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Electrical charateristics of MIS BST thin films

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Abstract The variation of electrical properties of (Ba,Sr)TiO_3 [BST] thin films for Metal-Insulator-Semiconductor (MIS) capacitors was investigated. BST thin films were deposited on p-Si(100) substrates by the RF magnetron sputtering with temperature range of 500~600°C. The dielectric properties of MIS capacitors consisting of Al/BST/SiO_2/Si sandwich structure were measured for various conditions. We examined the characteristics of MIS capacitor with various oxygen pressure, substrate temperature and (Ba+Sr)/Ti ratio. It was found that the leakage current was reduced in MIS capacitor with high quality SiO_2 layer was grown on bare p-Si substrate by thermal oxidation. The BST MIS structure showed relatively high capacitance even though it is the combination of high-dielectric BST thin films and SiO_2 layer. The charge state densities of the MIS capacitors and Current-voltage characteristics of the MIS capacitor were investigated. By applying SiO_2 layer between BST thin films and Si substrate, low leakage current of 10^{-10} order was observed.

Key words Capacitor, BIS, Thin film, MIS

1. Introduction

(Ba,Sr)TiO_3 [BST] is an attractive capacitor material for dynamic random access memories (DRAM) which requires a very high density of stored charge [1-3]. BST thin films which have SiO_2 equivalent thickness less than 0.5nm and low leakege current density is one of the most desirable material for DRAM capacitor [4-5].

The paraelectric phase of BST thin film can be formed by controlling the Ba/Sr ratio. $BaTiO_3$ is a ferroelectric material with a Curie temperature of 120°C while $SrTiO_3$ is a paraelectric material without ferroelectric phase transition [6-7]. Therfore it is possible to change the characteristics of BST thin film from paraelectricity to ferroelectricity or vice versa by Ba/Sr ratio control. The paraelectric phase at the operating temperature of DRAMs is also desirable to avoid fatigue due to ferroelectric domain switching [8]. For the stability of BST thin film capacitor, the lower leakage current density is required. Futhermore, a lot of studies to reduce the leakage current of BST films and improve the dielectric properties of the films have been reported [9-10]. However, in spite of these investigations, the studies on the electrical properties of (Ba,Sr)TiO_3 MIS structure have been very few.

The purpose of this study is to investigate the application of BST thin films for MIS structure with low leakage current, high charge storage capacity and the characteristics of BST MIS capacitor. In this study, (Ba,Sr)TiO_3 thin films were deposited on SiO_2/p-Si(100) substrate by using RF magnetron sputtering. In oder to reduce the leakage current, SiO_2 layer was grown on Si substrate by thermal oxidation. The dependences of leakage current and dielectric properties on the oxygen concentration in plasma gas and on the (Ba+Sr)/Ti ratio were described. The crystallinity, surface morphology and composition of the BST thin films were reported. By C-V measurement. The polarity of oxide charge was investigated.

2. Experiment

High quality silicon oxide layer of 250 Å was grown on p-Si(100) substrate by thermal oxidation. (Ba,Sr)TiO_3 thin film was deposited on SiO_2/Si substrate by RF magnetron sputter using *in-situ* technique at temperature range of 500~600°C. The (Ba,Sr)TiO_3 ceramic powder targets were prepared for various (Ba+Sr)/Ti ratios of 1, 1.025, 1,05 by mixing 99.98 % $BaTiO_3$ and 99.9 % $SrTiO_3$ powder and excess 99.5 % BaO,SrO powder. The sputtering gas flow ratio were O_2/Ar = 1/9, 3/7, 5/5. Total pressure was maintained at 1.0×10^{-2} Torr. Deposition rate, calculated by measuring film thickness with a surface profiler - Tencor α-step and scanning electron microscope (SEM), was 8~9 Å/min.

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Crystallinity analysis of BST thin film was performed with X-ray diffraction (XRD) using Cu K_α radiation. The composition of BST thin films was confirmed by Rutherford Backscattering Spectroscopy (RBS) and showed almost same value with that of sputtering target. For electrical measurements, Al upper electrodes of 200 μm radius were formed by thermal evaporation. Capacitance vs. voltage characteristics were measured with HP 4280A 1 MHz C meter/CV plotter. The leakage current was measured with an HP 4145B semiconductor parameter analyzer. The polarization versus voltage hysteresis loops were obtained by using the test system from Radiant Technology.

3. Results and Discussion

Figure 1 shows the X-ray diffraction patterns of the BST films deposited on SiO_2/p-Si(100) substrate at various O_2/Ar ratio in plasma gas. The BST films were deposited at 550°C and the (Ba+Sr)/Ti ratio was 1.025. As the O_2 content in the plasma gas increases, diffraction peaks of BST(100) and (200) showed strong intensity, but peak from BST(110) was negligibly weak when O_2/Ar is 5/5, while, at the O_2/Ar ratio of 1/9, 3/7, peaks of BST (110), (111) and (211) were observed.

It showed the tendency of epitaxy as the oxygen pressure increased. X-ray diffration patterns of BSTfilms are shown in Fig. 2. When the (Ba+Sr)/Ti was 1.025 for sputtering target, the (Ba+Sr)/Ti ratio in the BST films was almost same as that for the sputtering target. Futhermore,the Ba : Sr ratio was 1 : 1. It is in the range of paraelectric region [10].

Figure 3 shows the leakage current density of the films under various sputtering gas mixture. The leakage current density decreased with increasing O_2 ratio in plasma gas. Also the films deposited at O_2/Ar = 5/5 showed the lowest leakage current density of 10^{-9} order higher electric field of 600 kV/cm (9 V). It is consid-

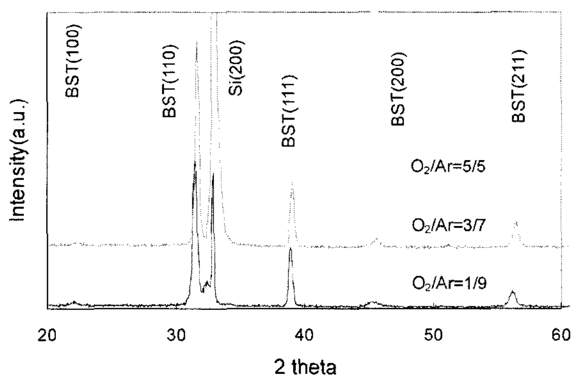

Fig. 1. XRD patterns of BST (1200 Å) films deposited on SiO_2/Si at 550°C with various O_2/Ar ratio.

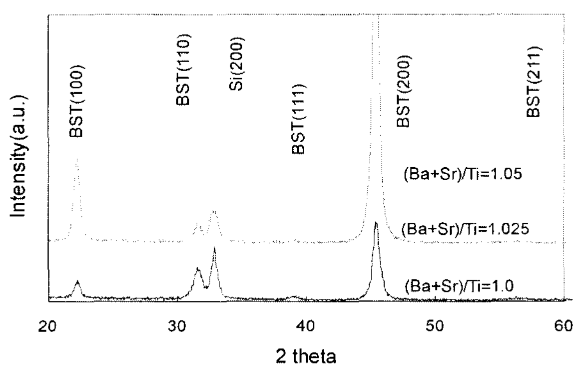

Fig. 2. XRD patterns of BST (1200 Å) films deposited at 550°C, O_2/Ar = 5/5 with various (Ba+Sr)/Ti ratio.

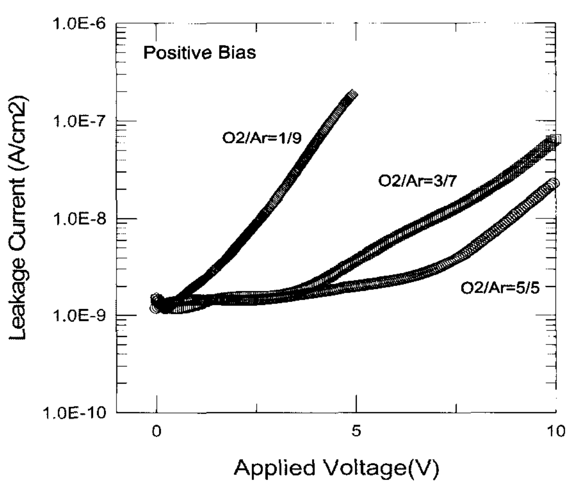

Fig. 3. Leakage current density of 1500 Å thick BST films with various O_2/Ar ratio.

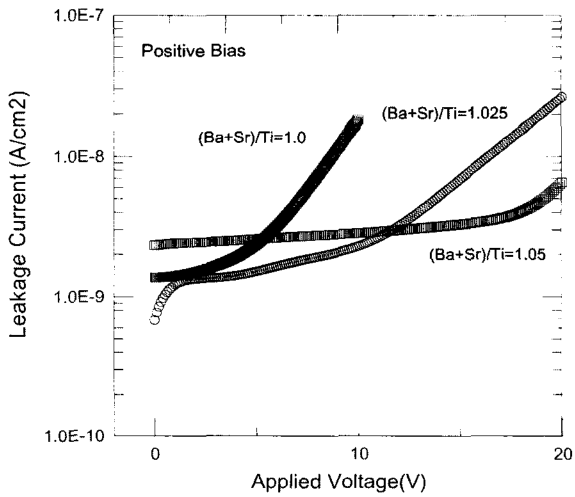

Fig. 4. Leakage current density of BST films with various (Ba+Sr)/Ti ratio.

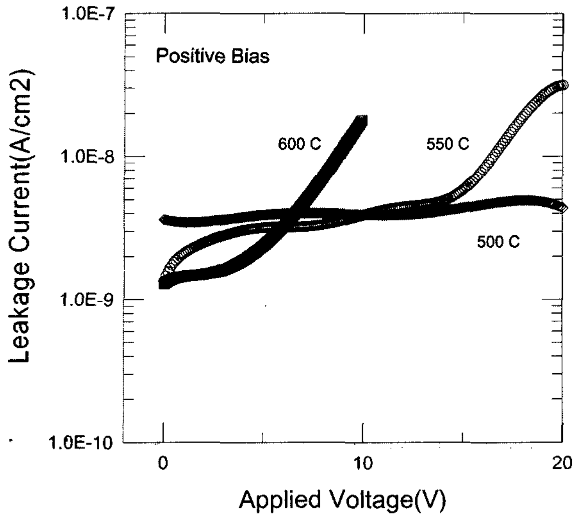

Fig. 5. Leakage current density of BST films with various deposition temperature.

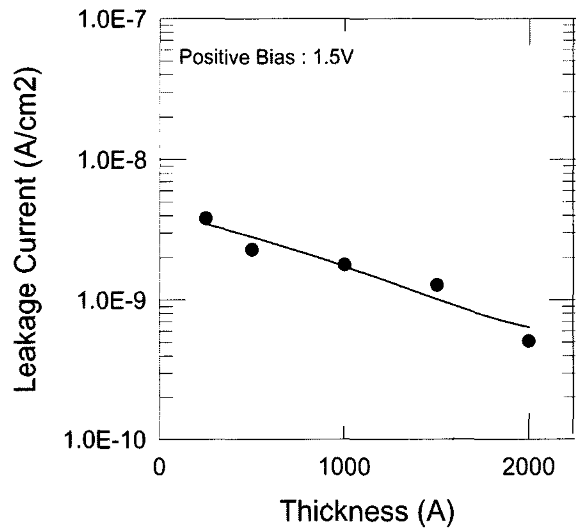

Fig. 6. Leakage current density with BST films thickness.

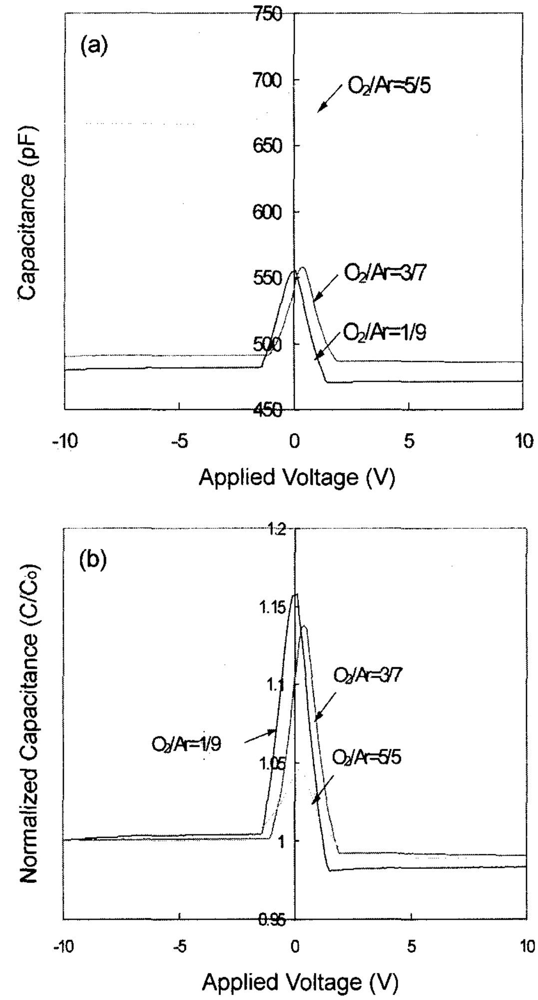

Fig. 7. C-V characteristics of BST film with various O_2/Ar ratio.

ered that the increase of O_2 ratio has the effect of decreasing the oxygen vacancy concentration in the BST films and then decreasing the leakage current densities. The dependences of leakage current density as function of (Ba+Sr)/Ti ratio were shown in Fig. 4. Leakage current densities for BST films with excess (Ba+Sr) (A/B ratio > 1) are lower than stoichiometric BST films for higher voltage. The leakage current density increased again for (Ba+Sr)/Ti = 1.05 in the range of 0~10 V. Figure 5 shows the I - V characteristics for various deposition temperatures.

The film deposited at 600°C showed the lowest leakage current density in the region less than 5.5 V but increased rapidly for applied voltage greater than 5.5 V. In the case of 2000 Å thick film, the leakage current density showed the lowest value of 5.1×10^{-10} at 1.5 V [Fig. 6]. The leakage current densities increase with decreasing thickness, but the films of 250~1500 Å show leakage current densities of 10^{-9} order.

Figure 7 shows the C-V plot for BST film with MIS structure deposited at various O_2/Ar ratio in plasma gas. The BST+SiO_2 layer shows its maximum value of capacitance, 696.2pF, at O_2/Ar = 5/5 and the dielectric constant of 110 [Fig. 9(a)]. As the O_2 ratio increases, the C-V plot shifts to more positive bias. In Fig. 7(b), a positive flat band voltage shift of C-V plot implies effective negative charge residing at (BST + SiO_2)/Si interface [8].

(Ba + Sr)/Ti ratio is shown in Fig. 8. The maximum capacitance was at the (Ba + Sr)/Ti = 1.05 [Fig. 10(a)]. And the C-V plots shift to more positive bias direction with increasing (Ba + Sr)/Ti ratio [Fig. 8(b)]. As the deposition temperature increases, the capacitance increases. But, in this case, there was no remarkable flat band voltage shift with temperature [Fig. 9(a), (b)].

The increase of capacitance near zero field is consid-

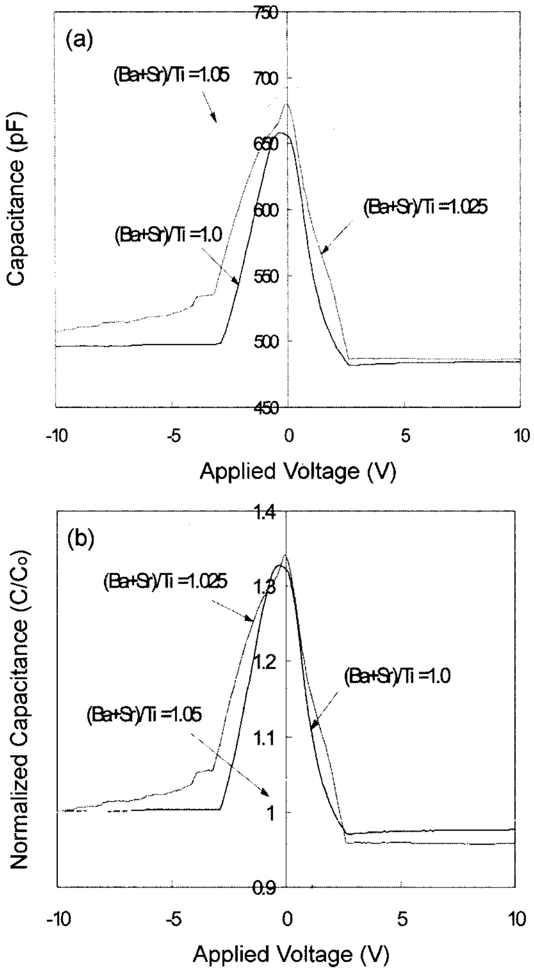

Fig. 8. C-V characteristics of BST film with various (Ba + Sr)/Ti ratio.

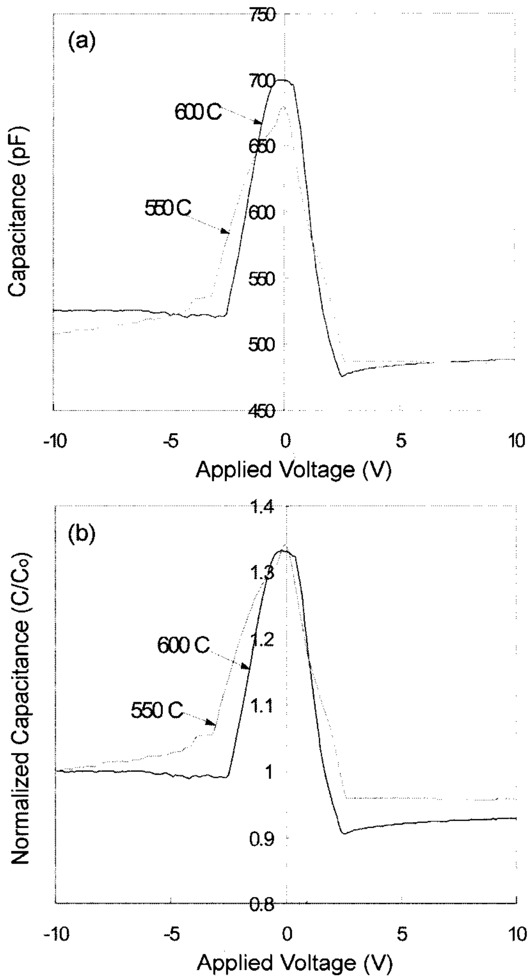

Fig. 9. C-V characteristics of BST film with temperature.

ered as the result of ferroelectricity of BST films even though the Ba/Sr ratio is in the range of paraelectricy for bulk BST. The ferroelectricity of the epitaxial BST films, confirmed by X-ray pattern, is considered to be caused by the elongation of lattice constant in the direction of thickness. It is supposed that the elongation of the lattice constant enhances an ionic displacement and an interaction among dipoles.

Figure 10 shows the dielectric constant as a function of the film thickness. Dielectric constants of (BST + SiO_2) layer decreased with the decrease of the film thickness. It is assumed that the local field induced by space - charge layer at the dielectric-electrode interface would cause lowering of the dielectric constant [7].

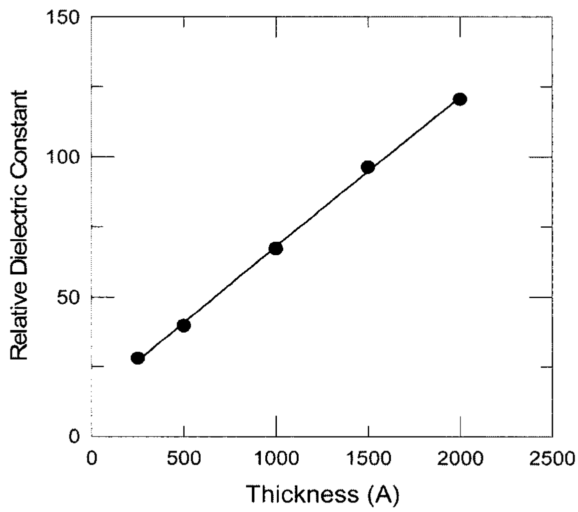

Fig. 10. Relative dielectric constant of BST films with thickness [550^{0}C,O_2/Ar =5 /5,(Ba + Sr)/Ti = 1.025].

4. Conclusion

The electrical properties of BST films were investigated for the application of MIS sturucture. Epitaxial BST films could be deposited on SiO_2/Si substrate by controlling the O_2/Ar ratio and the (Ba + Sr)/Ti ratio in the films. MIS sturucture with SiO_2 layer between BST and Si substrate shows low leakage current density of 10^{-9} A/cm^2 order. The leakage current densities have the dependences on the O_2/Ar ratio in plasma gas, the (Ba + Sr)/Ti ratio and the deposition temperature.

C-V measurements showed the ferroelectricity in the BST films near zero field. It is considered that the elongation of lattice constant in the direction of thickness. The dielectric constant of (BST +SiO_2) film calculated at the maximum capacitance was 109(t = 1750 Å). The BST MIS structure showed relatively high capacitance even though it is the combination of high-dielectric BST thin films and SiO_2 layer.

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