Extended Abstracts of the 2000 International Conference on Solid State Devices and Materials, Sendai, 2000, pp. 158-159

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Inductive-Coupled RF Magnetron Plasma Deposition of (Ba, Sr)TiO_3 for Decoupling Capacitors

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1. Introduction

Barium Strontium Titanium Oxide $(Ba_x,Sr_{1-x})TiO_3$ (BST) is one of the most attractive candidates not only for dynamic random access memory (DRAM) capacitors [1,2] but for decoupling capacitors on high-speed logic ultra-large scale integrated circuits (ULSI) because of its high dielectric constant. From this point of view, it is necessary to form BST capacitors at low temperatures in the back-end of the line process. An inductive-coupled plasma (ICP) in conjunction with a radio frequency (RF) magnetron plasma was applied for sputtering a target to control crystallinity and stoichiometry of BST films.

In this paper the properties of BST films deposited by ICP-RF magnetron plasma sputtering were investigated for the first time.

2. Experimental

$(Ba_x,Sr_{1-x})TiO_3$ films were deposited by ICP-RF magnetron plasma sputtering on 2 inch Si (100) substrates in Ar and O_2 mixture gas ($Ar:O_2$=4:1) as shown in Fig. 1. The ratios of target composition (Ba+Sr)/Ti and Ba(Ba+Sr) were 0.986 and 0.499, respectively. The sputtering gas pressures were changed from 0.5 Pa to 2.0 Pa. ICP powers were changed from 0 to 100 W. RF powers were changed from 100 to 200 W. Si substrates were heated at 500-700°C during sputtering. A ruthenium (Ru) electrode was sputtered by direct current (DC) magnetron plasma sputtering at room temperature. Film properties were characterized by X-ray diffraction (XRD), Rutherford backscattering spectrometry (RBS), capacitance-voltage (C-V) measurement, atomic force microscopy (AFM), and X-ray photoelectron spectroscopy (XPS)[3].

3. Results and Discussion

Figure 2 shows XRD spectra of BST films which were deposited by ICP-RF magnetron plasma sputtering in Ar+O_2 mixture gas ($Ar:O_2$=4:1) ambient at 2.0 Pa at 680°C. $(Ba_{0.5},Sr_{0.5})TiO_3$ (200), (100), (110) peaks were observed. As can be seen, it is found that the ICP plasma enhances the crystallinity of the BST film. The dependences of Ar+O_2 mixture gas pressures on BST films in terms of XRD spectra and RBS spectra are shown in Figs. 3(a) and 3(b), respectively. The ratios of (Ba+Sr)/Ti were 0.736 and 0.402 for 2.0 Pa (50 nm) and 0.5 Pa (140 nm), respectively. The ratios of Ba/(Ba+Sr) for 2.0 Pa and 0.5 Pa, were 0.459 and 0.434, respectiely. It is found that the ratio of Ba to Sr was not changed by the pressure but the ratio of Ti to (Ba+Sr) was changed. More Ti atoms were incorporated in the BST film when the $(Ba_{0.5},Sr_{0.5})TiO_3$ target was sputtered at 0.5 Pa. The BST stoichiometry could be improved by increasing the pressure. Annealing temperature dependence of the BST film is shown in Fig. 4. The BST films were deposited at 500°C and annealed at different temperatures for 30 minutes. Surface morphologies were investigated by AFM as shown in Fig. 5. Although no clear indication of crystallization was observed by XRD, the surface morphology by AFM started to change at 600°C. Figure 6 shows energy loss spectra of BST/SiO_2/Si(100) layers. An interfacial SiO_2 layer was formed because a BST film was deposited on a Si(100) substrate by ICP-RF magnetron plasma at 680°C in Ar+O_2 ambient. Valence band spectra of BST/SiO_2/Si are shown in Figs. 7(a) and 7(b). It is found that the band gap of the BST film deposited by ICP-RF magnetron plasma sputtering was 4.30±0.05eV. The valence band offsets at BST/Si and BST/SiO_2 interfaces were determined to be 3.55±0.05eV and 1.86±0.05eV, respectively. Since the valence band offset at SiO_2/Si interface is 4.48eV, there exists an internal electric field due to fixed positive charges in BST/SiO_2/Si system, resulting in the potential difference of 0.93eV. The work function of Ru was obtained to be 4.99±0.05eV by photoelectron yield spectroscopy. An energy band diagram of Ru/BST/SiO_2/Si(100) system is shown in Fig. 8, assuming that the electric field was mainly applied across the SiO_2.

4. Conclusion

BST thin films were deposited by ICP-RF magnetron plasma sputtering for the first time. The ICP plasma enhances the crystallinity of the BST film. The energy band alignment of a Ru/BST/SiO_2/Si system was investigated.

Acknowledgment

Part of this work was supported by the Ministry of Education, Science, Sports and Culture under the Grant-in-Aid for Scientific Research (#11555088).

References

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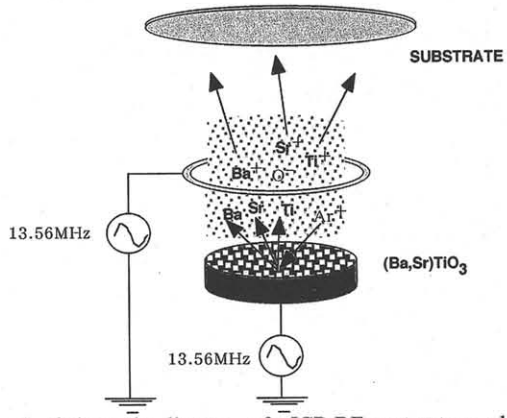


Fig. 1 Schematic diagram of ICP-RF magnetron plasma reactive sputtering deposition system.

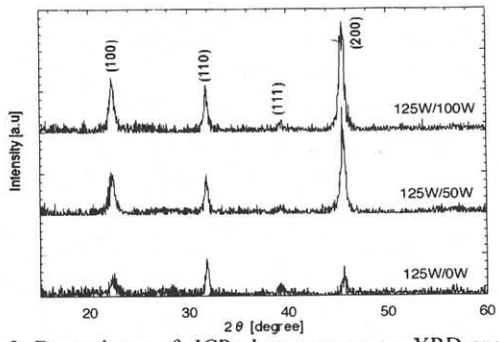
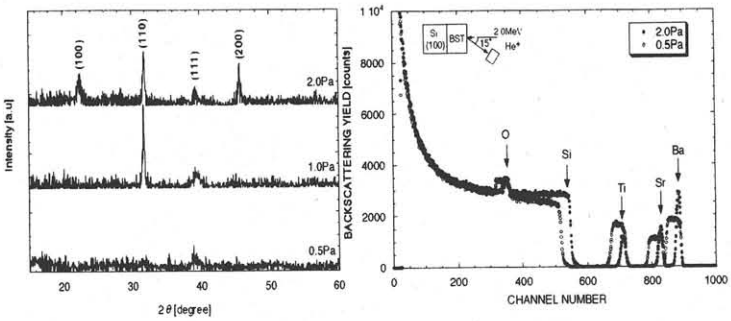


Fig. 2. Dependence of ICP plasma power on XRD spectra of BST films. deposited by ICP-RF magnetron plasma sputtering in $Ar+O_2$ ($Ar:O_2$=4:1) ambient at 2.0 Pa°C. RF power was 125 W.



(a) (b)

Fig. 3. Dependence of $Ar+O_2$ mixture gas pressure on BST films. (a) XRD spectra. (b) RBS spectra.

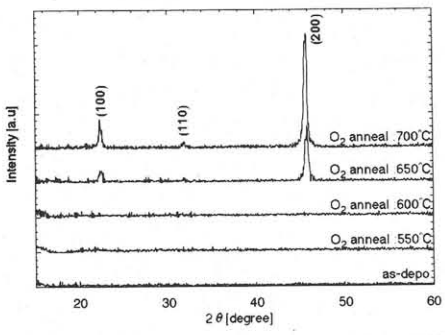


Fig.4. Annealing temperature dependence of the BST films which were deposited at 500°C and annealed at different temperatures for 30 minutes.

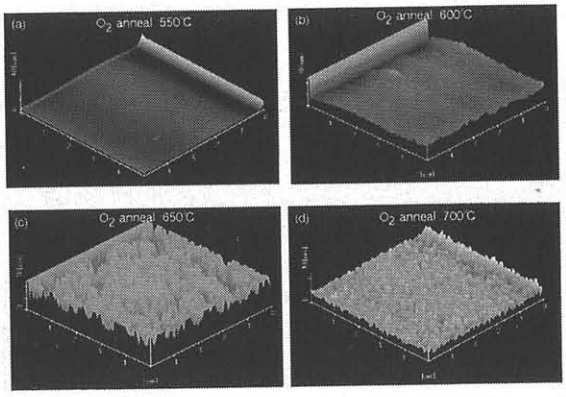


Fig. 5. Surface morphologies of the BST films deposited at 500°C and annealed at (a) 550°C, (b) 600°C, (c), 650°C, and (d) 700°C, respectively.

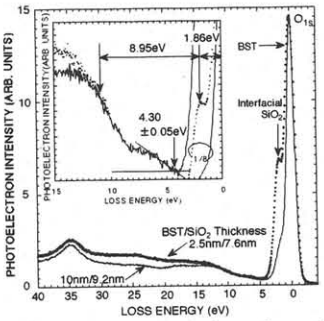


Fig. 6. Energy loss spectra of O_{1s} photoelectrons from $BST/SiO_2/Si$ layers.

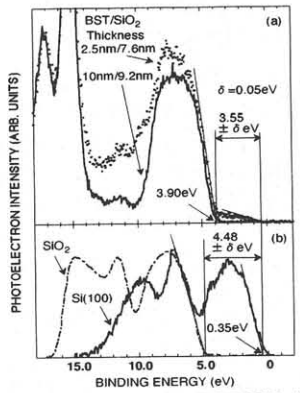


Fig. 7. Valence band spectra for $BST/SiO_2/Si$ (a), SiO2 and Si(100) (b).

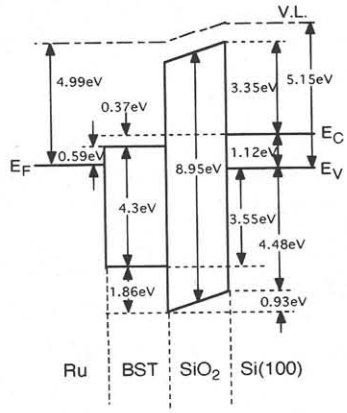


Fig. 8. Energy band diagram of a $Ru/BST/SiO_2/Si$ system.