Effect of Bottom Electrode Materials on the Electrical and Reliability Characteristics of (Ba, Sr)TiO₃ Capacitors

Ming Shiahn Tsai, S. C. Sun, and Tseung-Yuen Tseng, Senior Member, IEEE

Abstract—The dielectric constant and the leakage current density of (Ba, Sr)TiO₃ (BST) thin films deposited on various bottom electrode materials (Pt, Ir, IrO₂/Ir, Ru, RuO₂/Ru) before and after annealing in O₂ ambient were investigated. The improvement of crystallinity of BST films deposited on various bottom electrodes was observed after the postannealing process. The dielectric constant and leakage current of the films were also strongly dependent on the postannealing conditions. BST thin films deposited on Ir bottom electrode at 500 °C, after 700 °C annealing in O₂ for 20 min, has the dielectric constant of 593, a loss tangent of 0.019 at 100 kHz, a leakage current density of 1.9 × 10⁻⁶ A/cm² at an electric field of 200 kV/cm with a delay time of 30 s, and a charge storage density of 53 fC/μm² at an applied field of 100 kV/cm. The BST films deposited on Ir with post-annealing can obtain better dielectric properties than on other bottom electrodes in our experiments. And Ru electrode is unstable because the interdiffusion of Ru and Ti occurs at the interface between the BST and Ru after postannealing. The ten-year lifetime of time-dependent dielectric breakdown (TDDDB) studies indicate that BST on Pt, Ir, IrO₂/Ir, Ru, and RuO₂/Ru have long lifetimes over ten years on operation at the voltage bias of 2 V.

Index Terms—(Ba, Sr)TiO₃, electrode, electrical properties, reliability, thin film capacitors.

I. INTRODUCTION

The advancement of dynamic random access memories (DRAM’s) has significantly decreased the available area per cell. Electroceramic thin films with high dielectric constant have attracted great attention for practical use in capacitors of gigabit DRAM’s since the adoption of high-dielectric-constant materials can lower the height of the storage node and simplify the cell structure [1]–[4]. One of the most promising materials for the capacitor dielectric films is (Ba,Sr)TiO₃ (BST) because of its high dielectric constant, low leakage current density, high dielectric breakdown strength, paraelectric perovskite phase that does not exhibit fatigue, and the ease of composition control due to the absence of volatile lead oxide [1]–[9].

The electrical characteristics of BST thin films greatly depend on the deposition conditions (sputtering power, substract temperature, sputtering ambient, gas pressure, etc.) [6], [9]–[11], the composition of the BST thin films [3], [12], the bottom electrode materials, (Pt, Ru, Ir, Pt/Ta, Pt/TiN/Ti, Pd/Ti, Pd, etc.) [13]–[27], and the postdeposition annealing conditions [10], [28]–[30]. Although there is much experimental verification that annealing conditions can have significant effects on the properties of the films, systematic studies of the effect of annealing conditions on the dielectric and electrical properties of BST thin films on various bottom electrodes are still lacking. Integration of ferroelectric capacitors with Si CMOS technology for DRAM and FeRAM applications usually demands several high temperature annealing treatments (>500 °C) which imposes stringent requirements on electrode materials. Among the electrode materials, Pt has a merit of small leakage current density, which is the most studied electrode material for ferroelectric capacitors. However, problems in using Pt in ferroelectric/Si technology such as difficulties in etching, poor adhesion to SiO₂/Si substrate, poor diffusion barrier to oxygen, and high costs have prompted the search for alternative electrode materials. Some transition metal oxides are attractive candidates for electrode materials because of their stability in oxygen ambient at high temperature and metallic conductivity (Table I) [31]. Cho et al. have reported that 36-nm-thick (Ba₀.₅Sr₀.₅)TiO₃ films with the equivalent SiO₂ thickness of 0.4 to 0.5 nm and sufficiently low leakage current of 2 × 10⁻⁸ A/cm² at 1.5 V were obtained on Ir and IrO₂ electrodes [25]. NEC’s researchers have successfully deposited BST thin films on fine-patterned RuO₂, which showed low leakage current and high dielectric constant [19], [20], [23]. Mitsubishi’s researchers have also succeeded in obtaining high quality BST thin films on Ru without RuO₂ formation (leakage current of 2 × 10⁻⁷ A/cm² at 1.5 V) [13]. Advantages gained through the ease of etching Ru may be offset by a higher leakage current [32]. Conducting metal
oxide RuO_2 is perhaps the most widely studied transition metal oxide for electrode material for ferroelectric capacitors [5]. However, IrO_2 has a lower bulk resistivity than RuO_2 (30 \mu \Omega \cdot cm versus 40 \mu \Omega \cdot cm). IrO_2 and Ir have been used with PZT capacitors to reduce fatigue [33]. It has been shown by previous investigation that BST film capacitors can exhibit excellent electrical characteristics by using Ir as the top electrode [17]. Although there is much experimental proof that bottom electrode materials can significantly affect the properties of the films, systematic studies of the effect of various bottom electrodes during rf sputtering on the electrical and reliability characteristics of BST thin films are still quite limited.

In this work, we have investigated the effects of bottom electrode materials (Pt, Ir, IrO_2/Ir, Ru, RuO_2/Ru) on the dielectric constant and the leakage current density in BST thin films without and with postannealing and propose them as optimum electrode materials. The structural, electrical, and dielectric properties of the films are evaluated and discussed.

II. EXPERIMENTAL

BST thin films were deposited on metals/SiO_2/(100)Si bottom electrodes (metals are Pt, Ir, IrO_2/Ir, Ru, and RuO_2/Ru) by RF magnetron sputtering. The starting p-type silicon wafer was cleaned by a standard RCA cleaning process and chemically etched in a dilute HF solution. The 100-nm thick SiO_2 layer was thermally grown at 1050 °C in a dry oxidation furnace. The metal-layers on SiO_2/Si substrate with a thickness of 100 nm were deposited using a separate RF magnetron sputtering system. The Pt, Ir, and IrO_2 films were prepared at fixed power of 50 W (power density is 2.55 W/cm²), constant pressure of 5 mtorr, and substrate temperature of 350 °C. The Ru and RuO_2 films were prepared at fixed power of 100 W (power density is 5.1 W/cm²), constant pressure of 10 mtorr, and substrate temperature of 350 °C. IrO_2 and RuO_2 films were formed by RF magnetron sputtering with Ar and O_2 mixture in the mixing ratio of 4:1. The measured resistivities of Pt, Ir, IrO_2, Ru, and RuO_2 were about 17, 27, 67, 228, and 370 \mu \Omega \cdot cm at room temperature, respectively.

The BST 50/50 targets with a diameter of 3 in and a thickness of 1/4 in were synthesized using standard solid-state reaction process. The sputtering chamber was evacuated to a base pressure of 2 \times 10^{-6} torr. All films were prepared at fixed power of 100 W (power density is 2.26 W/cm²) and constant pressure of 10 mtorr which was maintained by a mixture of argon and oxygen at a mixing ratio of 1:1 with a total flow of 20 sccm. All of the BST films have the same thickness of around 80 nm. The substrate temperature of the sputtered BST films was at 500 °C. The composition of sputtered films was Ba/Sr = 0.47/0.53 on the basis of ICP analysis. To understand the effect of postannealing, part of the BST thin films after deposition was annealed at temperatures ranging from 500 to 700 °C in O_2 atmosphere using a quartz glass tube furnace (FN) for 20 min. Finally, the 50-nm thick Pt top electrodes with diameters of 165, 255, and 350 \mu m were formed by sputtering and then patterned by the shadow mask process.

The film thickness was determined from ellipsometry. The structure was characterized by X-ray diffraction (XRD, Siemens D5000). On the basis of XRD data, the average grain size was determined by using Scherrer’s formula [6]. The surface roughness and morphology were examined by atomic force microscopy (AFM, Digital Instruments Nano-Scope III). Depth profiles of oxygen near the interface of BST/bottom electrodes were analyzed by secondary ion mass spectrometry (SIMS, CAMECA IMS-4f). The capacitance-voltage (C-V) characteristics were measured on the metal-insulator-metal (MIM) structure by measuring the capacitance at 100 kHz as a function of a swept positive-to-negative voltage bias. Dielectric constant of the films was calculated from the capacitance measured at 100 kHz without bias voltage. The dielectric and loss properties were measured as a function of frequency with a Hewlett-Packard (HP) 4194A impedance gain phase analyzer. The current-voltage (I-V) measurements were performed by measuring the current through the sample with an HP4145B. A Pt top electrode of BST capacitor was connected to the voltage source and the bottom electrode was grounded. The polarity is positive when a positive voltage is applied to the top electrode. All data reported in this paper are the average values of ten specimens. The dielectric constant and leakage current density are independent on the electrode area.

III. RESULTS AND DISCUSSION

A. Effect of Bottom Electrodes

The importance of the bottom electrode materials in determining the microstructure of the BST film grown on them is evident from the XRD patterns shown in Fig. 1. The as-deposited BST films exhibit (110) peak for all electrode materials. We note that the (110) peak for the films on Ru and RuO_2/Ru has stronger intensity, while that for the film on Pt reveals fairly weak intensity. Moreover, the films on Ru and RuO_2 also exhibit BST(111) peak. Stronger and sharper perovskite peak of (110) from the films on Ru in comparison with those from the films deposited on other bottom electrodes implies an improved crystallinity occurred in the films on Ru. A (101) peak corresponding to RuO_2 is present in the XRD pattern of BST, indicating that an RuO_2 layer was formed at the interface between the BST and Ru during deposition. Fig. 2 depicts that the average grain size and BST(110) peak...
intensity for the films on various bottom electrodes. The better crystallinity of BST on Ru than on other electrode materials is demonstrated by its high (110) peak intensity. The average grain size of a thin film can be estimated from full width at half maximum (FWHM) of the (110) peak in the XRD pattern by Scherrer’s formula, because only the (110) peak appears clearly in all the samples. The calculated average grain size of BST deposited on Ru has a maximum value, while that of BST on Pt has the smallest value. It was confirmed that the grain size from XRD and the grain size in the direction of thickness from TEM are in fairly good agreement, for both BST films with columnar structure and those with granular structure [6]. Therefore, the grain size evaluated from XRD is suitable for helping to explain the properties of the BST thin films.

Fig. 3(a) and (b) indicates the variations of dielectric constant and loss tangent with frequency. The dielectric dispersion of BST deposited on Pt, Ir, IrO$_2$/Ir, Ru, and RuO$_2$/Ru is low (less 0.5% per decade) and these capacitors are expected to have a high charge storage density even at high frequencies. The loss tangent of BST on Pt, Ir, IrO$_2$/Ir, Ru, and RuO$_2$/Ru increases slightly with frequency. In addition, the defects in the BST films often lead to a dielectric relaxation as a function of frequency, in which the dielectric constant decreases and loss tangent increases with increasing frequency [34]. Fig. 4 shows the leakage current characteristics of the capacitors. The asymmetry of the curves implies that the leakage current is electrode-limited. The difference in work functions which are, respectively, 5.6, 5.35, and 4.8 eV for Pt, Ir, and Ru [35], and bottom electrode roughnesses, which are 1.5, 1.4, and 2.9 nm for Pt, Ir, and Ru (Fig. 5), may explain the leakage behavior of the capacitors in the positive bias. Leakage current in negative bias (gate injection) is mainly affected by the interface of BST and Pt top electrode. The greater roughness for BST films deposited on Ru compared to others (Fig. 5) may also lead to higher leakage current.

The importance of the bottom electrode in determining the root-mean-square (rms) surface roughness of the BST thin films grown on it is evident from the AFM images, as shown in Fig. 5. The greater rms surface roughness of BST on Ru and RuO$_2$/Ru compared to the Pt, Ir, and IrO$_2$/Ir may be due to the higher roughness of the Ru and RuO$_2$/Ru bottom electrodes themselves. The grain size of the films would play an important role on the rms surface roughness of BST, the amorphous or small grain size film usually has a smooth surface. On the other hand, the surface roughness may also be affected by the number of bottom stack layers, and it mostly increases with the increase in the number of stack layers. Therefore, the rms surface roughness of BST on Ru may be attributed to both the higher roughness of the Ru bottom electrode and larger grain size.
Fig. 5. RMS surface roughness of BST thin films and bottom electrodes.

Fig. 6. Dielectric constant and leakage current of BST thin films deposited on Pt, Ir, IrO$_2$/Ir, Ru, and RuO$_2$/Ru bottom electrodes.

(Fig. 2), while that of BST on RuO$_2$/Ru may be due to both the higher roughness of the RuO$_2$/Ru bottom electrode and the effect of the number of bottom stack layers. The rms surface roughness of BST on Pt, Ir, and IrO$_2$/Ir mainly increases with the increase of surface roughness of the bottom electrodes, but the effect of grain size is less. Hence, the rms surface roughness of BST deposited on Ru and RuO$_2$/Ru is higher.

The dependence of the dielectric constant and the leakage current density (electrons transport from bottom electrode to top electrode) measured at 200 kV/cm with a delay time of 30 s on the various bottom electrodes are shown in Fig. 6. It indicates that the BST film deposited on Ru bottom electrode has a maximum dielectric constant of 548 and leakage current density of $4.4 \times 10^{-4}$ A/cm$^2$, The BST film deposited on Pt bottom electrode has the minimum dielectric constant of 219 and leakage current density of $2.2 \times 10^{-6}$ A/cm$^2$. The BST films can exhibit large dielectric constants due to polarization of electric dipoles. It has been reported that dielectric constant of the films was influenced by oxygen stoichiometry [13], composition [36], grain size (grain and grain boundary) [6], [29], [37], [38], crystallinity (dipole density, polarization) [6]–[8], and the space charge capacitance which may be due to space charge accumulation at the electrode interface by Schottky potential of metal electrodes [38]–[40]. In general, large grain size, good crystallinity, and small space charge capacitance width can enhance the dielectric constant of the BST films. The space charge capacitance can be affected by the metal work function and the oxygen vacancies accumulation at electrode interface. When the metal work function is large, the width of space charge capacitance will become large and the barrier height of the interface of BST/metal will become high. When the oxygen vacancies accumulate at the interface of BST/metal, the width of space charge capacitance will become small and the barrier height of the interface of BST/metal will become low. The details are illustrated in Figs. 7 and 8. The local field probably originates from the formation of space charge layers at the interface, which are located at both the top and the bottom electrode. The local field would cause lowering of the dielectric constant at the interfacial layers. The interfacial layers could be expected to work as parasitic series capacitors ($C_2$) with small capacitance [38] (Fig. 8). Lee reported that $C_2$ is a low dielectric-constant capacitance [40]. Surface roughness also enlarges the capacitor electrode area,
which would be one of the factors affecting the properties of the films. However, the surface roughness of BST/RuO$_2$/Ru is larger than that of BST/Ir by a factor of 2.3 (Fig. 5), but the dielectric constant of BST/Ir approaches that of BST/RuO$_2$/Ru at approximately the same grain size and crystallinity [Figs. 2 and 3(a)]. Hence, the surface roughness effect is negligible in this study. On the other hand, the BST on Ru has the maximum grain size (the BST grains with a size of 10–100 nm, the dielectric constant increases with increase of the grain size [6, 7]) (Fig. 2), the stronger and sharper (110) peak imply an improved crystallinity (Fig. 1), and there is smaller space charge width. Hence, the BST on Ru has the maximum dielectric constant, as shown in Fig. 6. The BST on Pt has minimum grain size (Fig. 2), weaker (110) XRD peak (Fig. 1), and larger width of space charge capacitance (large work function). Hence, the BST on Pt has the minimum dielectric constant (Fig. 6). The dielectric constant of BST on Ir is between the dielectric constant of BST/Ru and BST/Pt, because the grain size (Fig. 2), (110) XRD peak intensity (Fig. 1), and work function (5.35 eV) of BST/Ir are between BST/Ru and BST/Pt. The dielectric constant of BST deposited on Ru is larger than that of BST on RuO$_2$/Ru, because the grain size (Fig. 2) and XRD (110) peak intensity (Fig. 1) of BST on Ru are larger than those of BST on RuO$_2$/Ru. For similar reasons, the dielectric constant of BST deposited on Ir is larger than that of BST on IrO$_2$/Ir. Hence, the grain size and crystallinity seem to play important roles in promoting the dielectric constant. The leakage current of BST thin films may be affected by the contact potential barrier. The details are illustrated in Fig. 4. The leakage current of BST deposited on RuO$_2$/Ru and IrO$_2$/Ir has the same value (as shown in Fig. 6) which indicates that their contact potential barriers are probably the same.

The breakdown field of BST on Pt, Ir, and IrO$_2$/Ir is around 3.5 MV/cm and on Ru and RuO$_2$/Ru is around 1.8 MV/cm (Table II). The difference in breakdown field between these two groups of BST films may be attributed to the different grain size and rms surface roughness between them. It is shown that the BST films on Pt, Ir, and IrO$_2$/Ir with smaller grain size (Fig. 2) and smooth surface (Fig. 5) show higher breakdown field, which is similar to that previously reported by Parker et al. [41]. Their work indicated that the smaller grain size films with higher breakdown field were obtained because they could produce more grain boundaries. On the other hand, the smooth surface can suppress the accumulation of electrons at local position, which leads to the uniform electric field, therefore, the breakdown field would also be higher. BST on Ru with larger grain size (Fig. 2) and larger surface roughness (Fig. 5) shows lower breakdown field. However, the BST on RuO$_2$/Ru has smaller grain size (Fig. 2) and nearly the same surface roughness (Fig. 5) in comparison with that on Ru, but both films have near breakdown field. This inconsistent result may be due to the high surface roughness of these two films, that is, the surface roughness is the dominant factor.

The effect of bottom electrodes is summarized in Table II. We deduce a flatband model for metal-BST-metal system, the band-diagrams before contact are shown in Fig. 7(a) for the Pt-BST-Pt system where the work function of Pt is 5.6 eV and Fig. 7(b) for the Ru (bottom electrode)-BST-Pt (top electrode) system where the work function of Ru is 4.8 eV. The electron affinity of BST is assumed to be 4.1 eV and the energy bandgap is 3.5 eV [12]. Fig. 8(a) and (b) shows the energy band situation after contact for both systems in which $C_f$ is the film-capacitance and $C_s$ the space charge capacitance. It has been reported that $C_s$ is a low dielectric constant capacitance [40]. Fig. 8(c) indicates the equivalent circuit of BST thin films. Summarizing the discussion of the energy band structure of the investigated metal-BST-metal system and the experimental data of dielectric constant and leakage current, the correlation between the work function of contact material and the space charge capacitance can well explain the dependence of the dielectric constant and leakage current on various bottom electrodes, as shown in Fig. 6.
Fig. 9. BST(110) intensity of BST films deposited at 500 °C on Pt, Ir, and Ru and afterward annealed for 20 min at 500, 600, and 700 °C in O₂ ambient.

Fig. 10. Surface roughness of BST films deposited at 500 °C on Pt, Ir, and Ru and afterward annealed for 20 min at 500, 600, and 700 °C in O₂ ambient.

B. Effect of Annealing in O₂ Ambient

Fig. 9 depicts that the BST(110) peak intensity for the BST films deposited on Pt, Ir, and Ru at 500 °C and afterward FN annealed at 500, 600, and 700 °C in O₂ ambient for 20 min. The (110) diffraction peak of the BST films increases with increasing annealing temperature. The results of XRD suggest that an improvement of the crystallinity of BST films can be achieved by annealing treatment. Fig. 10 depicts that the surface roughness of BST thin films deposited on Pt, Ir, and Ru at 500 °C and afterward FN annealed at 500, 600, and 700 °C in O₂ ambient for 20 min. The surface roughness of BST films increases with increasing annealing temperature. The surface roughness effect was considered to be negligible in this study, which was illustrated in Fig. 6.

Fig. 11(a) shows that the variation of dielectric constant of BST thin films, deposited on Pt, Ir, and IrO₂/Ir bottom electrodes at 500 °C and sequentially annealed in O₂ at 500, 600, and 700 °C for 20 min. The dielectric constant increases with increasing the annealing temperature because the intensities of the XRD peaks of BST on Pt and Ir increase with increasing annealing temperature, while that of BST on Ru decreases with increasing the annealing temperature. Hence, the BST deposited on Pt, Ir, IrO₂/Ir, and RuO₂/Ru after postannealing are more stable than that on Ru.

From SIMS data, we observed that the oxygen concentration at the BST/Ru interface is larger than the oxygen concentration at BST/Pt and BST/Ir interfaces, as shown in Fig. 12(a)–(c). The BST/Ru interface may be oxidized during deposition and form a thin transition-metal-oxide-layer. The XRD data shows the RuO₂(101) peak of BST on Ru (Fig. 1) and a thin RuO₂ layer was formed at the interface between the BST and Ru during deposition. Hence, the interfaces of BST/Ru may suppress the accumulation of oxygen vacancies. Fig. 13(a)–(c) indicates that the SIMS data of the BST deposited on Pt, Ir, and Ru and afterward annealed in O₂ at 600 °C for 20 min. For understanding the effect of annealing on the dielectric properties of the BST on various bottom electrodes, we compare SIMS data of BST films before and after annealing (Figs. 12 and 13). There is no change in the Ti, Pt, and O concentration profiles at the interface of BST/Pt after annealing, as indicated in Figs. 12(a) and 13(a). The Ti and Ir profiles of BST on Ir remain the same, but the oxygen concentration at the interface slightly increases [Figs. 12(b) and 13(b)], that is, an IrO₂ layer is probably formed. No change in the leakage current at 200 kV/cm happens in BST on Pt after postannealing, while the leakage current of BST on RuO₂/Ru increases with increasing the annealing temperature, while that of BST on Ru decreases with increasing the annealing temperature. Hence, the BST deposited on Pt, Ir, IrO₂/Ir, and RuO₂/Ru after postannealing are more stable than that on Ru.
BST on Ir after postannealing decrease with the annealing temperature (Fig. 14). It is indicated in Figs. 12(c) and 13(c) that changes in the Ti and Ru profiles of BST on Ru occur and the oxygen concentration at the interface increases due to annealing. A thin interfacial layer of RuO$_2$ at BST/Ru was formed during deposition (Fig. 1), and this layer becomes thicker after annealing (XRD data indicates the RuO$_2$(101) peak is stronger after annealing). This change leads to the leakage current of BST on Ru after postannealing approaches to that on RuO$_2$/Ru (Figs. 6 and 14). The large change in the dielectric constant is also attributed to a possible thin interfacial layer like (Ba, Sr)(Ru, Ti)O$_3$ formed at BST/Ru by the interdiffusion of those ions after annealing, because of the similarity of the ionic radii of Ru$^{4+}$ and Ti$^{4+}$, as shown in Fig. 11(b). On a separate study, we found that the (Ba, Sr)(Ru,
The paraelectric perovskite phase of BST over the device operating temperature shows that it does not exhibit fatigue. Because of the large variations in material characteristics that take place at $T_c$, it is desirable to use a material with a transition temperature lower than the normal temperature range of DRAM operation: 0–70 °C ambient and 0–100 °C on chip [4], [9]. Fig. 16(a)–(c) shows that the 80-nm thick BST films deposited at 500 °C with various bottom electrodes are linear from experimental data of polarization versus electric field. The film deposited on Ru at 500 °C has a charge storage density of 49 fC/μm² at an applied field of 100 kV/cm. And the BST film deposited on Ir at 500 °C and annealed at O₂ 600 °C for 20 min has a charge storage density of 47 fC/μm² at an applied field of 100 kV/cm. The polarization of the films may be enhanced in BST films deposited on the Ir bottom electrode after postannealing. It demonstrates an extremely thin polarization voltage loop. This thin polarization loop could lead to a low energy dissipation during switching. Fig. 17 depicts the endurance data of BST films. The samples
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Ru samples. C, Ir samples have C) have longer lifetimes at 2 V operating
600 10
10
at an applied field of 100 kV/cm. A/cm C for 20 min) and IrO
600
for 20 min has
Ru. The longest lifetime
700 C) (BST
Ru, RuO
Ru and RuO2/Ru versus cycle number at 100 kV/cm.

RuO2/Ir, and Ir (600
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cycles. These results confirm that the sputtered
43x44
on Ir at 500
43x56
lowers the dielectric constant to 325. The BST film deposited
an electric field of 200 kV/cm with a delay time of 30 s and
20 min reduces the leakage current to 2.1 \times 10^{-8} \text{ A/cm}^2 at
an electric field of 200 kV/cm with a delay time of 30 s and
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on Ir at 500
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Fig. 17. Polarization of BST films deposited on Pt, Ir, Ir (600 °C), IrO2/Ir, Ru, and RuO2/Ru versus cycle number at 100 kV/cm.

Fig. 18. Time to breakdown of the BST films on various bottom electrodes as a function of stress field.

exhibit very little degradation of polarization at \pm 3 V square
wave after 10^{11} cycles. These results confirm that the sputtered
BST films do not experience any fatigue problem which was
commonly observed in PZT films. The effect of bottom elec-
trodes is summarized in Table II. Lifetime extrapolation using
constant voltage stress time-dependent dielectric breakdown
studies (Fig. 18) predicts the ten-year lifetime at 2 V operating
voltage. It indicates that the BST on Pt, Ir, Ir (600 °C) (BST
annealed at O2 600 °C for 20 min) and IrO2/Ir samples have
a longer lifetime at 2 V operating voltage than the BST on
Ru and RuO2/Ru samples.

IV. CONCLUSIONS

The crystallinity and electrical properties of BST films de-
posited on Pt, Ir, IrO2/Ir, Ru, and RuO2/Ru bottom electrodes
strongly depend on the postannealing process after deposition.
We have shown that BST thin film, deposited on Ru at 500 °C,
has the dielectric constant of 548, a loss tangent of 0.083
at 100 kHz, a leakage current of 4.4 \times 10^{-7} \text{ A/cm}^2 at an
electric field of 200 kV/cm with a delay time of 30 s, and
a charge storage density of 49 \text{ fC/\mu m}^2 at an applied field
of 100 kV/cm. And such film after annealing in O2 at 700 °C
for 20 min reduces the leakage current to 2.1 \times 10^{-8} \text{ A/cm}^2 at
an electric field of 200 kV/cm with a delay time of 30 s and
lowers the dielectric constant to 325. The BST film deposited
on Ir at 500 °C after 700 °C annealing in O2 for 20 min has

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an electric field of 200 kV/cm with a delay time of 30 s and
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on Ir at 500 °C after 700 °C annealing in O2 for 20 min has

the dielectric constant of 593, a loss tangent of 0.019 at 100
kHz, a leakage current of 1.9 \times 10^{-8} \text{ A/cm}^2 at an electric
field of 200 kV/cm with a delay time of 30 s, and a charge
storage density of 53 \text{ fC/\mu m}^2 at an applied field of 100 kV/cm.
On the basis of the measurement results, the BST films on Ir
with postannealing can obtain better dielectric properties than
on other bottom electrodes.

We have demonstrated that the bottom electrodes appear
to have a strong influence on the degradation and breakdown
properties of the BST thin films. The BST film deposited on
Ru has faster degradation than those deposited on Pt, Ir, and
Ir (600 °C). The ten-year lifetime of time-dependent dielectric
breakdown (TDBB) studies indicate that BST films on Pt, Ir
IrO2/Ir, and Ir (600 °C) have longer lifetimes at 2 V operating
voltage than those on Ru and RuO2/Ru. The longest lifetime
occurred in the BST film on Pt was ascribed to smaller grain
size, higher Schottky barrier, and less polarization-enhanced
electron transport in the film on Pt.

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