Phase Control of Ga_2O_3 Films Grown by Atomic Layer Epitaxy

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Ga_2O_3 has attracted significant interest as an ultra-wide bandgap material for next generation high-power, high-temperature electronic device applications. While there are five polymorphs of Ga_2O_3, the β-Ga_2O_3 (monoclinic) is the most stable and most widely studied to-date. By comparison, the α-Ga_2O_3 phase is less energetically favorable but has a similar bandgap (5.3 eV) and a rhombohedral corundum crystal structure. The ability to attain this metastable state can encourage bandgap engineering between α-Al_2O_3 and α-In_2O_3 similar to other III-V alloys. In addition, Schottky barrier diodes made with α-Ga_2O_3 films have shown improved performance over both β-Ga_2O_3 and SiC [1], demonstrating the benefit of this polymorph in next generation devices. Here, we use atomic layer epitaxy (ALE) to produce high-quality, heteroepitaxial Ga_2O_3 films and demonstrate phase selectivity with variations in growth temperature, plasma chemistry and gas pressure.

ALE Ga_2O_3 films were grown on c-plane sapphire substrates in a Veeco Fiji 200 reactor. All films were produced using trimethylgallium and O_2 plasma precursors with pulse/purge times of 0.015s/10s and 10s/10s, respectively. The growth temperature, plasma gas flow, and pressure were varied to assess their impact on resulting film crystallinity and phase composition. Independent of growth conditions, all films were crystalline and highly resistivity with Ga/O ratios between 0.68-0.70 and no indication of C contamination by XPS.

Decreasing chamber pressure an order of magnitude during the plasma step drastically effected the resulting phase, yielding pure β-Ga_2O_3 at 80 mTorr and pure α-Ga_2O_3 at 8 mTorr. Additionally, at 350°C and 8 mTorr, the phase could be altered by a varying the O_2 plasma flow from 5-100 sccm. For these conditions, optical emission spectroscopy and ion flux measurements were made to correlate the impact of ions and other plasma species on the preferential promotion of different phases. By varying the growth temperature from 300 to 500°C at 8 mTorr, films went from mixed phase, to pure α-Ga_2O_3 at 350°C, to pure β-Ga_2O_3 at 500°C. High-quality β-Ga_2O_3 films were produced at 5sccm O_2 that had an RMS roughness of 0.38nm and XRD FWHM of 268 arc-sec for a 30nm film. At 40sccm, high-quality α-Ga_2O_3 films were obtained with an RMS roughness of 0.15nm and XRD FWHM of 250 arc-sec for a 30nm film. Thus, using ALE high-quality, phase selective films can be achieved to satisfy application requirements.

[1] S. Fujita, M. Oda, K. Kaneko and T. Hitora. JJAP 55, 1202A3 (2016).

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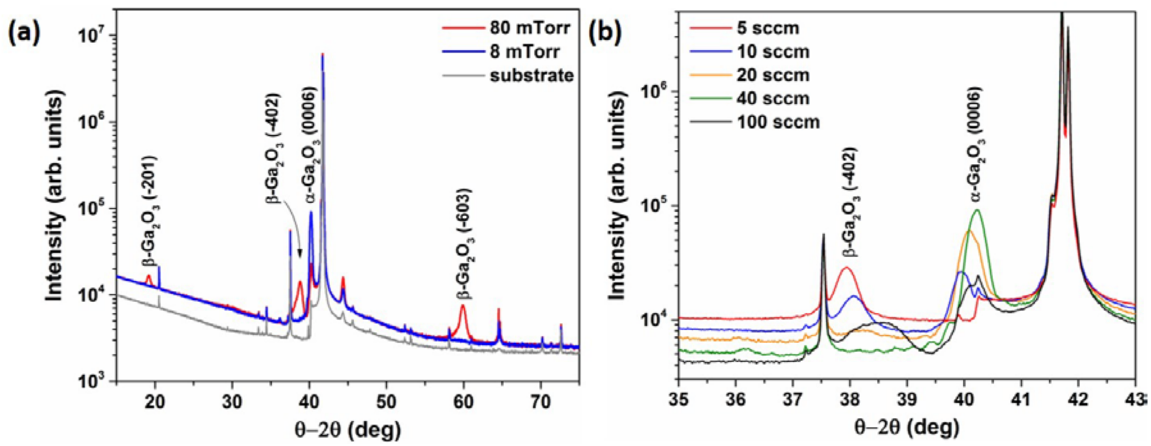

Fig. 1: XRD spectra showing (a) the influence of chamber pressure and (b) O_2 plasma flow on the resulting Ga_2O_3 phase.

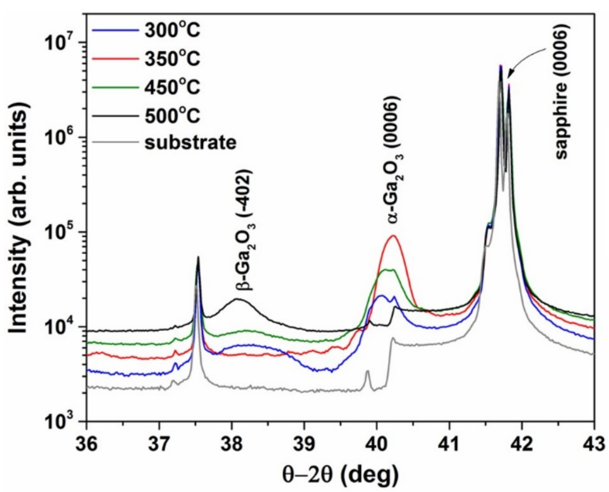

Fig. 2: XRD spectra showing phase selectivity of Ga_2O_3 with various growth temperatures at 8 mTorr