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In-plane Anisotropy in The Direction of The Dislocation Bending in Corundum Ga_2O_3 Grown by Epitaxial Lateral Overgrowth

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Abstract

We observed dislocations in epitaxial lateral overgrown α-Ga_2O_3. The films were grown by halide vapor phase epitaxy and flattened by chemical mechanical polishing. The α-Ga_2O_3 films grown by halide vapor phase epitaxy and flattened by chemical mechanical polishing were etched by 10 wt % KOH solution heated at 60ºC. The threading dislocations were observed by atomic force microscopy as emphasized lines and dots, which consists with the results and discussion in our previous study. It was revealed that α-Ga_2O_3 possess in-plane anisotropy in the direction of the dislocation bending, that is, dislocations in α-Ga_2O_3 tended to bend in the directions of *m*-axes instead of *a*-axes, leading to the expansion of the areas with few dislocations in the *a*-directions from the position of an ELO window.

1. Introduction

Alpha-gallium oxide (α-Ga_2O_3) is one of the most promising semiconductors for power device applications owing to the large bandgap energy (E_g ~5.3 eV) [1]. α-Ga_2O_3 films usually include a high density of dislocations (~10^{10} cm^{-2}) because α-Ga_2O_3 is grown on foreign substrates, such as sapphire. We have reported that the dislocations in α-Ga_2O_3 were blocked and bent by epitaxial lateral overgrowth (ELO) technique. Transmission electron microscopy revealed that the dislocation density was reduced to less than 5 × 10^6 cm^{-2} [2]. Thus, we performed a simple low-cost wet etching using KOH to observe lower density of dislocations in ELO α-Ga_2O_3.

2. Experimental

Facet-initiated ELO of α-Ga_2O_3 was performed by conventional halide vapor phase epitaxy on (0001) α-Ga_2O_3/sapphire templates with dot-patterned TiO_x masks. The circle-shaped ELO windows with a diameter of 3 μm were arranged to form a triangle lattice. The distance between the edges of the nearest windows was 20 μm or 5 μm. A regular array of α-Ga_2O_3 islands was regrown in the same way as our previous study [3,4]. The KOH etching was applied to ELO islands with a diameter of approximately 20 μm which did not coalesce with each other yet and ELO film into which islands regrown through 5 μm distanced windows coalesced. The ELO α-Ga_2O_3 was flattened by chemical mechanical polishing in order to observe the horizontal plane of the α-Ga_2O_3 before etching. The flattened α-Ga_2O_3 films were immersed in 10 wt % KOH solution heated at 60ºC with ultrasonic vibration (40kHz). Etching time was varied up to 40 min. The dislocations were observed by atomic force microscopy (AFM).

3. Results and Discussion

Figure 1 shows AFM images of a polished ELO α-Ga_2O_3 island after KOH etching. The broken circle line represents the position of the ELO window. It is confirmed that traces corresponded to dislocations were emphasized as etch pits. The etch-pit method was applicable to the evaluation of dislocations in α-Ga_2O_3 crystal. The dislocations directly above ELO mask windows and in the vicinity (the center of the α-Ga_2O_3 island) were observed as integrated dots and/or short lines. Meanwhile, the dislocations in the laterally grown area (the periphery of the α-Ga_2O_3 island) were observed as long lines sparsely. The difference in the length and the place of

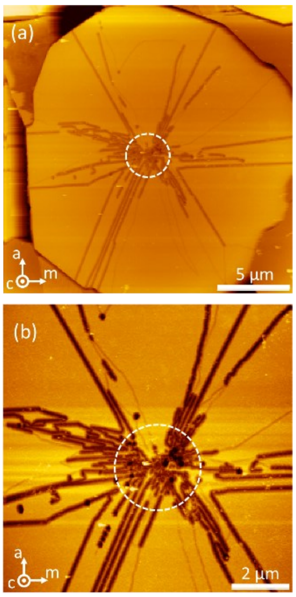

Fig. 1 (a) AFM image of a polished ELO α-Ga_2O_3 island after KOH etching. The broken circle lines represent the position of ELO window (b) is a magnified image taken near the center of the island.

the dislocations implied the blocking and the bending of dislocations, which consisted with the previous study [1].

It was revealed that α-Ga_2O_3 had an in-plane anisotropy in the direction of the dislocation bending. Almost all the dislocations in ELO α-Ga_2O_3 islands bent in the directions of *m*-axes, and few dislocations were introduced in the directions of *a*-axes. The in-plane anisotropy implied that the dislocations in ELO α-Ga_2O_3 islands behaved as follows: The lattice mismatch between the α-Ga_2O_3 film and the substrate caused dislocations. Some of the dislocations were blocked by ELO masks; others were propagated into the regrown region layer through ELO windows. The dislocations introduced through the windows were gradually reduced by bending of dislocations as the islands grew (Fig. 2(a)). At the same time, the areas with few dislocations expanded in the *a*-directions from the position of an ELO window owing to in-plane anisotropy in the direction of the dislocation bending (Fig. 2(b)).

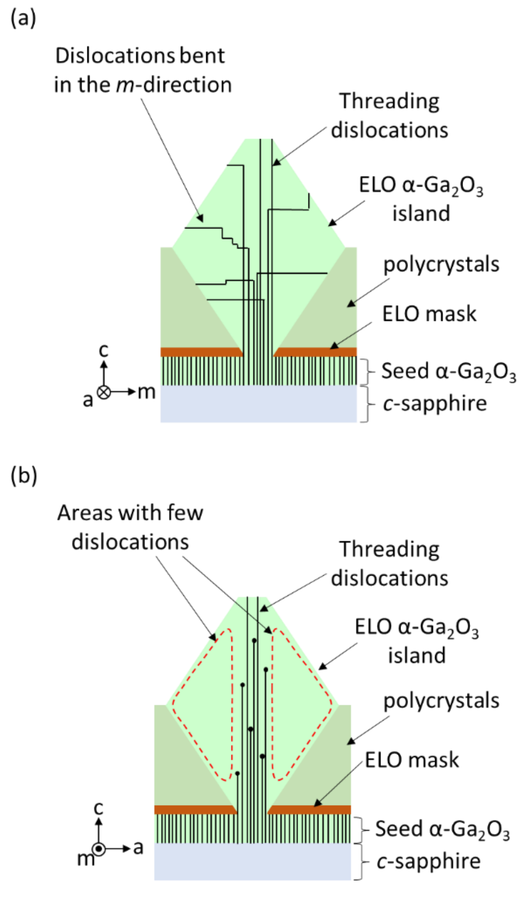

Fig. 2 Schematic cross-sectional of an ELO α-Ga_2O_3 island with dislocation bending in the m-directions.

Figure 3 show AFM images of polished KOH-etched α-Ga_2O_3 films of which the ELO mask was arranged to be parallel to *m*-axes and *a*-axes, respectively. The dislocation bending only in the direction of *m*-axes was also observed in α-Ga_2O_3 film into which the α-Ga_2O_3 islands coalesced. At the same time, there was an important difference between the way areas with few dislocations form: the ELO α-Ga_2O_3 film grown with the mask of which one sides of the triangle lattice was parallel to the *a*-axes possessed rhombus areas with few dislocations, and that with the mask of which one sides of the triangle lattice was parallel to the *m*-axes form triangular areas with few dislocations. These results and discussions suggested that in-plane anisotropy is an important factor in controlling dislocations in ELO of α-Ga_2O_3. The designs for ELO mask patterns and the process of ELO can be optimized on the basis of the in-plane anisotropy.

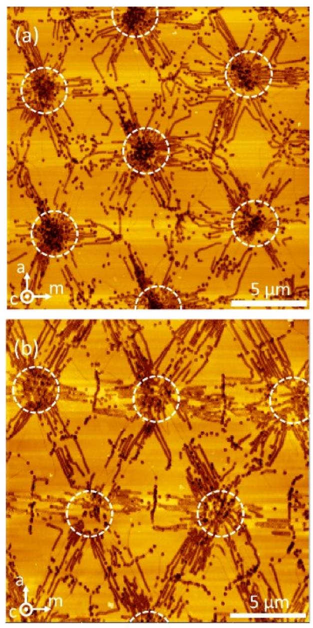

Fig. 3 AFM images of polished and KOH-etched ELO α-Ga_2O_3 films of which the mask was arranged to be parallel to (a) *a*-axes and (b) *m*-axes. The broken circles represent the position of ELO window.

4. Conclusions

It was confirmed that the etch-pit method was applicable to the evaluation of dislocations in α-Ga_2O_3 crystal. Moreover, it was revealed that α-Ga_2O_3 has an in-plane anisotropy in the direction of the dislocation bending. The dislocations in α-Ga_2O_3 tended to bend in the directions of *m*-axes, and the areas with few dislocations expanded in the *a*-directions from the position of an ELO window.

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