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Elimination of Threading Dislocations in Corundum Ga_2O_3 Grown by Double-layered Epitaxial Lateral Overgrowth

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Abstract

We demonstrated double-layered epitaxial lateral overgrowth (DLELO) of α-Ga_2O_3 by halide vapor phase epitaxy for the first time. The second ELO α-Ga_2O_3 islands which selectively grew through the windows of the patterned masks prepared on a polished ELO α-Ga_2O_3 film coalesced step-by-step due to the nested-structure mask pattern. No dislocation was observed by TEM not only above the masks but also above the windows of second ELO. We obtained the continuous crystalline α-Ga_2O_3 with a low density of dislocations (estimated to be less than 5×10^6 cm^{-2}) in the entire second-ELO surface by DLELO technique.

1. Introduction

Alpha-gallium oxide (α-Ga_2O_3) is one of the most promising semiconductors for power device applications because of the large bandgap energy (E_g ~5.3 eV) [1]. Thus far, α-Ga_2O_3 films have been grown by heteroepitaxy, such as mist-CVD [1] and halide vapor phase epitaxy (HVPE) [2], and usually include a high density of dislocations (~10^{10} cm^{-2}) because of the lattice mismatch. We have reported epitaxial lateral overgrowth (ELO) of α-Ga_2O_3, and confirmed that the quality of the regrown α-Ga_2O_3 was improved by blocking and bending of dislocations (estimated to be less than 5×10^6 cm^{-2}) [3]. However, there still remained areas with a high density of dislocations periodically. Thus, we performed the ELO process twice so that the second ELO mask covered the first ELO windows to reduce the dislocation density in the entire surface of α-Ga_2O_3 films.

2. Experimental

Figure 1 shows double-layered epitaxial lateral overgrowth (DLELO) process. The first ELO was performed by a typical HVPE system on (0001) α-Ga_2O_3/sapphire templates with dot-patterned TiO_x masks. The regrowth of α-Ga_2O_3 islands were stopped before coalescence in order to avoid simultaneous coalescence of α-Ga_2O_3 islands, which prevent the film from seriously cracking and breaking. We prepared the second patterned mask on the first ELO α-Ga_2O_3 after flattening the α-Ga_2O_3 islands by chemical mechanical polishing. The distance between windows of the second mask was shorter than that of the first mask and nested-structure mask pattern was employed so that α-Ga_2O_3 islands of the second ELO coalesce each other in a step-by-step manner, leading to the suppression of the steep increase of tensile strain associated with the island coalescence. We employed HVPE to regrow α-Ga_2O_3 islands on the second mask windows. The DLELO α-Ga_2O_3 films were observed by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Crystal structure of the DLELO α-Ga_2O_3 was investigated with selected area electron diffraction (SAED).

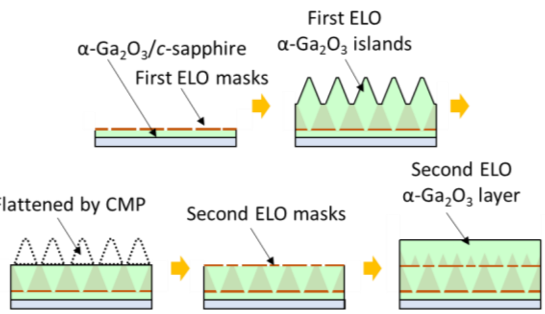

Fig. 1 Schematic process flow of DLELO of α-Ga_2O_3.

3. Results and Discussion

Figure 2 shows a cross-sectional SEM image of a DLELO film grown with a nominal thickness (thickness for a flat film grown under the same growth conditions) of 10 μm. The bright-contrast portions represent α-Ga_2O_3 islands and the dark-contrast portions represents polycrystalline κ-Ga_2O_3 [3,4]. The layer below the horizontal boundary line was the polished first ELO film. Meanwhile, the layer above the horizontal boundary line was the regrown and coalesced second ELO film. It was confirmed that the α-Ga_2O_3 regrew homoepitaxially through the second ELO windows and that lateral growth of α-Ga_2O_3 was carried out on second ELO masks.

Figure 3 present a plan-view and a cross-sectional SEM images of the second ELO α-Ga_2O_3 with a nominal thickness of 86 μm. All the islands regrown through the second ELO windows coalesced with each other in a step-by-step manner because of nested structure mask pattern. On the other hand, polycrystals deposited on the mask was completely buried by the second ELO α-Ga_2O_3 islands. The first ELO layer and the polycrystalline κ-Ga_2O_3 depositions were entirely covered with an α-Ga_2O_3 layer regrown in the second ELO. The film thickness was ~100 μm, although the surface was bumpy at the present stage. The second ELO of α-Ga_2O_3 was successfully performed.

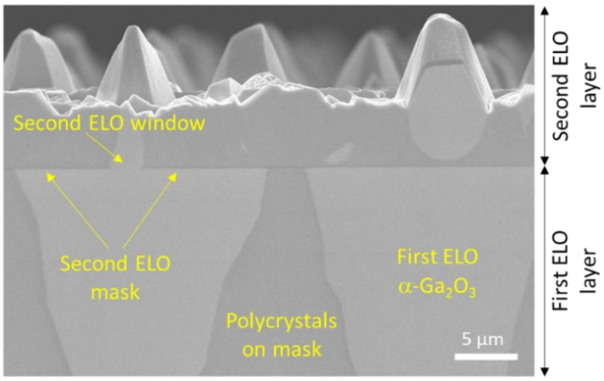

Fig. 2 Plan-view SEM image of the second ELO α-Ga_2O_3 regrown with a nominal thickness of 10 μm.

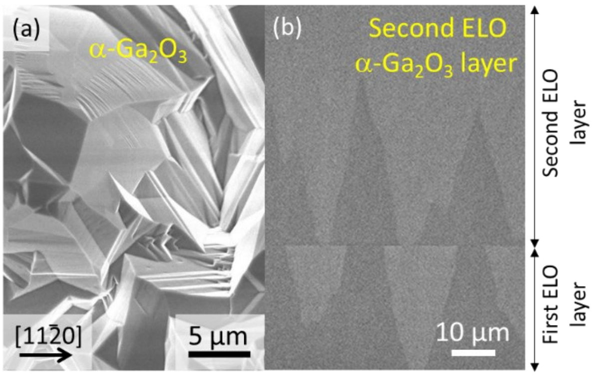

Fig. 3 (a) Plan-view and (b) cross-sectional SEM images of the second ELO α-Ga_2O_3 regrown with a nominal thickness of 86 μm. Note that the first ELO layer and polycrystals deposited on the second ELO mask were completely covered with the second ELO α-Ga_2O_3 layer.

Figure 4 shows a plan-view TEM image of a second ELO α-Ga_2O_3 island and its SAED patterns. We observed an incompletely coalesced second ELO α-Ga_2O_3 island regrown above both mask and window, which would be easy to identify the positions of the windows and masks. The SAED patterns observed both above mask and window of the ELO α-Ga_2O_3 island. The crystal structure of the island was corundum. No dislocation was observed not only in the laterally grown area but also directly above the second ELO window. The threading dislocation density was estimated to be less than 5×10^6 cm^{-2} on the basis that the there was no dislocation in all area sampled. The periodically remained dislocations in the first ELO α-Ga_2O_3 film were eliminated and the entire second-ELO surface of α-Ga_2O_3 was improved in quality by the DLELO technique.

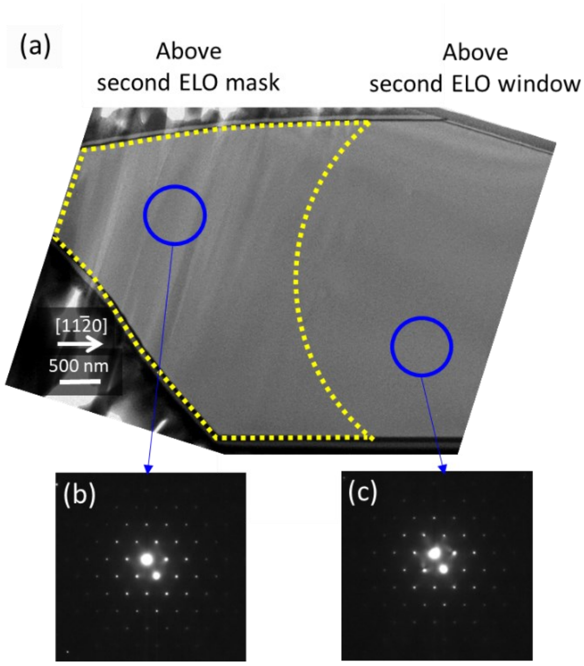

Fig. 4 (a) Plan-view TEM image of a second ELO α-Ga_2O_3 island. The area surrounded by broken line was above the second ELO mask and the other area was above the second ELO window. (b), (c) SAED patterns of the island taken at the circled areas in (a).

4. Conclusions

DLELO of α-Ga_2O_3 by HVPE was demonstrated for the first time. The second ELO α-Ga_2O_3 grew epitaxially and selectively in a step-by-step manner due to the nested-structure mask pattern. No threading dislocation was found by TEM not only above the second ELO mask but also above the second ELO window. The dislocation density was estimated to be less than 5×10^6 cm^{-2}. We obtained a continuous α-Ga_2O_3 film with a low density of dislocations in the entire second-ELO surface.

Acknowledgements

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