# PAMBE による m 面サファイア基板上 α-$Ga_2O_3$ の成長

## Stabilization of α-$Ga_2O_3$ on m-plane α-$Al_2O_3$ by Plasma-Assisted MBE

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Metastable α-$Ga_2O_3$, which has the rhombohedral corundum structure, has attracted a lot of interest in recent years, because its alloys with α-$In_2O_3$ and α-$Al_2O_3$ (sapphire) allow wide bandgap engineering from 3.7 to 8.7 eV [1]. Very recently, it has been demonstrated that binary single phase α-$Al_2O_3$/$Ga_2O_3$ superlattices can be coherently grown on r-plane sapphire by MBE [2]. However, the growth of thick isomorphic α-$Ga_2O_3$ is challenging as the stabilization of α-$Ga_2O_3$ is limited by the formation of the thermodynamically most stable phase β-$Ga_2O_3$, which was found to depend on the orientation of sapphire surface [3]. In this research, by comparatively studying $Ga_2O_3$ grown on r- and m-plane sapphire, we show that α-$Ga_2O_3$ is considerably better stabilized on m-plane sapphire.

$Ga_2O_3$ was grown on r- and m-plane sapphire substrates by oxygen plasma-assisted MBE, at a substrate thermocouple temperature of 650°C. The r-plane sapphire substrate was annealed at 1050°C in air in order to obtain atomic steps in the surface morphology. Single phase epitaxial α-$Ga_2O_3$ is confirmed by the XRD (Fig.1). The $(\alpha h\nu)^2$-$h\nu$ Uv-vis transmission spectra of the $Ga_2O_3$ films have two step-like onsets (Fig.2), which has been described earlier as two allowed direct transitions with excitonic effects in the α-$Ga_2O_3$ (5.61 and 6.44 eV) [4]. The XRD and in situ RHEED patterns [Fig. 1 (a) and (c)] confirm that isomorphic α-$Ga_2O_3$ was stabilized on m-plane sapphire up to a film thickness of ca. 200 nm. On the other hand, RHEED patterns of $Ga_2O_3$ grown on r-plane sapphire revealed the inclusion of β-$Ga_2O_3$ phases [Fig.1 (d)]. These results suggest that m-plane sapphire is more suitable for the growth of thick α-$Ga_2O_3$ films. The explanation of the enhanced stability of α-$Ga_2O_3$ can be attributed to geometrical effect: the c-plane facet is believed to facilitate the formation of the β-$Ga_2O_3$ [5] and when $Ga_2O_3$ is grown on m-plane sapphire, unlike c- and r-plane sapphire, the c-plane is exactly perpendicular to the growth direction and therefore the c-plane facet can be greatly shadowed from growth.

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[3] Z. Cheng, *et. al*., Appl. Phys. Lett. **111**, 162104 (2018). [4] A. Segura, *et. al.*, Phys. Rev. Materials **1**, 024604 (2017).
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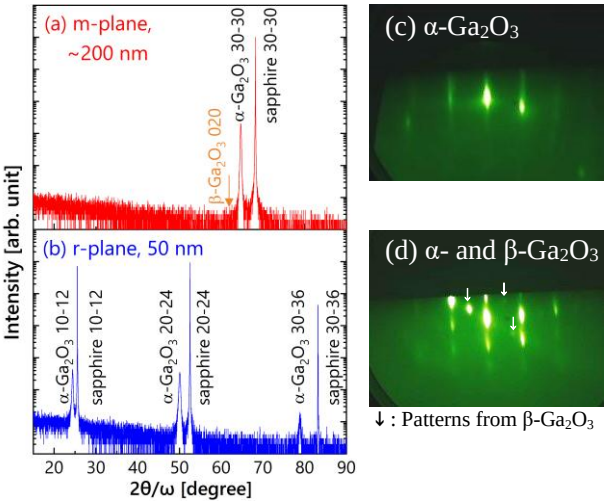


Fig. 1. Symmetric XRD 2θ/ω scans and RHEED patterns of $Ga_2O_3$ grown on [(a) and (c)] m-plane and [(b) and (d)] r-plane sapphire.

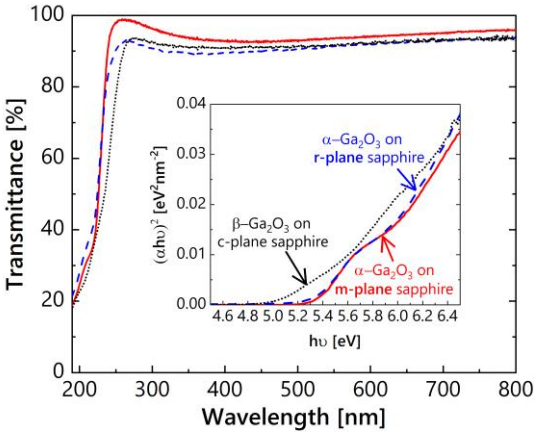


Fig. 2. Optical transmission and (inset) the corresponding $(\alpha h\nu)^2$-$h\nu$ plots of $Ga_2O_3$ of similar thicknesses on r-plane (blue dashed lines) and m-plane sapphire (red solid lines). The results of β-$Ga_2O_3$ (black dotted lines) are shown for comparison.

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