Cooperative Agreement No. DMR-2039380 as well as the NSF REU Site: Summer Research Program at PARADIM under Cooperative Agreement No. DMR-2150446.

References

[1] Pearton et al. 2018, Appl. Phys. Rev. 5, 011301
[2] Jinno et al. 2021, Sci Adv. 7, eabd5891
[3] McCandless et al. 2021, Appl. Phys. Lett. 119, 062102
[4] Azize et al. 2023, APL Mater. 11, 041102
[5] Vogt et al. 2021, APL Mater. 121, 031101
[6] McCandless et al. 2023, Jpn. J. Appl. Phys. 62, SF1013
[7] Wickramaratne et al. 2022, Appl. Phys. Lett. 121, 042110
[8]Chikoidze et al. 2016, J. Appl. Phys. 120, 025109
[9] Alema et al. 2021, APL Mater. 9, 091102
[10] Dang et al. 2020, AIP Advances 10, 115019