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Electrical Properties of $(Ba,Sr)TiO_3$ Films on Ru Bottom Electrodes Prepared by ECR Plasma CVD at Extremely Low Temperature and RTA

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1. Introduction

$(Ba,Sr)TiO_3$ (BST) films are promising high dielectric constant materials for cell capacitors of Gbit DRAMs [1,2]. We have reported the BST capacitor process with a BST deposition temperature of 550℃ using electron cyclotron resonance (ECR) plasma chemical vapor deposition (CVD) without post-annealing for Gbit DRAMs [2]. In this work, we studied ECR plasma CVD at extremely low temperature combined with a post-annealing by means of rapid thermal annealing (RTA) for the purpose of minimizing BST-electrode and electrode-Si reactions and oxidation of the electrode and underlying Si during the BST formation.

2. Experimental

30-nm-thick BST films were deposited on Ru/Ti bottom electrodes having smooth surface by ECR plasma CVD. Source materials used were $Ba(DPM)_2$, $Sr(DPM)_2$, $Ti(O\text{-}i\text{-}C_3H_7)_4$, and oxygen. BST deposition temperatures were between 120 and 250℃, and μ-wave power was 750 W. RTA for each film was carried out at 700℃ in N_2 ambient. The top electrodes were made of Ru. The BST film composition was measured by X-ray fluorescence spectroscopy. The film thickness was measured with a surface profiler after a selective-area etching of the films. The dielectric constant (ε_r) was determined from the capacitance at 10 kHz. The BST film structures and the interface roughness between the films and electrodes were evaluated by cross-sectional transmission electron microscopy (TEM).

3. Results and discussion

Figure 1 shows the dependence of leakage current densities at $\pm$ 1 V on (Ba+Sr)/Ti ratio for three deposition temperatures, (a) 120℃, (b) 180℃ and (c) 250℃. The leakage current densities for a (Ba+Sr)/Ti ratio of 1.1 - 1.5 decrease with reduction of the deposition temperature. As for the crystallinities, films deposited at 120℃ have uniform amorphous structures before RTA, whereas ones deposited at 180℃ and 250℃ show some crystalline nuclei in the amorphous structures. This suggests a relationship between crystalline nuclei in as-deposited films and leakage current paths in fabricated capacitors.

For the films deposited at 120℃, leakage current densities less than 10^{-7} A/cm^2 are obtained at a (Ba+Sr)/Ti ratio of 1.1 - 1.5 (Fig. 1(a)). The ε_r for the same (Ba+Sr)/Ti ratios are between 63 and 120, as shown in Fig. 2. The leakage current densities of stoichiometric and Ti-rich films, on the other hand, are higher. In particular, stoichiometric films show the highest leakage current densities. This behavior differs from that of the films deposited at 500℃ without post-annealing, wherein the leakage current density simply and slightly increases with the (Ba,Sr)/Ti ratio [3].

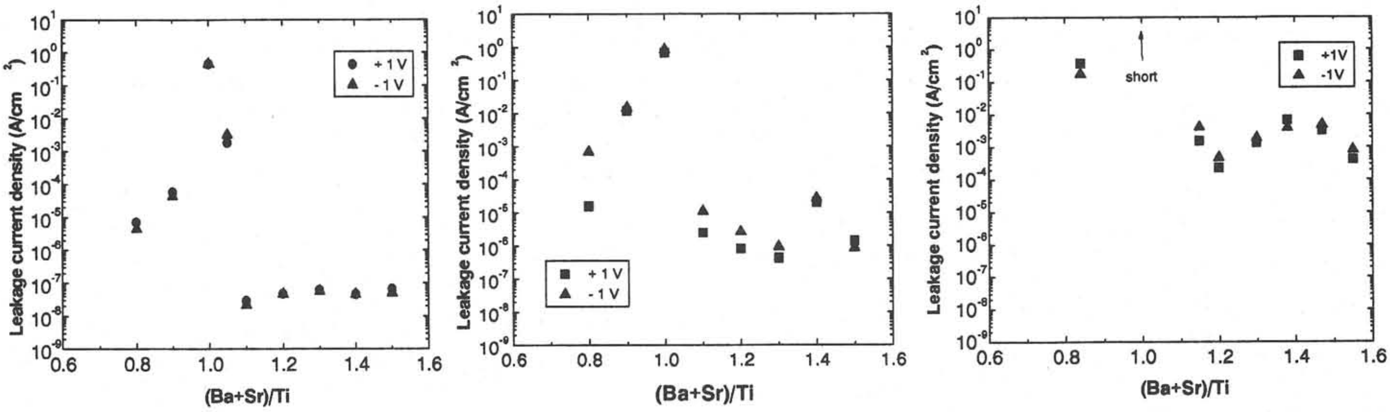
Figure 3 shows cross sectional TEM images for three (Ba+Sr)/Ti ratios, (a) 0.8, (b) 1.0, (c) 1.2 (Ts=120℃). It is observed the Ti-rich film (Fig. 3(a)) is partially crystallized (grain width of 40 - 50 nm). The stoichiometric film (Fig. 3(b)) consists of columnar grains with width of 20 - 30 nm. The (Ba+Sr)-rich film (Fig. 3(c)) consists of granular grains with a size of 7 - 9 nm. As for the interface roughness between the BST and top electrodes, the (Ba+Sr)-rich film shows 1 - 2 nm. Whereas, growth of columnar grains causes larger interface roughness for the Ti-rich film (2 - 3 nm) and especially for the stoichiometric film (3 - 6 nm). For the latter two films, the narrow valleys between the columnar grains, pointed with arrows in Fig. 3(a) and 3(b), are filled with top Ru. These valleys can act as leakage current paths because such pointed conductors concentrate the electric field. The (Ba+Sr)-rich films, on the other hand, show good leakage current characteristics, presumably, because such leakage current paths are few.

4. Summary

Low-leakage BST films were prepared on Ru bottom electrodes by a combination of low temperature deposition and RTA. Leakage current characteristics were improved with the reduction of the BST deposition temperature down to 120℃. (Ba+Sr)-rich films had lower leakage current densities than stoichiometric and Ti-rich films. Cross sectional TEM observations showed the 120℃ (Ba+Sr)-rich film had a granular structure and smooth interfaces with the electrodes. The stoichiometric and Ti-rich films had columnar structures and larger interface roughness. As a result, low leakage current density of $(2 - 5)\times 10^{-8}$ A/cm^2 at $\pm$ 1 V (ε_r = 110 - 120, BST thickness=30 nm) were obtained for a (Ba+Sr)/Ti ratio of 1.1 - 1.2 with a combination of 120℃ deposition and 700℃ RTA.

References

1) A. Yuuki et al., IEDM Tech. Dig., p.115, 1995.
2) H. Yamaguchi et al., IEDM Tech. Dig., p. 675, 1996.
3) Y. Kato et al., MRS Symp. Proc. Vol. 433 , p.3. 1996.



(a) (b) (c)

Fig. 1 Dependence of leakage current densities on (Ba+Sr)/Ti ratio; (a) Ts=120℃, (b) 180℃, (c) 250℃.

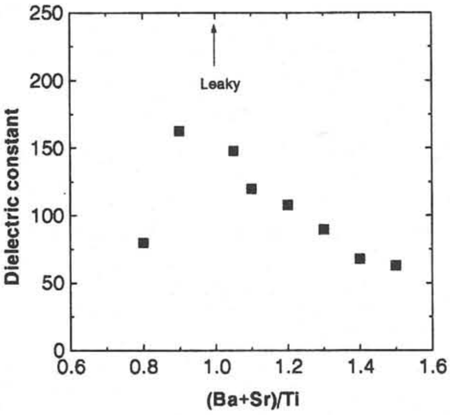
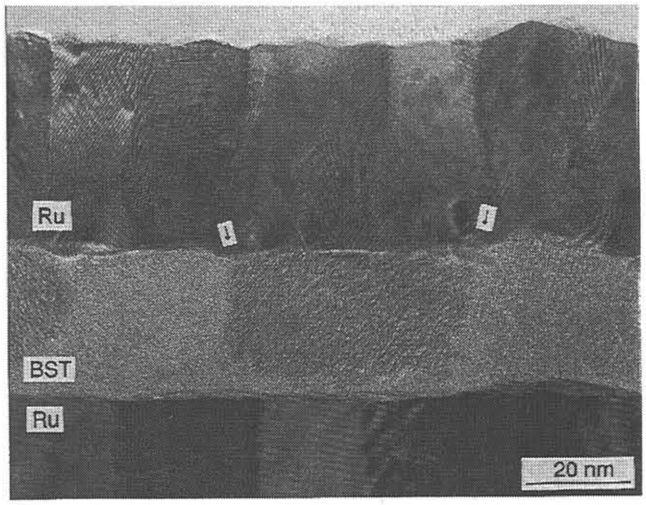
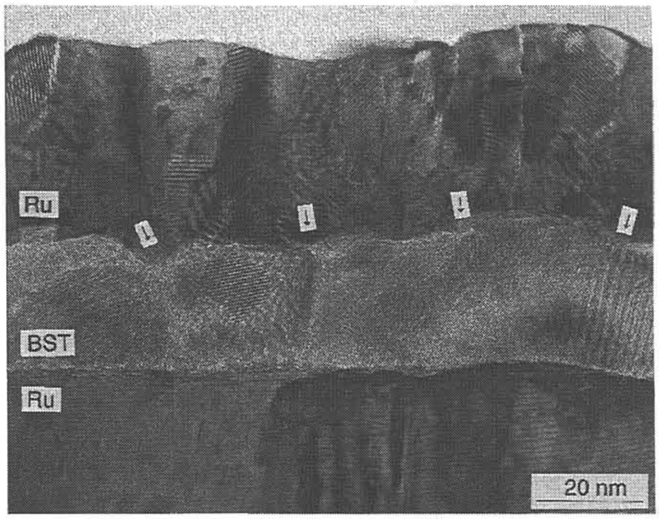


Fig. 2 Dependence of dielectric constant on (Ba+Sr)/Ti ratio; Ts=120℃.



(a)



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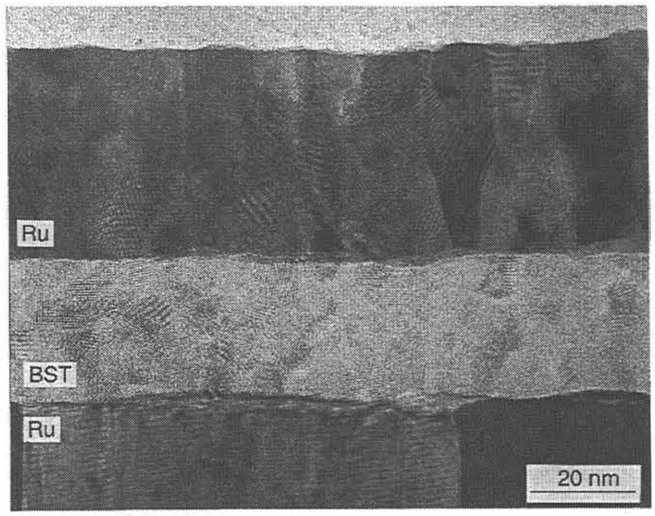

(c)

Fig. 3 Cross sectional TEM images; (a) (Ba+Sr)/Ti=0.8, (b) 1.0, (c) 1.2