Growth of (100) β-Ga_2O_3 on Miscut Substrates using MOCVD

Soren Hellyer[1], Joshua Buontempo[2], Cameron Gorsak[2], Hari Nair[2]

[1]Department of Materials Science and Engineering, Iowa State University
[2]Department of Materials Science and Engineering, Cornell University

Abstract

β-Ga_2O_3 is a promising material for use in vertical transistors due to its ultra-wide band gap and high breakdown field. Epitaxially growth using MOCVD is a commercially scalable technology that can meet the thickness requirements and growth rates required for vertical devices. Current growth on (010) substrates result in rough films and extended defects. In this work, β-Ga_2O_3 is grown on miscut (100) substrates to encourage step flow growth, reduce roughness, and prevent twinning. Growths on 4° and 6° miscut substrates show incredible promise for device use, being the smoothest thick β-Ga_2O_3 films in the world.

Introduction

β-Ga_2O_3 is a promising material for use in power electronics. It has an ultra-wide band gap (4.8 eV) and a higher breakdown field than currently used materials, silicon carbide and gallium nitride [1,2]. Additionally, β-Ga_2O_3 has a lower specific on-resistance than these materials for a given breakdown voltage. For high voltage applications, these properties mean that vertical transistors made using β-Ga_2O_3 can have thinner drift layers, resulting in increased efficiency and higher operating voltages. However, for commercial applications Ga_2O_3 vertical devices require drift layers greater than 10 µm thick, sub-nm roughness, and high growth rates (>3 µm/hr).

Metal-organic chemical vapor deposition (MOCVD) is a popular epitaxial growth method that shows promise for thick β-Ga_2O_3 films grown at rates exceeding 3 µm/hr.

Previous investigations have shown that MOCVD growths on (010) β-Ga_2O_3 substrates produce rough films with high degree of faceting favoring the low energy (100) and $(\bar{2}01)$ facets [3]. Additionally, growing on (010) substrates show extended defects likely stemming from the substrate [4,5]. Growing directly on the (100) β-Ga_2O_3 substrates shows promise for smoother films but is also prone to twinning due to island growth. Twinning can be prevented by encouraging step-flow growth on terraces and preventing island growth.

Terraces are formed by introducing a miscut on the (100) surface in the $\langle 00\bar{1}\rangle$ direction with $(\bar{2}01)$ facets. The width of the terrace is controlled by changing the step height: the higher the miscut angle, the narrower the terrace width, as shown in Fig 1. Step-flow growth is most likely to occur when the diffusion length of the adatoms is close to the terrace width [6].

Methods

β-Ga_2O_3 films were grown using MOCVD on Fe-doped (~10^{18} cm^{-3}) β-Ga_2O_3 substrates of miscuts 1.8°, 3.5°, and 5.9°. The substrates were cleaned using acetone and IPA before being etched in HF for 30 minutes. They were then annealed at 1100 °C for 3 hours with a heating rate of 300 °C/hr and a cooling rate of 500 °C/hr. β-Ga_2O_3 growth was conducted in a MOCVD system using Trimethyl gallium as the gallium precursor. The samples were grown at 950 °C for 105 minutes with a growth rate of 2.94 µm/hr.

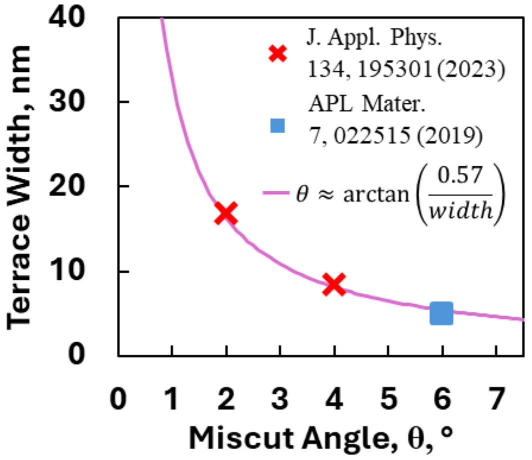

Fig. 1. Theoretical and expiremental values of β-Ga_2O_3 (100) *terrace widths as a function of miscut angle along the* $\langle 00\bar{1}\rangle$.

Results

Fig. 2 shows atomic force microscopy (AFM) images of the bare substrates post annealing as well as post growth. After the etching and annealing process, there is no clear sign of step formation. However, all three substrates show sub-1nm RMS roughness values, conducive to subsequent device fabrication. Additionally, as shown in the 2° images, there appear to be particles on the surface, which may be affecting the ability to form steps. It is worth noting that the terrace widths were comparable to our AFM tip radius of 10 nm, so it is unclear whether terraces would be resolvable.

We grew 5 µm of β-Ga_2O_3 on miscut β-Ga_2O_3 substrates at a growth rate of 2.94 µm/hr. The 2° miscut sample shows clear signs of island growth and has an RMS roughness of 1.08 nm. The 4° and 6° samples have RMS roughness values of 0.247 nm and 0.212 nm respectively. The 4° and 6° samples terraces are twice the height and twice the width of the calculated terrace dimensions, characteristic of step bunching. Step bunching could be attributed to over annealed substrates.

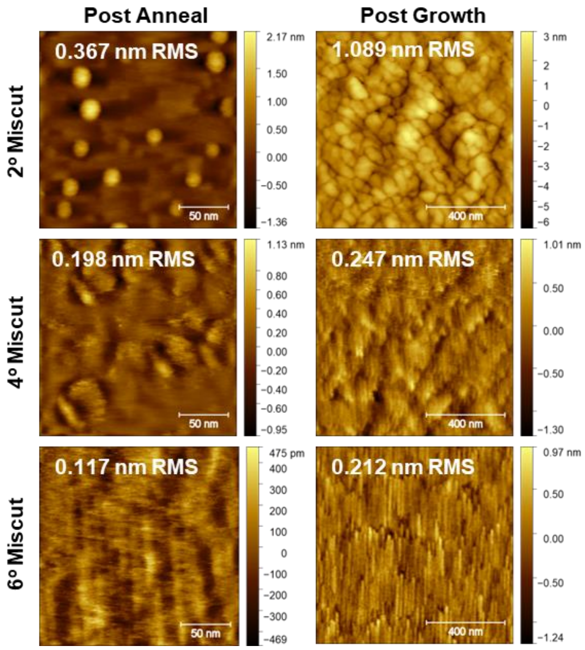

Fig. 2. AFM images of the β-Ga_2O_3 *substrates post-annealing (left) and the* β-Ga_2O_3 *films post growth (right) for a 2°, 4°, and 6° miscut.*

Conclusions

In this work, we grew the first thick β-Ga_2O_3 that meets the high growth rate and sub-nm roughness requirements needed for commercializing β-Ga_2O_3 vertical devices. 4° and 6° miscut substrates show the most promise for achieving step-flow growth which provides smooth films and reduces the likely hood of twinning.

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