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Chemical Mechanical Polishing (CMP) Characteristics of Ferroelectric Thin Films for FRAM Applications

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In this paper, we first applied the chemical mechanical polishing (CMP) process to the planarization of ferroelectric film in order to obtain a good planarity of electrode/ferroelectric film interface. $Ba_{0.6}Sr_{0.4}TiO_3$ (shortly BST) ferroelectric film was fabricated by the Sol-Gel method. And then, we compared the structural characteristics before and after CMP process of $Ba_{0.6}Sr_{0.4}TiO_3$ films. Their dependence on slurry composition was also investigated. We expect that our results will be useful promise of global planarization for ferroelectric random access memories (FRAMs) application in the near future.

Key words: CMP (chemical mechanical polishing), ferroelectrics, $BaSrTiO_3$ (BST), Sol-Gel, RMS (root mean square), RR (removal rate), WIWNU (within-wafer non-uniformity)

1. INTRODUCTION

With the advent of integration of dynamic random access memories (DRAMs) and ferroelectric random access memories (FRAMs), the thickness of insulator in capacitors will approach the quantum limitation. Using the conventional SiO_2 films, the thickness of the films can be less than 0.5 nm but the dielectric constant also will be lower. Therefore, the utilization of high dielectric constant materials will become inevitable [1]. The perovskite ferroelectric materials of the PZT, SBT and BST series [2, 3] will attract much attention for application to ULSI devices. Among, these materials, BST ($Ba_{0.6}Sr_{0.4}TiO_3$) is a well-known dielectric material and has been attractive for the applications such as capacitors and FRAMs due to its high dielectric constant and high capacity of charge storage [4]. It is also a potential material for active microwave tunable devices because of its variable dielectric constant under external electric field [5]. Especially, BST thin films have a good thermal-chemical stability, insulating effect and variety of phases. However, BST thin films have problems of the aging effect and mismatch between the BST thin film and electrode. On the other hand, the degradation of device performances was occurred due to the high defect-state density and surface roughness at grain boundaries and in the grains. In order to overcome these weaknesses, we first applied the chemical mechanical polishing (CMP) process [6-9] to the planarization of ferroelectric film. $Ba_{0.6}Sr_{0.4}TiO_3$ ferroelectric film was fabricated by the Sol-Gel method [10, 11]. And then, we compared the structural characteristics before and after CMP process of $Ba_{0.6}Sr_{0.4}TiO_3$ films.

2. EXPERIMENTS

Figure 1 shows the flow chart for preparation of BST film by Sol-gel method. The precursor solutions for BST were prepared by the Sol-Gel method using barium acetate [$Ba(CH_3COO)_2$], strontium acetate [$Sr(CH_3COO)_2$] and titanium isopropoxide [$Ti(OC_2H_4CH_3)_4$] as the starting materials. The solid-state barium acetate and strontium acetate were initially dissolved in acetic acid (CH_3COOH), and then mixed to obtain a (Ba, Sr) stock solution.

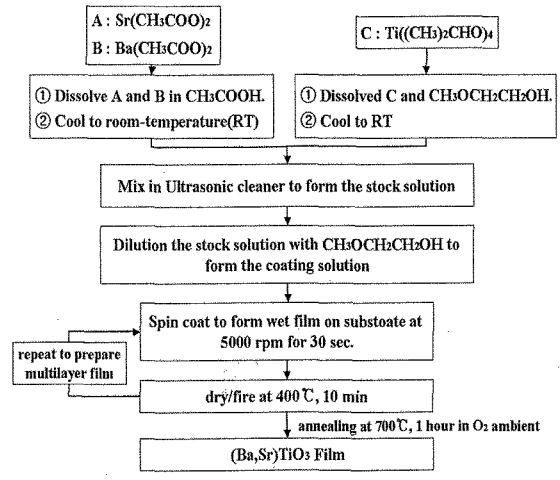


Fig. 1. Flow chart for preparation of BST film by Sol-gel method.

Titanium iso-propoxide was dissolved in 2-methoxyethanol ($CH_3OCH_2CH_2OH$) under a N_2 atmosphere. Finally, both starting solutions were mixed to prepare the stoichiometric, clear, transparent, and stable BST precursor. For the fabrication of BST thin films, the BST precursor solution was syringed through a 0.2 μm syringe filter on the SiO_2/Si substrate. The films were deposited by the spin-coating technique at 4000 rpm for 30 s. After the spin-coating procedure,

the films were kept on hot plate at 400 °C for 10 min to remove the organic contaminations. Then, the pre-baked films were annealed at 700°C for 1 hour in oxygen ambient for re-crystallization. The final thickness of BST thin film was about 400 nm. The CMP polishing of all test wafers were performed with a G&P POLI-380 CMP polisher as shown in figure 2. The parameter ranges of the optimized CMP process is summarized in table I. The polishing pad was a stack-type IC-1300/ Suba-IV double pad from Rodel Company. The SC-1 chemicals, DHF (diluted HF) and ultrasonic were used for the post-CMP cleaning.

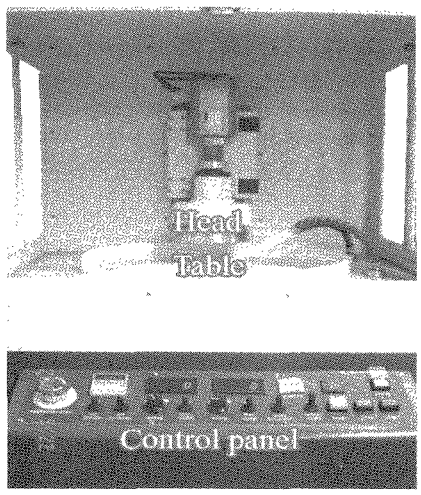
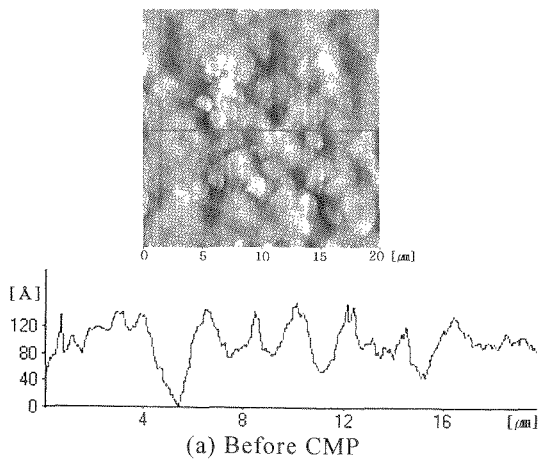


Fig. 2. POLI-380 CMP equipment of G&P Technology Company.

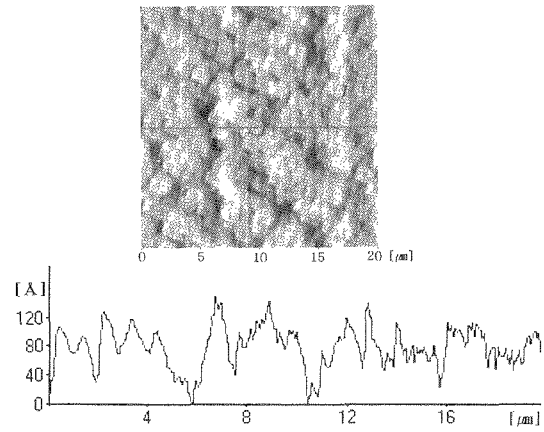
Table I. CMP conditions.

Table speed	60 [rpm]
Head speed	60 [rpm]
Down force	4.2 [psi]
Slurry flow rate	90 [ml/min]
Polishing time	40 [sec]

3. RESULTS AND DISCUSSION



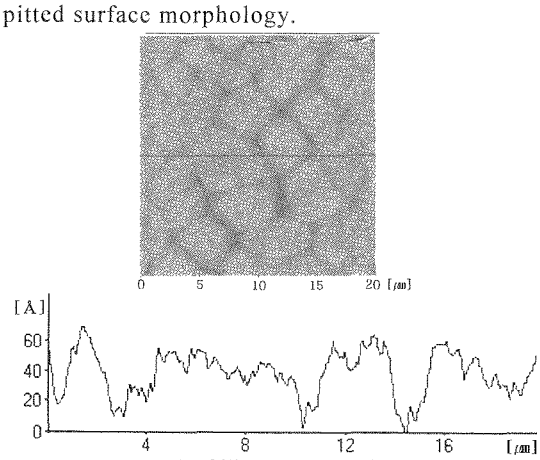
(a) Before CMP



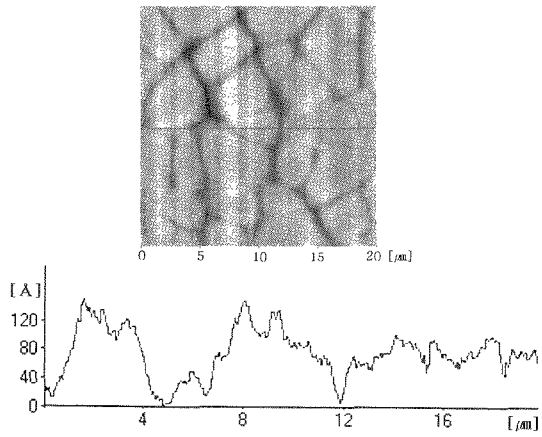
(b) After CMP (slurry #A)

Fig. 3. AFM surface morphology and height profiles of as-deposited films.

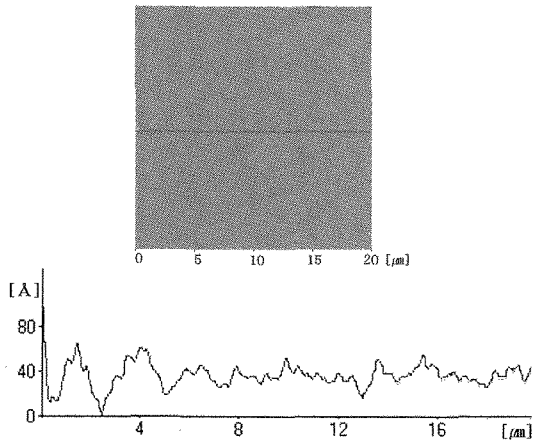
Figure 3 shows the atomic force microscopy (AFM) surface morphology and height profiles before and after CMP of as-deposited film. The initial surface, irregularly dotted with spherical features, went from a root mean square (RMS) roughness of 4.2 nm to a RMS roughness of 3.5 nm after 40 sec of polishing with silica slurry (#A). [See Fig. 5 (a) and (b)]. Additional CMP of this sample resulted in further removal of the pitted surface morphology.



(a) Silica slurry (# B)



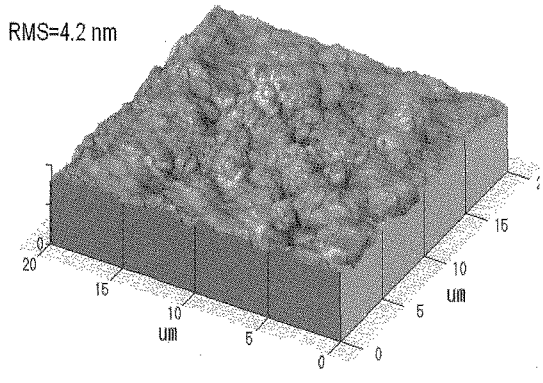
(b) Alumina slurry (#C)



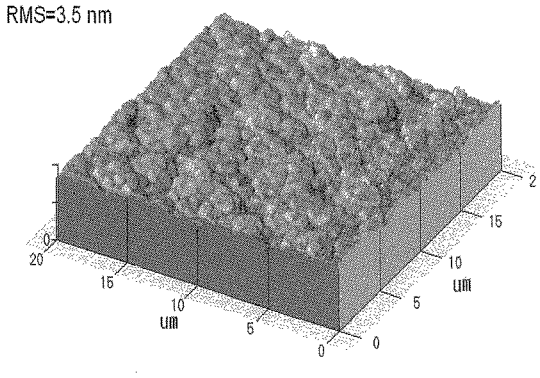
(c) Titania abrasive (1wt%) added silica slurry (#D)

Fig. 4. AFM surface morphology and height profiles after CMP of 700℃ and 1 hour annealed film.

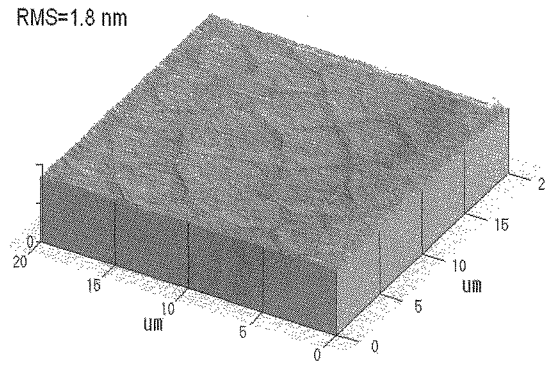
Figure 4 represents the AFM surface morphology and height profiles after CMP of 700℃ and 1 hour annealed film. After annealing, the irregularly dotted spherical grains were re-grown. The surface of samples had a relatively smooth surface after polishing. The RMS roughness of silica slurry (#B), alumina slurry (#C) and Titania and silica mixed slurry (#D) were about 1.8 nm, 2.9 nm, 1.5 nm, respectively.



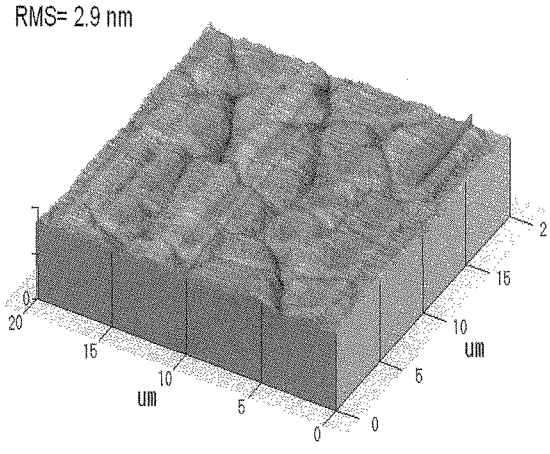
(a) Before CMP of as-deposited film, see Fig. 3(a).



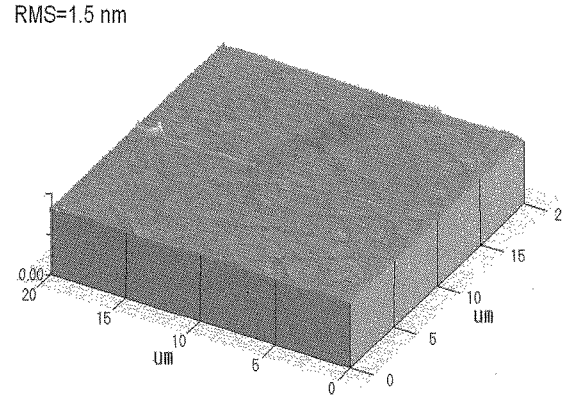
(b) After CMP of as-deposited film, see Fig. 3(b).



(c) Silica slurry #B, see Fig. 4(a).



(d) Alumina slurry #C, see Fig. 4(b).



(e) Titania abrasives (1wt%) added silica slurry (#D), see Fig. 4(c).

Fig. 5. AFM 3D micrographs after CMP of 700℃ and 1 hour annealed film.

Typical three-dimensional (3D) morphologies corresponding to Figure 3 and Figure 4 were summarized in Figure 5. Removal rates at room temperature were found to vary from 320 to 400 nm/min resulting in surface roughness as low as 4.25 nm root mean square (RMS) roughness of unpolished sample deceasing to 1.5 nm RMS after

CMP using titania-based slurry.

Table II. Removal rates and WIWNU (%) with different slurry.

	A	B	C	D
Abrasives	SiO_2	SiO_2	Al_2O_3	TiO_2
Hardness	6 ~ 7	6 ~ 7	8 ~ 9	5.5 ~ 6.5
Removal rate [nm/min]	345	370	400	320
WIWNU [%]	2.2	1.4	1.7	1.5

Table II shows the comparison of removal rates and within-wafer non-uniformity (WIWNU) as a function of slurry and its hardness. Removal rates and WIWNU (%) at room temperature were found to vary from 320 to 400 nm/min and 1.4 to 2.2 %, respectively. This means that CMP of BST film depends on the hardness of slurry abrasive. Polishing results of BST using silica or alumina abrasive particles, which are harder than titania, represented the high removal rates. However, polishing results using a much softer titania have revealed the relatively low removal rate and WIWNU (%).

4. CONCLUSION

Chemical mechanical polishing results of BST films with silica-, alumina- and titania-based slurry have been demonstrated. Removal rate, WIWNU (%) and surface roughness have been found to depend on slurry abrasive types and their hardness. Especially, surface roughness and planarity were strongly depend on our self-developed titania-based slurry. A maximum in the removal rate is observed in the alumina slurry, in contrast with the minimum removal rate occurs at titania slurry. We found that the surface roughness of BST films can be significantly reduced using the CMP technique. It will be further improved by further optimization of polishing condition, indicating the necessity of combining both a chemical and mechanical aspect in order to achieve optimal BST removal. Therefore, we expect that our results will be useful promise of global planarization for FRAM application in the near future.

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