Defect Luminescence in β – Ga2O3 for Next Generation Power Electronics

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Background

Gallium Oxide (Ga_2O_3) is attracting enormous attention as a promising material for next-generation high-power and high-voltage devices. Its ultra-wide band gap and favorable physical properties make it well-suited for applications where efficiency and performance are crucial. However, the presence of various defect sites within the can significantly degrade its electrical and optical performance. **The hypothesis guiding this research is that identifying and mitigating these defect states is essential for fully developing and optimizing Ga_2O_3 for device applications.** This work focuses on characterizing such defects as a first step toward controlling them through targeted processing techniques.

Goals

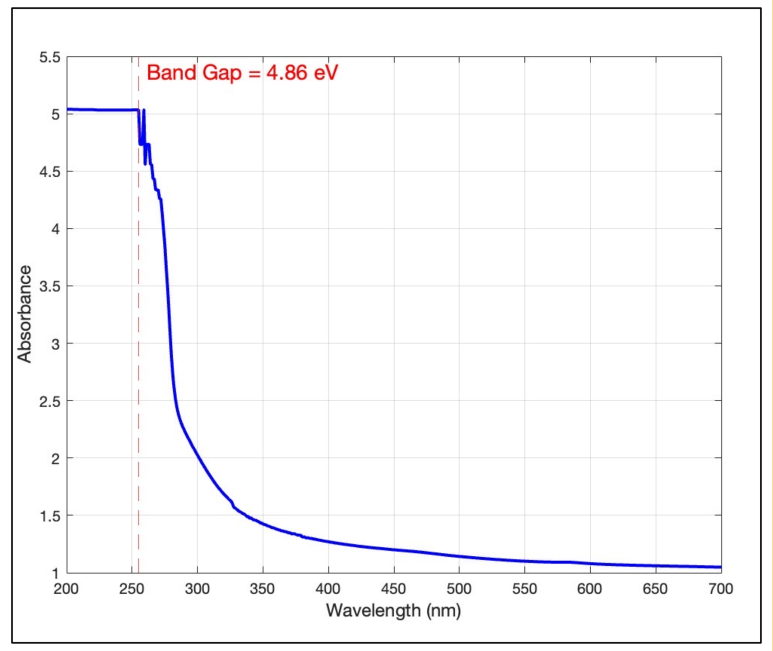
This work aims to employ several novel spectroscopy and luminescence techniques to reveal and characterize trap states within the band gap of bulk single-crystal Ga_2O_3 grown by Czochralski (CZ) and edge-defined film-fed growth (EFG) methods. Ultraviolet-visible (UV-vis) spectroscopy was first used to estimate the optical band gap. Cryogenic thermally stimulated emissions spectroscopy (C-TSES) was then applied to probe trap-related emissions across a range of temperatures and wavelengths, providing a detailed view into the nature and distribution of both shallow and deep traps.

Current Progress

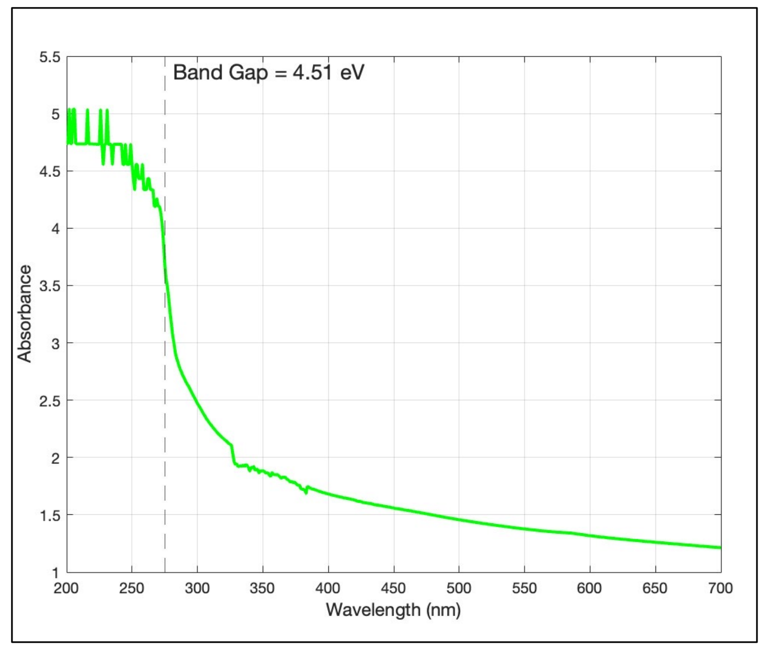
Ultraviolet-Visible Spectroscopy (UV-vis)

To estimate the optical band gap of the Ga_2O_3 samples, UV-Vis spectroscopy was performed. A light source was filtered to sweep wavelengths from 700 nm to 200 nm, then passed through the sample. Since photon energy is inversely proportional to wavelength, photons with energy equal to or greater than the band gap are absorbed, while lower-energy photons are transmitted. The absorption edge signals strong absorption onset, allowing band gap estimation. *Figures 1 and 2*).

(Figure 1): UV-Vis absorbance spectrum for Ga_2O_3 single crystal, grown through CZ method, showing the absorption edge at the estimated optical band gap.



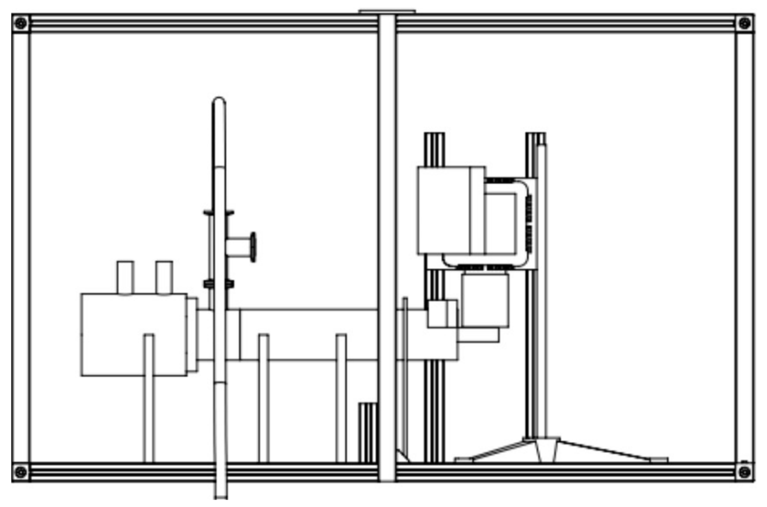
(Figure 2): UV-Vis absorbance spectrum for Ga_2O_3 single crystal, grown through EFG method, showing the absorption edge at the estimated optical band gap.



Cryogenic Thermally Stimulated Emissions Spectroscopy (C-TSES)

Samples were cooled under vacuum to ~7 K and irradiated for 5–15 minutes in the absence of ambient light. After removing the excitation source, a photomultiplier tube (PMT) and a photon counter were positioned above the sample. The temperature was then ramped at a rate of 60 K/min, while photon emission was recorded. The resulting glow curve reveals discrete trap states through distinct emission peaks. A custom light-tight enclosure was designed to minimize background noise. *Figure 3* shows the setup schematic.

(Figure 3): Detailed schematic of C-TSES system and light-tight enclosure.



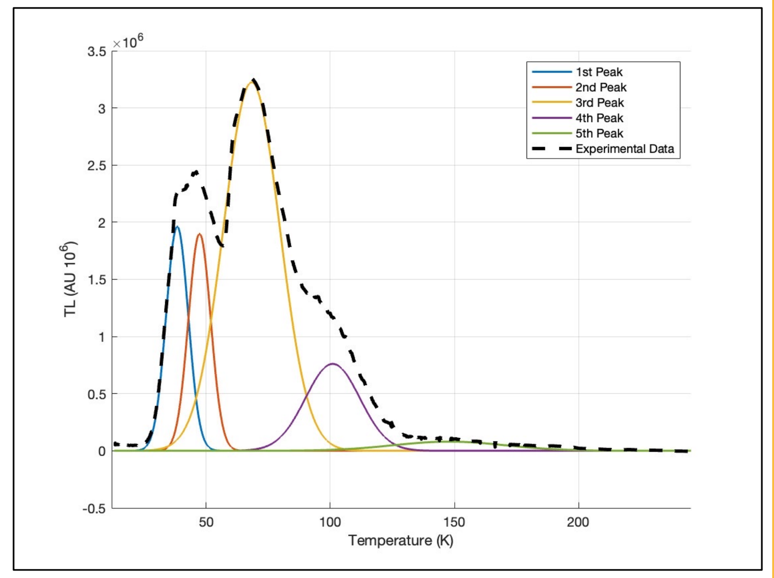
Glow Curve Deconvolution

Glow curve data was deconvoluted using R 4.20. Estimated peak positions and count were input, and the software fit individual peaks using a mixed-order kinetics model. *Figure 4 showcases the deconvoluted glow curve of Ga_2O_3, showing 5 distinct peaks (colored lines), each corresponding to separate trap levels. The dotted line represents the raw data.* The deconvolution software also extracts key kinetic parameters such as activation energy (E) and kinetic order (b).

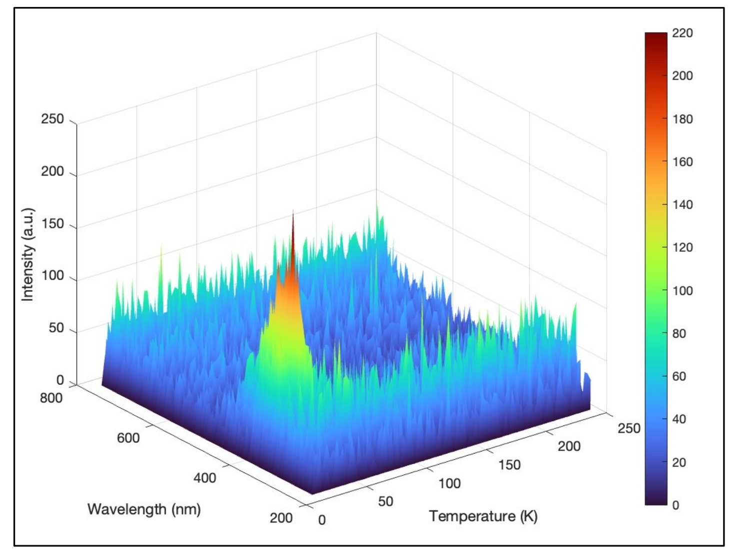
Spectral Intensity Mapping with Hamamatsu Spectrometer

In addition to glow curve analysis, luminescence data were collected using a Hamamatsu spectrometer, capable of capturing emission data as a function of temperature and wavelength, allowing for closer examination of the material's properties. *Figures 5 and 6 showcase the 3D surface plot and the 2D contour plot for the emission data as a function of temperature and wavelength. A sharp intensity peak slightly below 400 nm (~3.1-3.2 eV) was observed between 40-60K, consistent with radiative recombination between shallow donor states (likely oxygen vacancies) and deep acceptors (gallium vacancies).* This feature is characteristic of undoped β-Ga_2O_3 and supports the presence of intrinsic donor–acceptor pair (DAP) transitions within the material.

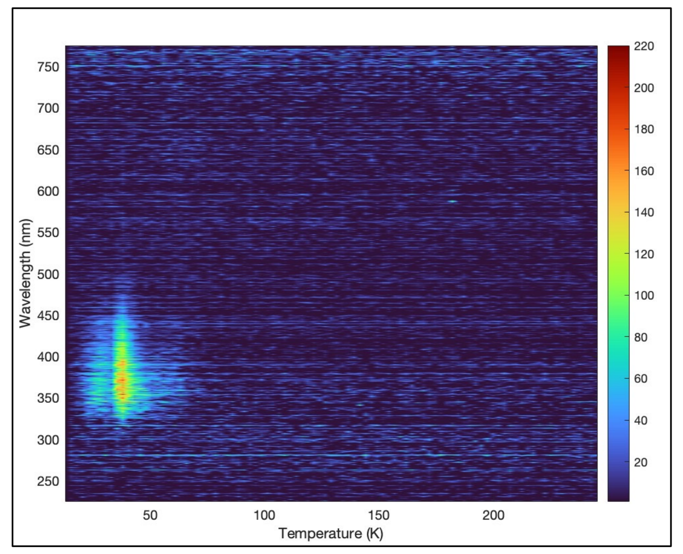
(Figure 4): Glow curve of Ga_2O_3 single crystal, grown through CZ method, with 5 resolved peaks.



(Figure 5): 3D Surface Plot of Ga_2O_3 single crystal, grown through EFG method.



(Figure 6): 2D Contour Plot of Ga_2O_3 single crystal, grown through EFG method.



Future Work

- Record the same experiments with different grown/doped samples to better understand how doping/processing can change the electrical properties of Ga_2O_3.
- Analyze archived X-ray-induced luminescence (XRIL) data provided by the research mentor to verify results.
- Improve the light-tight box to ensure consistent data is collected.

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