Study of Indium-Silicon Co-doped Gallium Oxide for Effective *n*-type Doping.

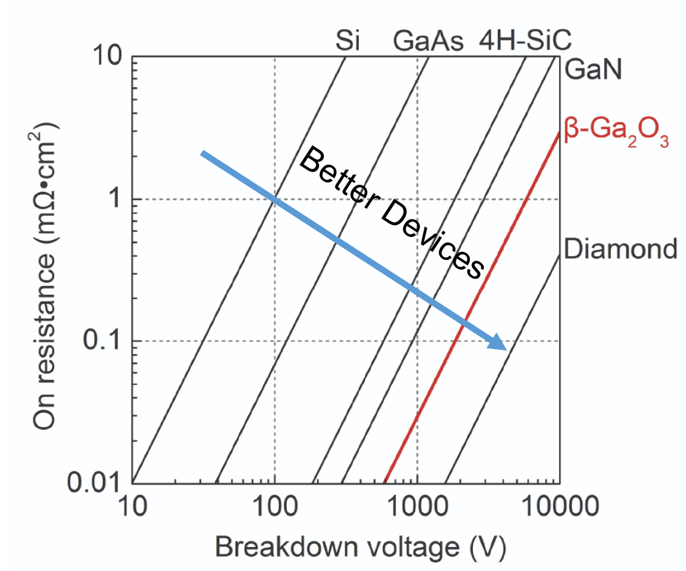
Muhammad Hassan Tahir, Nifat Jahan Nipa & Md. Ghulam Zakir

Supervisor: Dr. Iftikhar Ahmad

Electrical Engineering, University of South Carolina

Introduction

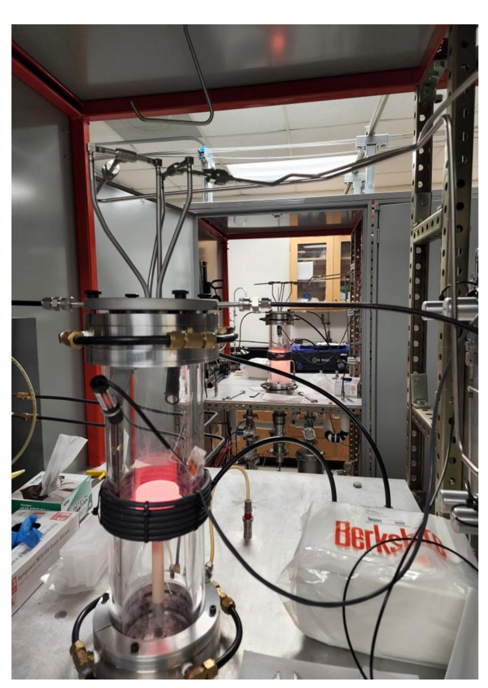
- Ga_2O_3 an emerging material for power electronics
  - Bandgap ~ 4.9 eV
  - Breakdown Voltage ~ 8-10 MV/cm
  - Chemical Stable
  - Thermally Stable
  - High Radiation Hardness



- The doping of Ga_2O_3 faces challenges: there's no effective p-type dopant, and n-type doping leads to low electron density and mobility, especially on sapphire substrate.
- Co-doping of Ga_2O_3 with Si and In leads to improved electrical properties, including enhanced electron density and mobility, making it suitable for various device applications and structural enhancements.

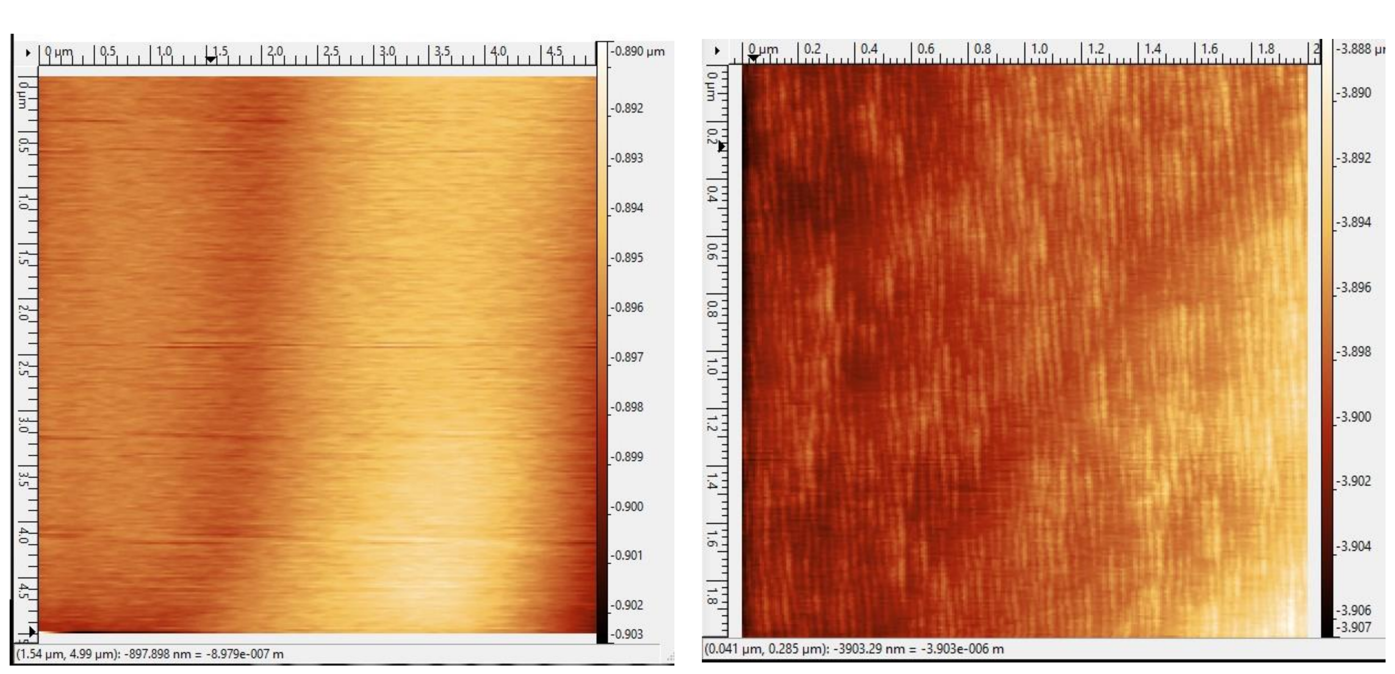
Step 1 – Growth using MOCVD

- We utilized a bulk gallium oxide substrate for our growth process, beginning with a thorough cleaning step to remove surface impurities.
- The cleaning process involved sequential treatments with toluene, acetone, isopropanol, and DI water to ensure a pristine substrate surface.
- Subsequently, we employed Metal Organic Chemical Vapor Phase Deposition (MOCVD) for the growth of n-doped Ga_2O_3 setup at the following parameters.
  - Growth Temperature : 700
  - Gallium Precursor : Tri-Methyl Gallium
  - Indium Precursor : Tri –Methyl Indium



Step 2 – Atomic Force Microscopy (AFM) Analysis

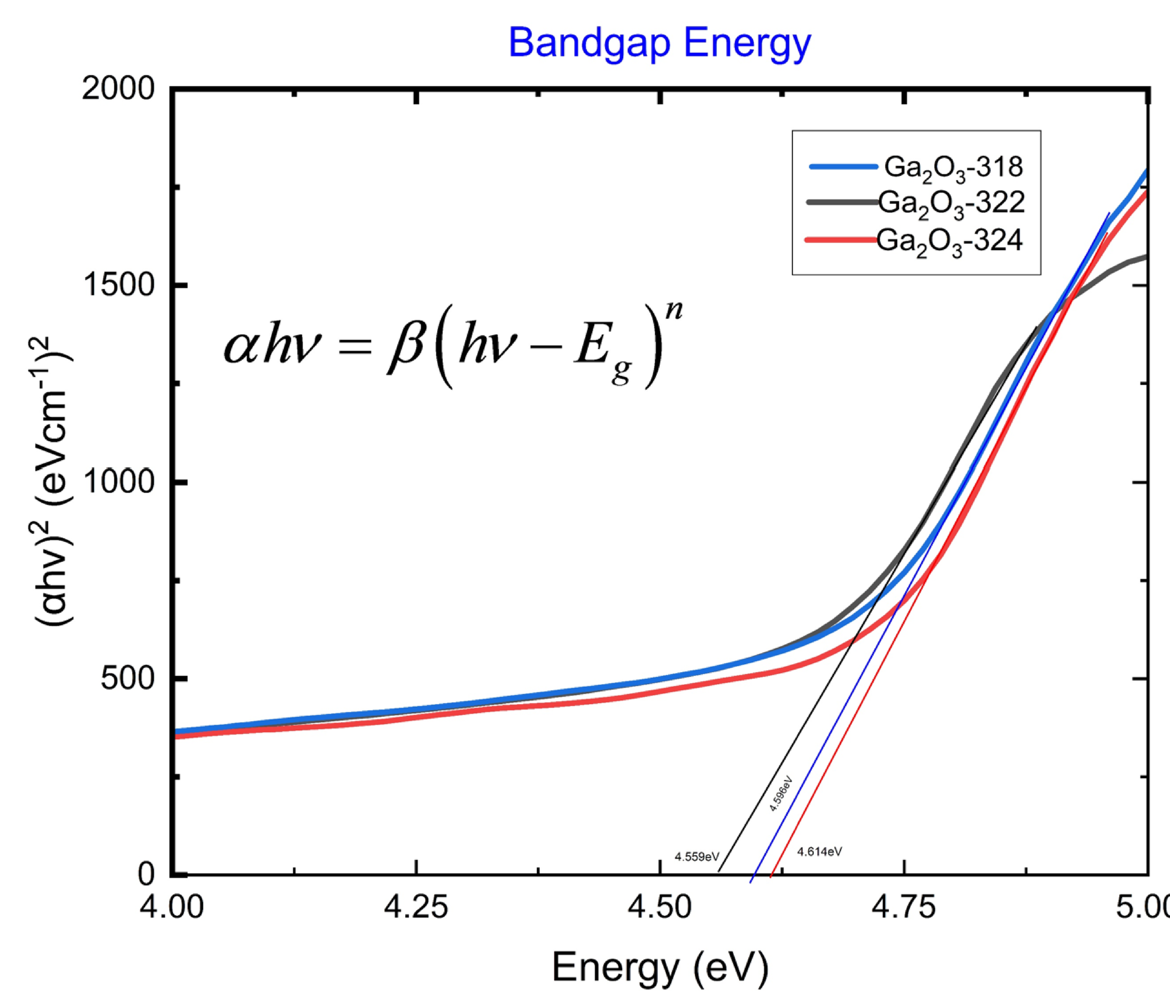
- Atomic force microscopy allows us to assess the surface topography of thin film with sub-nanometric vertical and lateral resolution within few minutes. The final epitaxially grown wafer along with bulk substrate was analysed using AFM to get the idea of mean roughness of the surface.



- The AFM image on the left shows bulk Ga_2O_3 with a mean roughness of 1.29nm, indicating a smooth surface. Conversely, the AFM image of N-doped Ga_2O_3 on the right exhibits a mean roughness of 1.49nm, indicating increased surface roughness post-experimentation. This change demonstrates the successful growth of an epitaxial layer atop the bulk substrate.

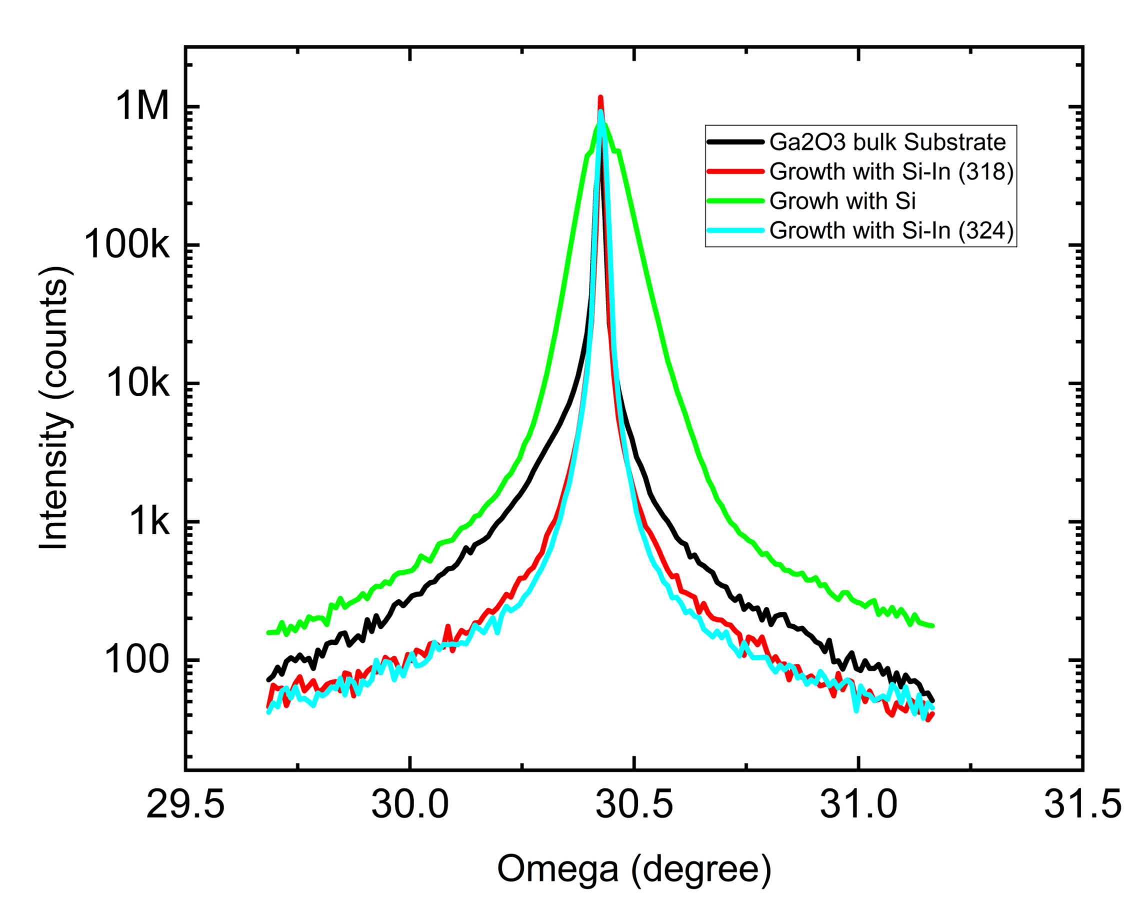
Step 3 – UV-Vis Spectroscopy Analysis

- UV-VIS spectrometer enables us to estimate the semiconductor's bandgap and thickness. The system measures thin-films absorption, transmission, and reflection spectra in the range of 200-900nm.
- After getting the average roughness the bandgap energy of the grown doped Ga_2O_3 was calculated and get compared with the band gap energy of bulk Ga_2O_3. The bandgap energy of doped Ga_2O_3 was lesser than the bulk material.



Step 4 – X-Ray Diffraction (XRD) Analysis

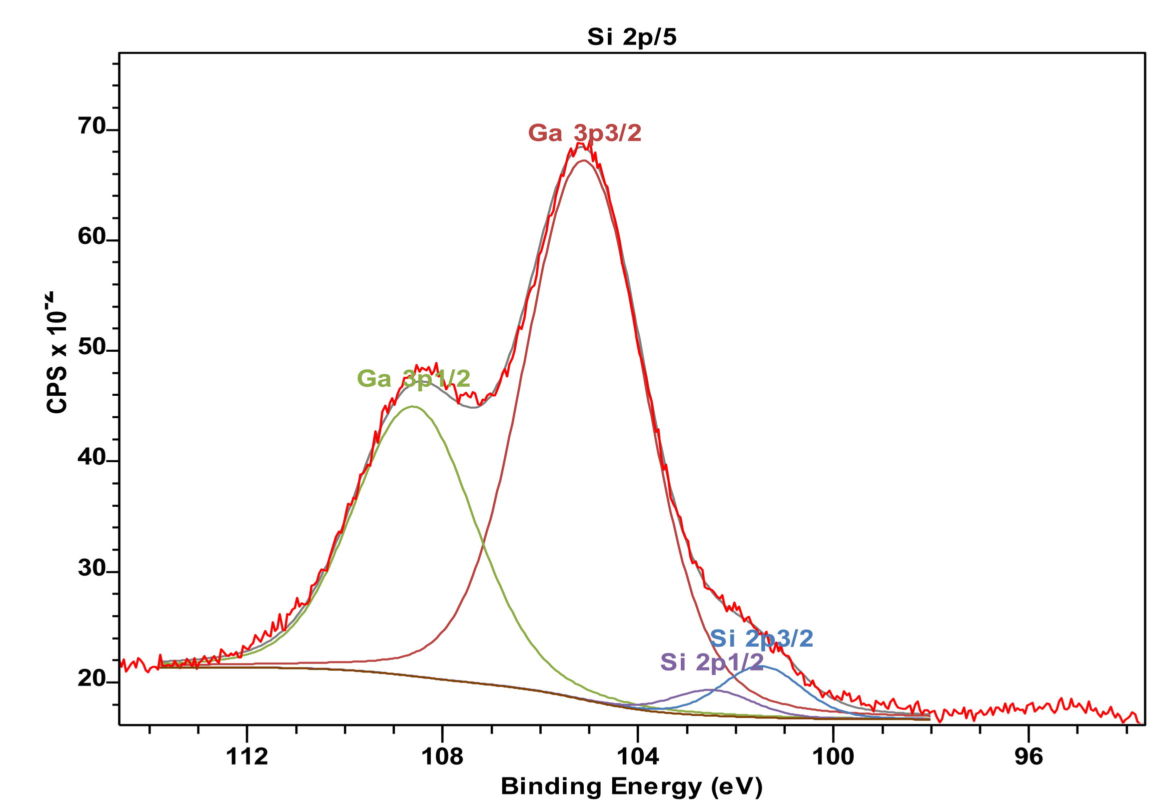
- X-ray diffraction (XRD) is a powerful technique used to analyze the crystal structure of materials. By directing X-rays at a sample, it produces diffraction patterns that reveal information about the material's atomic arrangement, crystal phase, and grain size.
- After getting the band-gap energy the next step was XRD to examine the crystal structure and defects.



- The above XRD analysis proves that the epitaxially grown Ga_2O_3 has better crystal structure with less defects than the bulk substrate. The full width half maxima of Ga_2O_3-324 is lesser than the FWHM of Ga_2O_3 bulk substrate. The results obtained are in-accordance with the past literature.

Step 5 – XPS Analysis

- X-ray Photoelectron Spectroscopy (XPS) is a surface-sensitive technique to analyze the elemental composition and chemical state of materials. By bombarding a sample with X-rays, XPS measures the kinetic energy of emitted electrons, providing insights into surface chemistry, oxidation states, and bonding configurations of elements present.



- The XPS analysis gave us the bonding configuration of Si and In on our grown layer and it furthers confirms the presence of indium in the crystal structure of doped Ga_2O_3.

Conclusion

- In a nutshell , In-Si Co-doped homoepitaxial (001) and (010) β-Ga_2O_3 thin films were grown on Ga_2O_3 substrates via MOCVD. The final product obtained has lower bandgap and better material quality than bulk Ga_2O_3.

References

- Rafique, S., Karim, M. R., Johnson, J. M., Hwang, J. & Zhao, H. LPCVD homoepitaxy of Si doped β-Ga2O3 thin films on (010) and (001) substrates. *Applied Physics Letters* **112**, 052104 (2018).
- Xue, H. *et al.* An Overview of the Ultrawide Bandgap Ga2O3 Semiconductor-Based Schottky Barrier Diode for Power Electronics Application. *Nanoscale Research Letters* **13**, (2018).

Lab Achievements

- Over the last two year;
  - Lab published six papers in well reputed peer reviewed journals
  - Submitted three patent applications
  - Graduated two Ph.D. students
  - Received fundings exceeding $800K
- Currently, three students are working on their graduate degrees on different projects.

Acknowledgements

- National Science Foundation, Grant # 2124624 and managed by Dr. Dominique Dagenias, and NSF grant # 2329786, managed by Dr. Samir Iqbal.