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CHEMICAL MECHANICAL POLISHING OF SAPPHIRE WAFER USING MIXED SILICA NANOPARTICLES

TRACK OR CATEGORY
Surface Engineering

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INTRODUCTION

Sapphire has become the most widely used substrate material for fabricating GaN based light emitting diodes (LED) devices. With the rapid development of photoelectric technology, the increment of substrate planarization efficiency and the study of removal mechanism have become increasingly significant due to the higher demand of superior surface finish. However, owing to its high hardness and brittleness, sapphire wafer is difficult to be polished ideally. Chemical mechanical polishing (CMP) is the most efficient method to obtain ultra smooth surface through the mechanical abrading and chemical reaction [1].

In the paper, CMP performances of sapphire using mixed silica abrasive nanoparticles with different sizes (10 nm and 100 nm) were studied. We found that the mixed silica nanoparticles could not only provider higher removal rate than any single size silica particles, but also obtain better and smoother surface. The relative removal mechanisms of sapphire were discussed.

EXPERIMENTAL

2 inch/370 μm c-plane (0001) sapphire wafers were carried out planarization through polishing machine. Material removal rate (MRR) of sapphire is through calculation as follows:

$$MRR = \Delta m/\rho\pi r^2 t$$

Δm is the removal mass of sapphire wafer by professional electronic balance (OHAUS DISCOVERY), whose resolution is 0.00001 g, ρ (the density of sapphire) is 4.0 g/cm^3, r is the radius of sapphire wafer, and t is the polishing time. The surface topography and roughness Ra were investigated by AFM (Bruker Dimension ICon).

RESULTS AND DISCUSSION

Fig. 1 shows that the relationship between MRR of sapphire and the content of 100 nm silica particle (with and without 2.5% 10 nm silica). When using the slurry without 10 nm silica, MRR of sapphire increases with the increment of the content of 100 nm silica. On the other side, when adding 10 nm silica into the slurry with 100 nm silica, MRR of sapphire becomes much higher than that by the original slurry with 100 nm silica. Thus, the mixed abrasives with 100 nm silica and 10 nm silica could improve MRR of sapphire remarkably.

Meanwhile, when the slurry including mixed particles with the total silica content of 15% (including 12.5 % 100 nm SiO_2 and 2.5% 10 nm SiO_2), MRR of sapphire is higher than that by the slurry including 20% 100 nm SiO_2. It is indicated that 10 nm silica particles under the same content show better the total removal effect towards sapphire than 100 nm SiO_2.

On the other side, when the content of 100 nm SiO_2 in the slurry with 10 nm silica is 20%, MRR of sapphire presents a half higher than that by the slurry without 10 nm silica, and then the increment of MRR induced by 10 nm SiO_2 reaches maximum. However, when the content of 100 nm SiO_2 increases to 28.5%, the increment of MRR falls off.

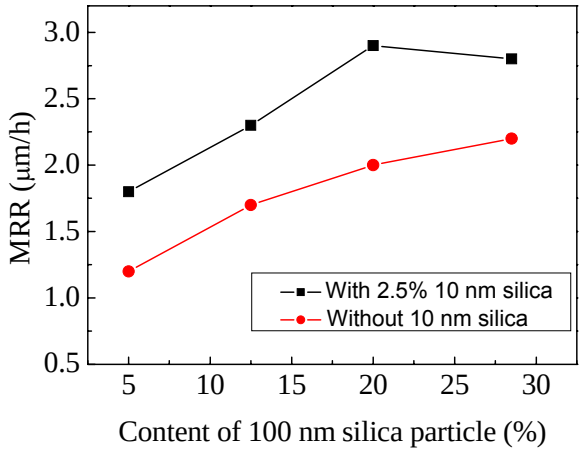


Fig. 1. The relationship between MRR of sapphire and the content of 100 nm silica particle (with and without 2.5% 10 nm silica).

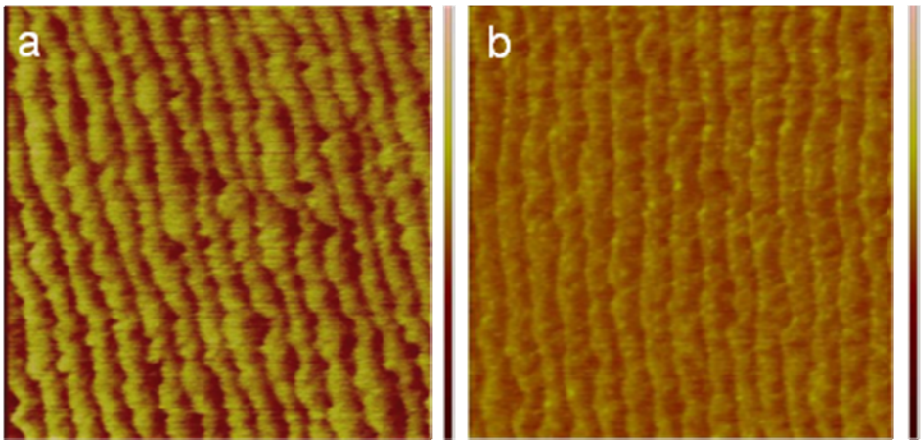


Fig. 2. AFM images (1×1 μm^2 area) of the sapphire surface polished by the slurry with different size silica abrasive. a. 100 nm silica, Ra: 0.106 nm; b. 100 nm silica and 10 nm silica, Ra: 0.0686 nm.

As we known, based on the theory of crystallography, hexagonal crystal wafer materials, like sapphire and SiC, have remarkable characteristics: if the (0001) surface have a slight misorientation off c-axis, the surface will present atomic step-terrace topography when atomically smooth [2]. Using colloidal SiO_2 nanoparticle as the abrasive, the polished sapphire surface with atomic step structure morphology and low roughness could be acquired by AFM measurement, as our previous study demonstrated [3].

Our research [4] demonstrates that we could observe the residual soft layer of the reaction product on the atomic step-terrace morphology surface via AFM measurements. Thus, we would investigate the effects of silica abrasive particle size on the formation and removal of soft layer to study the sapphire removal mechanism.

AFM images demonstrate the mixed abrasives with 100nm SiO_2 and 10nm SiO_2 could provide smoother surface with lower roughness surface, and straighter and smoother atomic step edge, comparing with the single 100nm SiO_2 abrasive. As our previous research demonstrated [5], under the same operating parameters, when the abrasive size is large, the impact force on the step edge by single abrasive is large, and the mechanical removal unit is also large, resulting in forming irregular step edge surface. Oppositely, if the abrasive size is small, the impact force on the step edge by single abrasive is also low, causing more regular and straighter step edge surface. Thus, owing to the smaller and finer mechanical removal unit, the mixed abrasive including 10 nm silica particles could obtain smoother surface.

On the other side, as the previous research demonstrated, under the approximate temperatures by the same polishing operating parameters, 10nm SiO_2 just needs the less activation energy of solid phase reaction with sapphire, resulting in helping to react with sapphire to promote the removal.

Fig. 3 shows that silica particles dispersion states in the polishing process seem distinct, under the different content 100 nm silica after adding 10nm SiO_2. When the content of 100 nm SiO_2 is low comparatively, 10 nm SiO_2 have a stable dispersion state, and could still participate in having solid state reaction with sapphire, so as to improve MRR of sapphire obviously. When the content of 100 nm SiO_2 is high comparatively, 10 nm SiO_2 particles could convert into the bridges between 100 nm SiO_2 particles, so as to lead to the aggregation of 100 nm SiO_2 particles. Thus, the "growth" of SiO_2 particles decreases the contact area of silica particles reacting with sapphire, resulting in the drop of the chemical activity with sapphire, and the decrement of the total MRR. Thus, when the content of 100 nm SiO_2 increases to 28.5%, the increment of MRR brought by 10 nm SiO_2 decreases indeed.

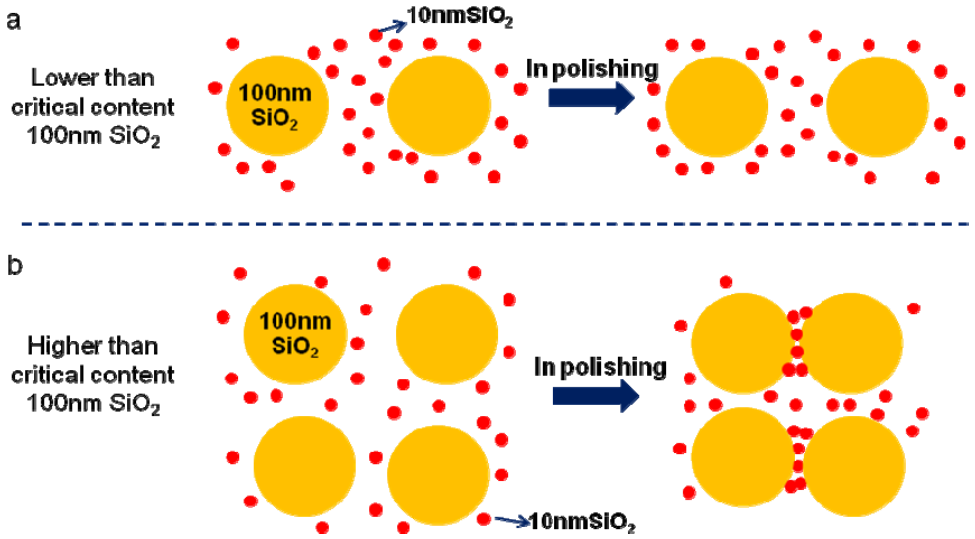


Fig. 3. Silica particles dispersion states in the polishing process, under the different contents 100 nm SiO_2 of the slurry adding 10nm SiO_2. a. Lower than critical content 100 nm SiO_2, b. Higher than critical content 100 nm SiO_2.

In summary, the slurry including the mixed abrasive with 10 nm SiO_2 and 100 nm SiO_2 is employed, so that the removal rate of sapphire is improved greatly and the ultra-smooth surface with lower roughness is obtained.

ACKNOWLEDGMENTS

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KEYWORDS

Sapphire, chemical mechanical polishing, silica, atomic step structure