A novel abrasive-free chemical planarization of oxide materials using pure water and Pt catalyst

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Abstract

A novel abrasive-free chemical planarization method has been developed. This method can produce a highly ordered surface using a polishing pad with a catalytic compound. The catalyst enhances an etching reaction at the protruded areas of the substrate surface which preferentially contact the pad. We employed platinum as a catalyst and pure water as the etching solution to planarize oxide materials such as quartz, sapphire, zinc oxide, and silica glass. The results show that one bilayer height steps and atomically ordered terraces were observed on the surfaces of the crystalline substrates. The etching and material removal mechanisms are discussed in this paper.

1. Background

Oxide materials are widely used in many industrial fields because of their excellent optical, electrical, and electronic properties. For example, sapphire is the most commonly used substrate to grow GaN single crystals. Zinc oxide is a promising material for optoelectronic devices because of its large band gap and high exciton binding energy. Quartz and silica glass are utilized for piezoelectric devices and highly accurate optical components. To enhance their performances, the preparation method of geometrically and crystallographically ordered surfaces is highly demanded. Generally, chemical mechanical polishing (CMP) is employed. However, to obtain crystallographically ordered surfaces is difficult because of the use of abrasives. We have developed a novel abrasive-free chemical planarization method named catalyst referred etching (CARE) to realize an atomically controlled planarization.

2. Introduction of CARE and research objective

A schematic of the CARE apparatus is shown in Figure 1. In this, the substrate is weakly pressed onto the catalyst pad. The pad and substrate independently rotate on each axis in an etchant. In this method, the catalyst pad generates atomic or molecular species that react with the substrate material. The substrate surface is flattened by selectively removing protrusions via a catalytic reaction induced at contact points mainly between the protrusion and pad surface. Therefore, a smooth and crystallographically well-ordered surface is obtained. This method has already been applied to planarize SiC and GaN semiconductor materials. The catalyst is a 100 nm thick film of platinum on a fluoro-rubber pad. As an example, the surface of GaN after CARE processing is shown here. Table 1 shows the experimental conditions. The etchant was pure water without any chemical. As shown in Figure 2, the obtained surface is highly ordered both geometrically and crystallographically on the entire area of the 2 inch GaN wafer [1]. A first-principle molecular dynamics calculation was also performed to understand the removal mechanism; a hydrolysis reaction enhanced by Pt seems to be responsible [2].

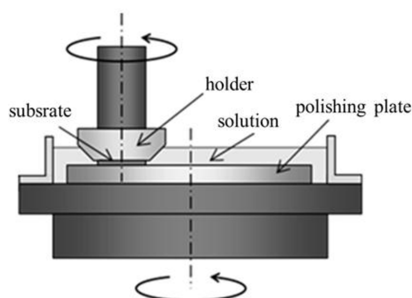


Figure 1. Schematic of CARE apparatus

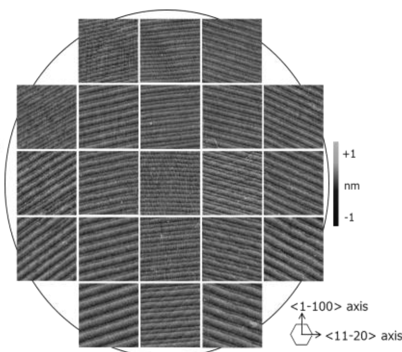


Figure 2. GaN surface after CARE

This result shows that CARE is expected to planarize oxide materials since these are generally produced by hydrothermal synthesis methods based on dehydration, which is the reverse reaction of

Table 1 Condition

Sample	2 inch GaN wafer
Catalyst	Pt
Pressure	400 hPa
Rotation speed	10 rpm
Solution	Pure water

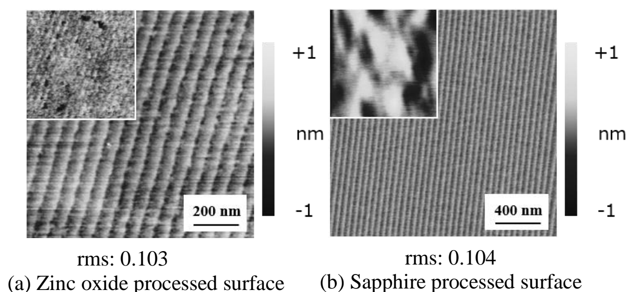
hydrolysis. In this paper, we applied the CARE method to planarize oxide materials.

3. Experimental method and condition

Two-inch wafers of quartz (10−11), sapphire (0001), zinc oxide (0001), and silica glass were tested. The experimental conditions are the same as those shown in table 1. The removal rate was determined by measuring weight loss. The surface morphology before and after CARE were observed by atomic force microscopy (AFM) (Digital Instruments) and optical interferometric microscopy (Zygo Newview).

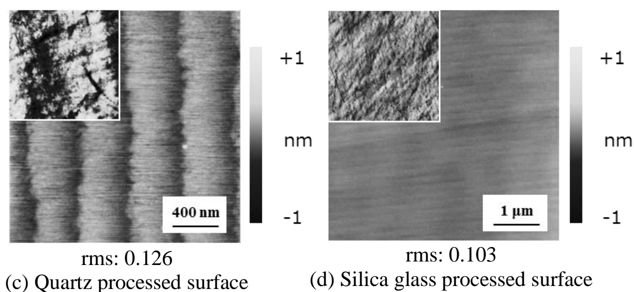
4. Results and Discussion

Figure 3 shows AFM images before and after CARE. Straight steps and atomically smooth terraces were observed on the crystalline substrates. The crystal structure and cross sectional surface profile of the CARE processed quartz substrate are shown in Figure 4. The step height corresponds to a single-bilayer height of 3.4 Å. Similarly, the step height of sapphire and zinc oxide surfaces were also single bilayer. The silica glass which is an amorphous oxide material, was also atomically flattened as shown in Figure 3 (d). Figure 5 shows the surface roughness of silica glass before and after CARE observed in the optical interferometric microscope. The roughness is drastically improved from 0.605 nm rms to 0.108 nm rms. We found that the CARE method is excellent in preparation of geometrically and crystallographically well ordered surfaces for oxide materials, where the CMP technique is difficult to realize. The removal rates of quartz, sapphire, zinc oxide, and silica glass were 6.6 nm/h, 3 nm/h, 126 nm/h, and 200 nm/h, respectively. To increase the removal rate, other catalyst materials are being combinatorially investigated.



rms: 0.103
(a) Zinc oxide processed surface

rms: 0.104
(b) Sapphire processed surface



rms: 0.126
(c) Quartz processed surface

rms: 0.103
(d) Silica glass processed surface

Figure 3. AFM images of before and after CARE process

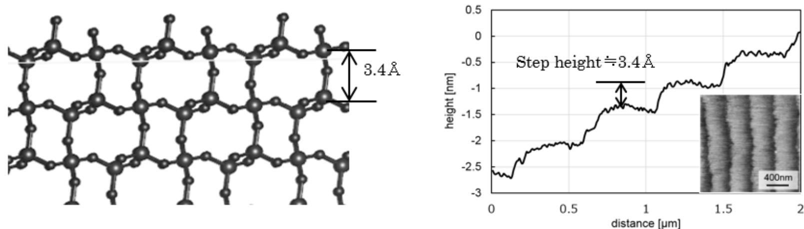
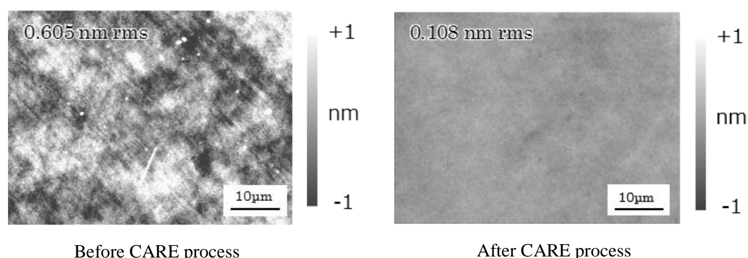


Figure 4. Crystal model and cross sectional surface profile of Quartz after CARE



Before CARE process

After CARE process

Figure 5. Surface roughness of silica glass before and after CARE

5. Conclusion

Geometrically and crystallographically highly ordered surfaces were obtained on oxide materials by only a wet etching procedure, which normally requires high-temperature annealing in vacuum or in a controlled gaseous atmosphere.

References:

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