From Hydroxides to Corundum: Experimental Constraints on Alumina Dust Evolution in AGB Star Outflows

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Introduction

Asymptotic giant branch (AGB) stars contribute a significant amount of dust to the interstellar medium. Alumina (Al_2O_3) is one of the first minerals to condense from the gaseous materials expelled from AGB stars. The key reason alumina is of interest to this work is its various crystal structures (polymorphs). These polymorphs are metastable, meaning they transform irreversibly with increasing temperature. Alumina polymorphs can be derived from a plethora of precursor materials, primarily aluminum hydroxide ($Al(OH)_3$) or aluminum oxide hydroxide (AlOOH). This work focuses on tracking and understanding the different pathways our starting materials undergo, as well as identifying what temperatures might be ideal for producing different polymorphs of alumina.

Methods

The annealing conditions for this work were adapted from Pecharromán et al. (1999). The starting materials gibbsite, bayerite, boehmite, and amorphous aluminum hydroxide were heated at a rate of 10 °C min⁻¹ to various target temperatures (300 °C, 500 °C, 700 °C, 900 °C, or 1000 °C) and held at each temperature for 2 hours. To determine the time required for corundum formation, high-temperature experiments were also performed at 1100 °C, 1150 °C, and 1200 °C. The analytical methods employed were differential scanning calorimetry (DSC), X-ray diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR).

X-Ray Diffraction

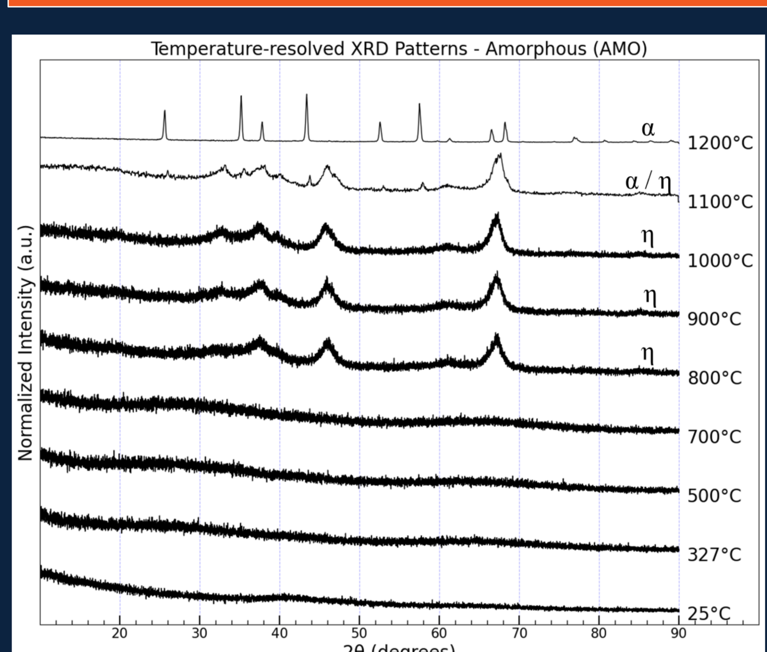

Figure 1. XRD of alumina derived from amorphous aluminum hydroxide, the Greek lettering indicated the crystal structure. η = FCC, α = Rhombic

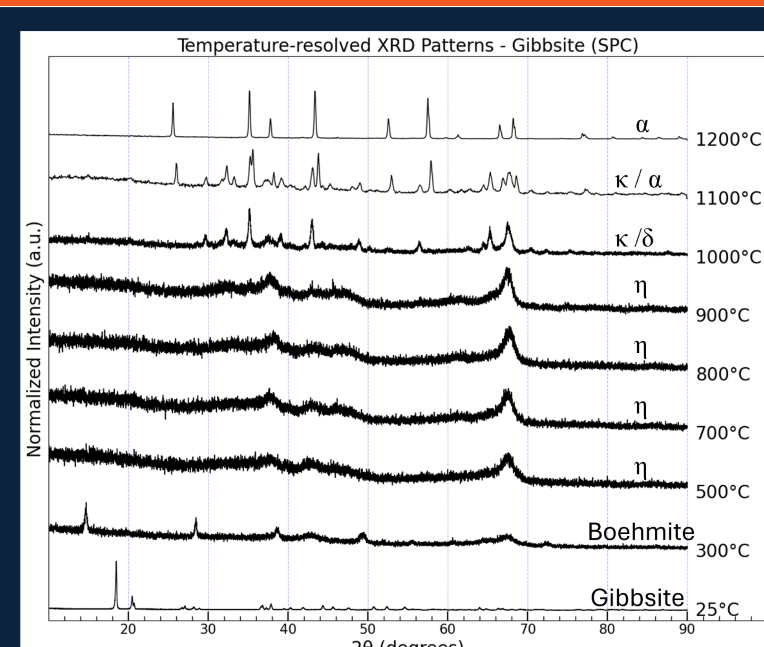

Figure 2. XRD resulting alumina derived from Gibbsite ($Al(OH)_3$). This includes κ = orthorhombic, δ = FCC

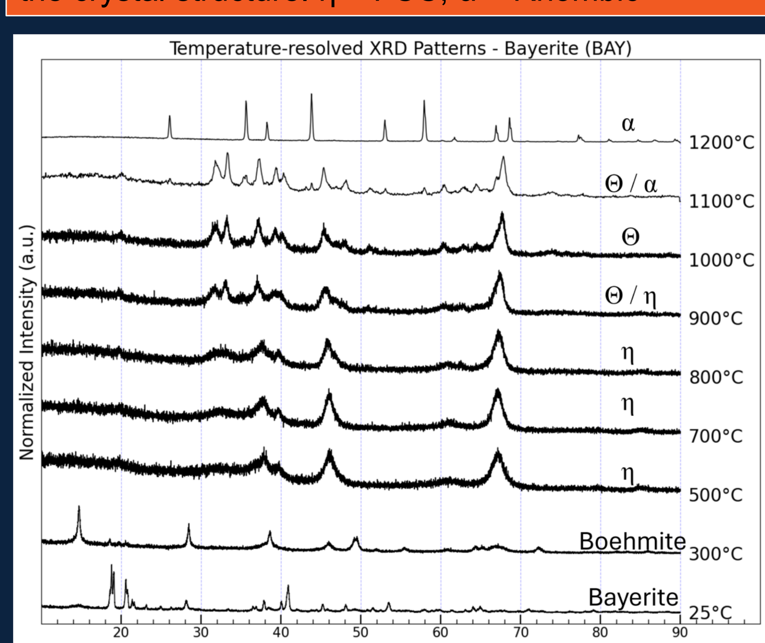

Figure 3. XRD resulting alumina derived from Bayerite ($Al(OH)_3$), this includes θ = monoclinic

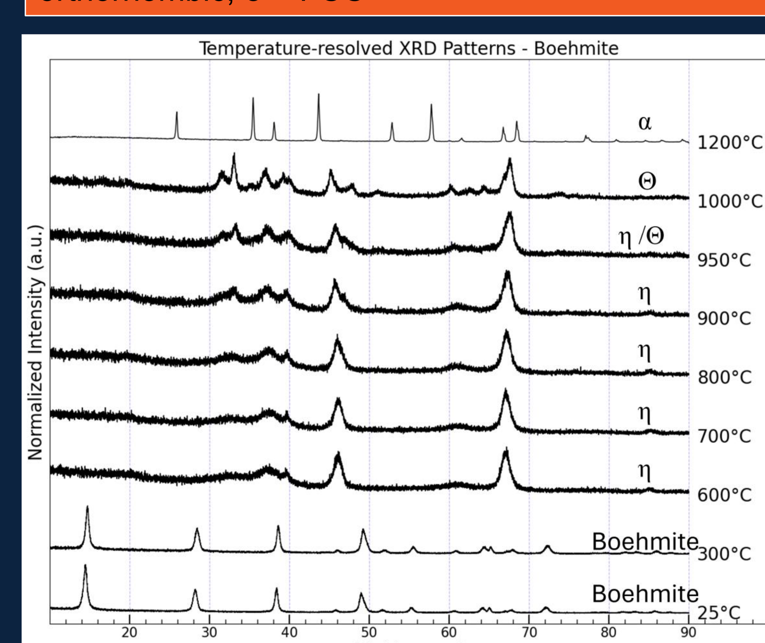

Figure 4. XRD resulting alumina from Boehmite derived (AlOOH).

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Pecharromán, C., Sobrados, I., Iglesias, J. E., González-Carreño, T., & Sanz, J. (1999). Thermal evolution of transitional aluminas followed by NMR and IR spectroscopies. *Journal of Physical Chemistry B*, *103*(30), 6160–6170. https://doi.org/10.1021/jp983316q

Sargent, B. A. (2018). Alumina Polymorphism in the Circumstellar Dust Shells of Asymptotic Giant Branch Stars. *The Astrophysical Journal*, *866*(1), L1. https://doi.org/10.3847/2041-8213/aae085

X-Ray Diffraction T-T-T

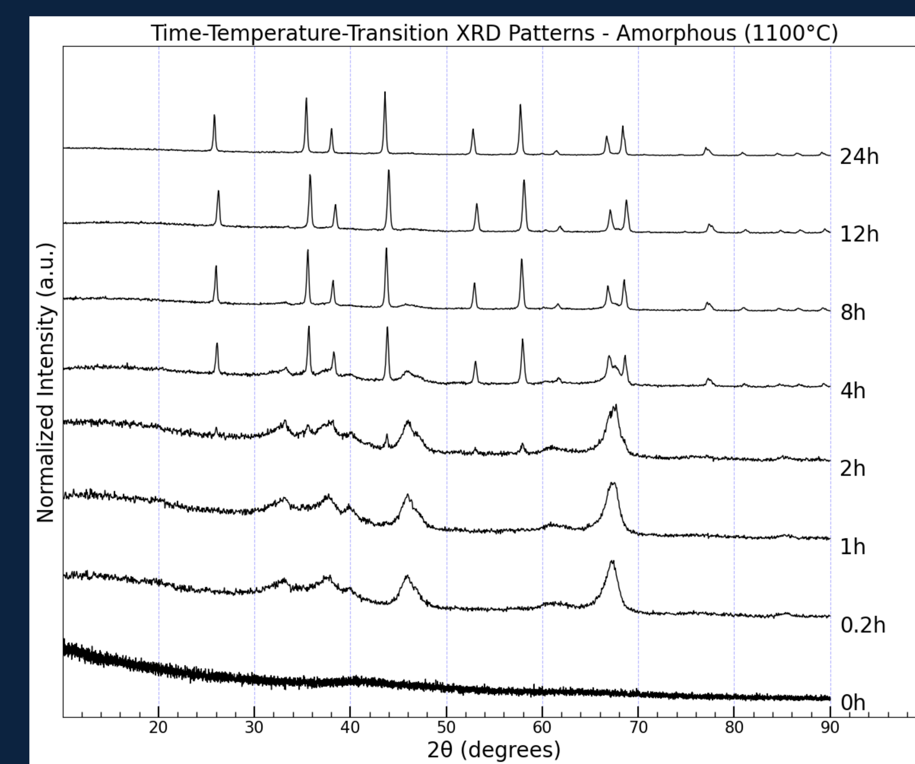


Figure 5. TTT of amorphous aluminum hydroxide this sample was annealed for 24 hours.

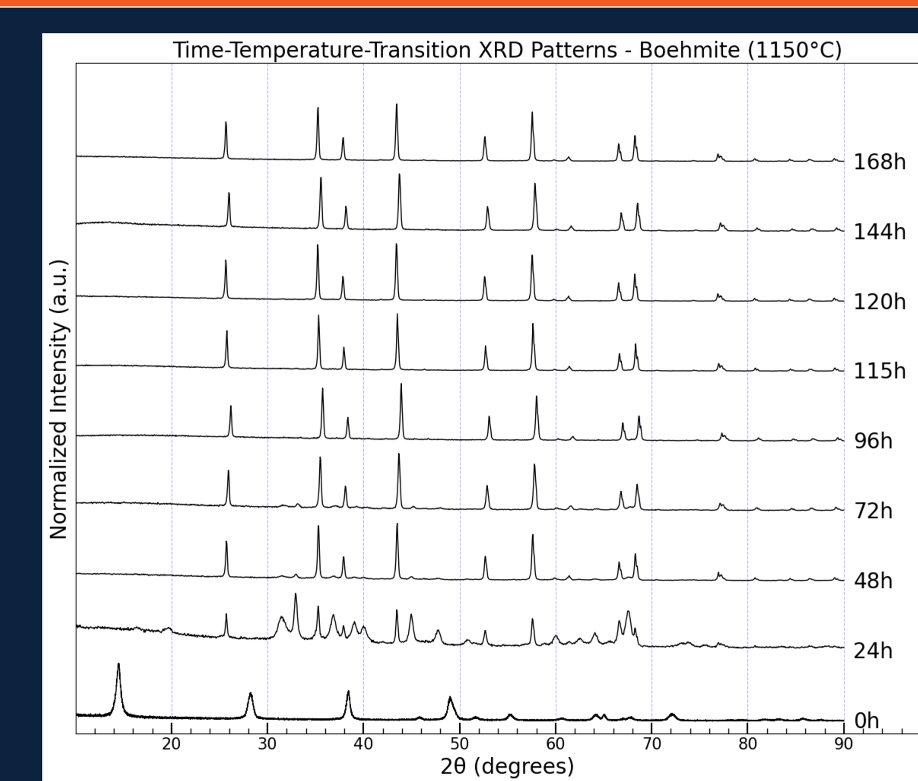
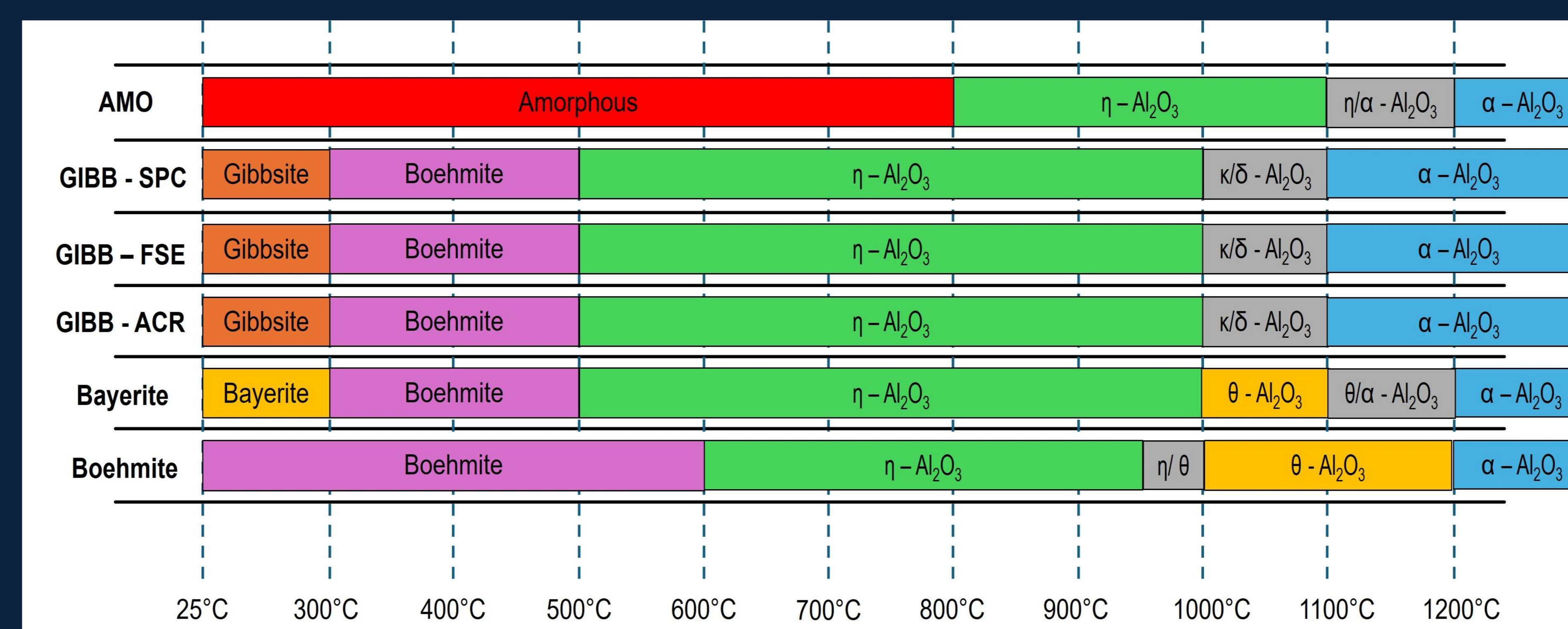
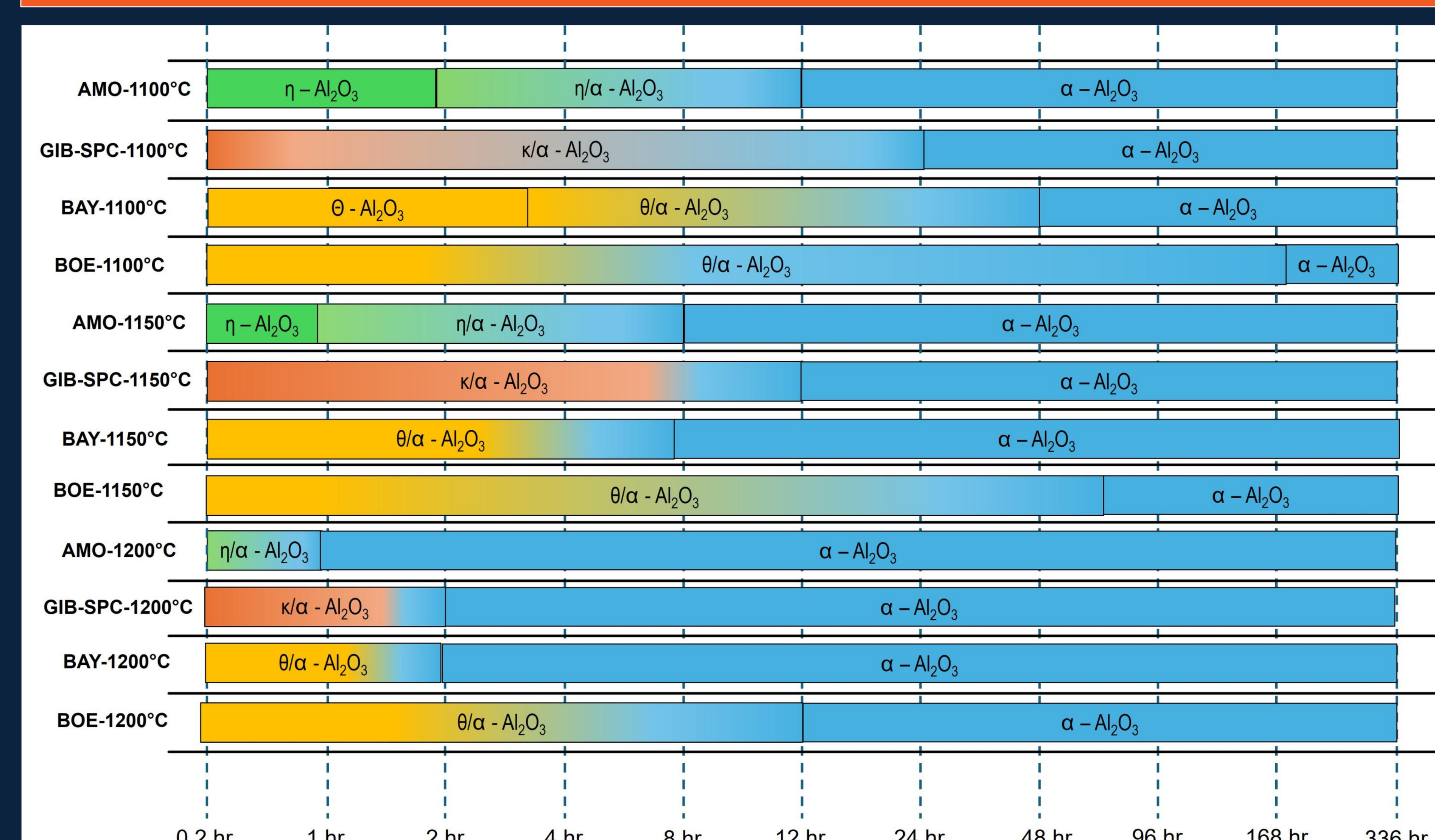


Figure 6. TTT of boehmite this sample set was annealed for a week.

Thermal Annealing Results



Time-Temperature-Transition Results



Crystal structures

Gibbsite = triclinic; Boehmite = orthorhombic; η - Al_2O_3 = FCC; δ - Al_2O_3 = FCC ; θ - Al_2O_3 = monoclinic ; κ - Al_2O_3 = orthorhombic; α - Al_2O_3 = trigonal

FTIR Spectra

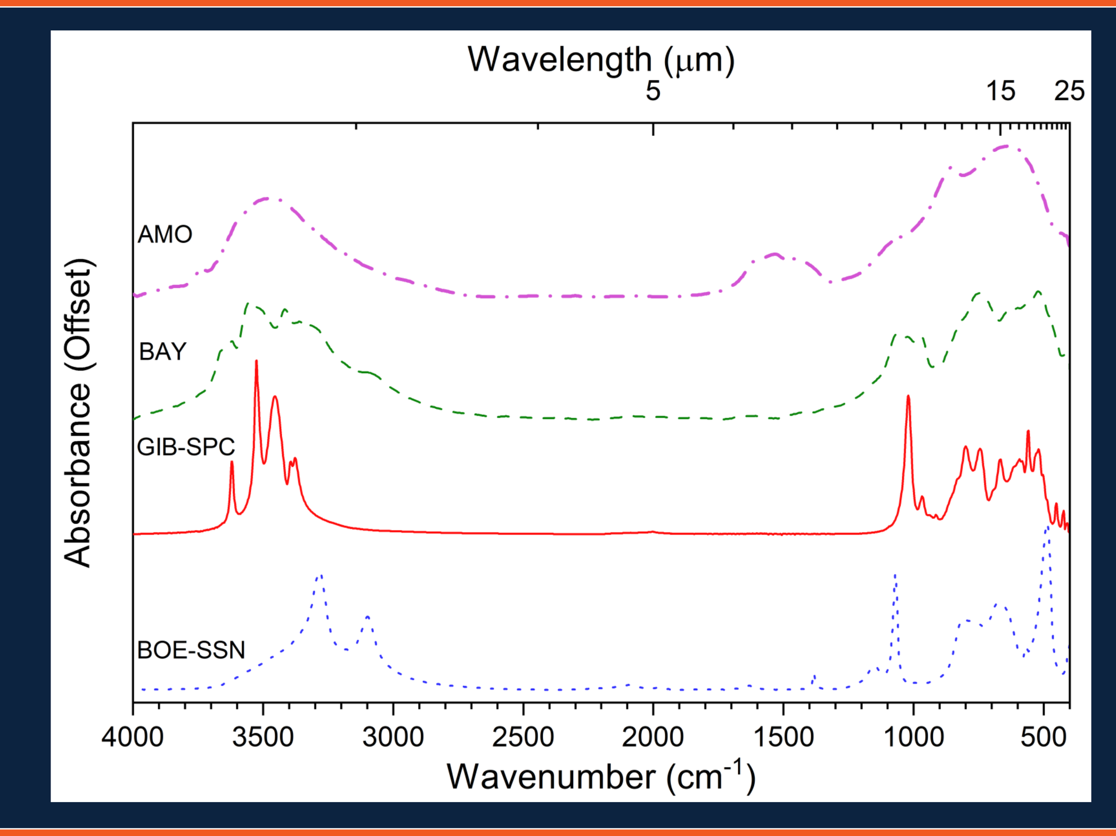


Figure 7. FIRT Spectra of initial hydrated alumina

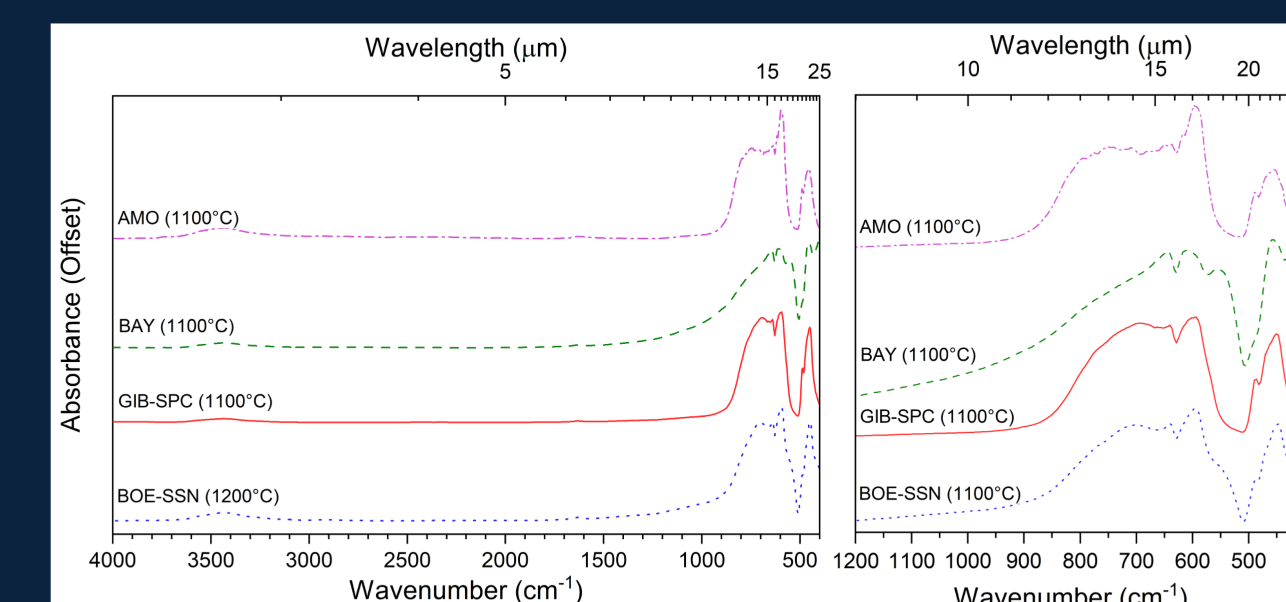


Figure 8. FTIR spectra of corundum or α – alumina derived from different parent minerals.

Differential Scanning Calorimetry

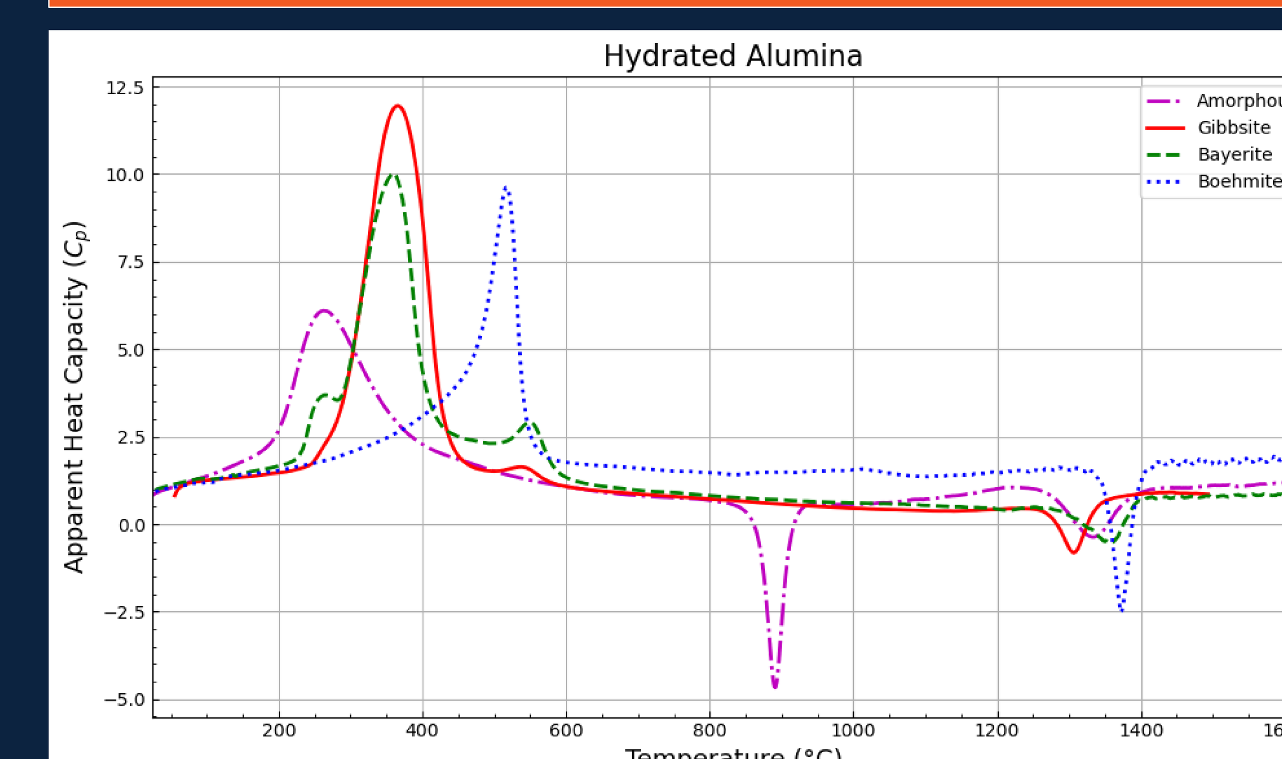


Figure 8. Apparent heat capacity curves for hydrated alumina precursors heated to 1650°C. This image shows the difference in thermal properties of all starting materials.

Key Take Away/Future work

- Metastable alumina may exist in certain regions of dust shells in AGB stars
- This work has application not just in AGB stars but various astronomical environments
- Kinetics of alumina in important in space
- Extraction of dielectric constants to get to modelers for radiative transfer modeling
- Future work entails including other abundant metals such as Fe, and Mg

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