Dielectric properties of Ba(Zr$_x$Ti$_{1-x}$)O$_3$ thin films prepared using radio frequency magnetron sputtering

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Pt/Ba(Zr$_x$Ti$_{1-x}$)O$_3$ /Pt/Ti/SiO$_2$ /Si capacitors were fabricated using radio frequency (rf) magnetron sputtering. The deposition parameter effects on the dielectric constant, capacitance, and leakage current density of the capacitors were investigated. Amorphous Ba(Zr$_x$Ti$_{1-x}$)O$_3$ (BZ$_{1-x}$) thin films were sputtered onto a substrate with a temperature of 300°C, rf power of 130 W, and in a no-oxygen atmosphere. BZ$_{1-x}$ thin films deposited onto Pt-coated Si substrates show a preferred orientation in the (100) reflection. The dielectric constants of the BZ$_{1-x}$ thin films increased with increasing Zr content and deposition temperature. The diffuse phase transition behavior of the BZ$_{1-x}$ thin films became more pronounced at high Zr content films. The leakage current density of the Pt/Ba(Zr$_x$Ti$_{1-x}$)O$_3$ /Pt/Ti/SiO$_2$ /Si capacitors at 1 kV/cm was about 1.0$\times$10$^{-7}$ A/cm$^2$. This increased with increasing deposition temperature but decreased with increasing O$_2$/(O$_2$ + Ar) ratio. From the films, $P$–$E$ hysteresis loops, the BZ$_{0.1}$T$_{0.9}$ thin films had ferroelectric characteristics. The BZ$_{0.31}$T$_{0.69}$ thin films exhibited paraelectric characteristics at room temperature. © 2003 American Institute of Physics. [DOI: 10.1063/1.1574179]

I. INTRODUCTION

Ferroelectric thin film materials with ABO$_3$ perovskite-type structure have attracted much attention for memory applications. In dynamic random access memory (DRAM) application, polarization hysteresis behavior is not required. In an 1 G Bit DRAM, the memory arrays contain $10^9$ cells surrounded by peripheral devices that manage the command and voltage levels. All DRAM chips manufactured to date use capacitors containing electrodes made of doped silicon or polysilicon and dielectric silicon dioxide and/or silicon nitride film. Incorporating a new dielectric film into the capacitor will break a 30 years precedent where long term dielectric performance and reliability are firmly established.

The following three features have crucial importance for the quality and reliability of memory devices: fast dielectric response, low leakage current loss and long lifetime. Recently, high dielectric constant ferroelectric thin film materials such as BaTiO$_3$, Pb(Zr,Ti)O$_3$, (Ba,Pb)(Zr,Ti)O$_3$, and (Ba,Sr)TiO$_3$ (Refs. 8–14) have generated great interest for cell capacitor applications in DRAMS that require very high storage charge densities. Among these materials, ferroelectric barium strontium titanate [(Ba,Sr)TiO$_3$, BST] film is one of the most promising capacitor materials for future DRAM applications because of its high dielectric constant and low leakage current at operating voltages.

The BST ceramic is a solid solution of BaTiO$_3$ (BT) and SrTiO$_3$ (ST), and can be expressed as $x$ BT–$(1-x)$ST. Zirconia (ZrO$_2$) was shown by Brager and Kulscar to increase the orthorhombic–tetragonal transition temperature of BT while slightly lowering the tetragonal–cubic transition temperature. Addition of unstabilized ZrO$_2$ to BaTiO$_3$ retards the grain growth and decreases the Curie temperature accompanied with a reduced $c/a$ ratio and a decrease in the spontaneous polarization. A flat permittivity profile between 30 and 125°C with significantly lower dielectric loss has also been measured from unstabilized ZrO$_2$ doped BaTiO$_3$.

Ferroelectric Pb(Zr,Ti)O$_3$ thin films possessing a broad range of chemical compositions have been applied in pyroelectric, piezoelectric, and electro-optic devices. Hu and Krupanidhi pointed out that the degree of (100) orientation, remnant polarization, coercive field, and dielectric constant of ferroelectric Pb(Zr,Ti)O$_3$ thin films are strongly dependent on the ion-beam flux and oxygen-ion bombardment energy. Barium lead zirconate titanate [(Ba,Pb)(Zr,Ti)O$_3$] thin films have been successfully fabricated from a stoichiometric target using rf magnetron sputtering. The dielectric properties of these films were investigated by Torii et al. However, studies on Ba(Zr$_x$Ti$_{1-x}$)O$_3$ (BZ$_{1-x}$) thin film deposition using rf magnetron sputtering and their dielectric properties have not been conducted.

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In this study, BZ$_{x}$T$_{1-x}$ thin films were deposited onto Pt/Ti/SiO$_2$/Si substrates using a rf magnetron sputtering process. The structures and dielectric properties of these films were investigated, using x-ray diffraction (XRD), scanning electron microscopy (SEM), and capacitance–voltage and current–voltage measurements. The influences of the processing parameters on the crystal structures, microstructures, and dielectric properties of BZ$_{x}$T$_{1-x}$ thin films are discussed.

II. EXPERIMENTAL PROCEDURE

A. Thin film deposition

Stoichiometric Ba(Zr$_x$Ti$_{1-x}$)$_2$O$_3$ ceramic targets with various Zr contents were prepared. The chemical compositions of these targets are listed in Table I. Commercial BaZrO$_3$ (purity 99.0%, supplied by Johnson Matthey, Inc., West Chester, PA) and BaTiO$_3$ (purity 99.0%, supplied by Noah Tech. Co., San Antonio, Texas) were weighted and ball milled with acetone and alumina balls for 10 h. The mixed slurries were dried using an infrared lamp and subsequently ground and passed through an 80 mesh sieve. The powders were then mixed with a 1.0 wt % polyvinyl acetate (PVA) binder and pressed into 5.0-cm-diam disks at 180 MPa pressure. The pressed disks were heat treated at 600 °C for 30 min with a 4.5 °C/min heating rate to burn out the binder. The binder burned out target disks were then heated at 1100 °C for 2 h with a 1.5 °C/min heating rate, and cooled to room temperature at a rate of 3 °C/min.

The n-type Si(100) wafer substrates were cleaned using a standard process. The substrate dimensions were 10.0 mm width, 10.0 mm length, and 0.50 mm thickness. A 200.0 nm silicon oxide layer was grown on top of the silicon substrate using thermal oxidation. Platinum (Pt) layers were used as the top and bottom electrodes in the capacitors structure. The 500.0-nm-thin Pt bottom electrode was sputter deposited on the top of 5.0 nm Ti film at a temperature of 400 °C. Both metals were sputtered in an Ar atmosphere at a working pressure of 1.0×10$^{-2}$ Torr with an applied power of 150 W.

Ba(Zr$_x$Ti$_{1-x}$)$_2$O$_3$ (BZ$_{x}$T$_{1-x}$) thin films with various Zr contents were deposited on Pt films using rf magnetron sputtering. The parameters for the BZ$_{x}$T$_{1-x}$ thin film deposition processes are listed in Table II. The thickness of the dielectric films was 500 nm. The Pt top electrodes were patterned using a shadow mask process with a thickness of 50.0 nm and diameters of 150.0, 250.0, and 350.0 nm, respectively.

B. Properties characterization

The thickness of the BZ$_{x}$T$_{1-x}$ thin films with various ZrO$_2$ contents was measured using an automatic ellipsometer (Rudolph Research Co., Flanders, NJ) with a He–Ne laser (wavelength 6328 Å) as a detecting probe and a profilometer (Tencor Alpha-Step 200, San Jose, CA).

BZ$_{x}$T$_{1-x}$ thin film cross section microstructures were observed using SEM (Hitachi, model S-4200, Tokyo, Japan). The BZ$_{x}$T$_{1-x}$ thin film crystal structures were analyzed using XRD (Rigaku Co., model Rad II A, Tokyo, Japan), using Cu Kα radiation.

The dielectric constants of the BZ$_{x}$T$_{1-x}$ films were measured at temperature from 20 to 160 °C using an impedance analyzer (HP 4192 A LF, Palo Alto, CA) with a thermostat (Mini-subzero MC-81, Kistner, Japan) using an applied ac voltage of 1 V and a frequency of 1 kHz. The dielectric constant ($\varepsilon_r$) was calculated using Eq. (1):

$$\varepsilon_r = \frac{C d}{\varepsilon_0 A},$$

where C is the capacitance (F), d is the film’s thickness (m), A is the area of Pt top electrode (m$^2$), and $\varepsilon_0$ is the permittivity of the free space ($8.854\times10^{-12}$ F/m).

The capacitance–bias voltage curves in the range from +5 to −5 V with a stair step voltage of 0.2 V were measured at 100 kHz and 25 °C using an impedance analyzer. The current–voltage sweep of the Pt/BZ$_{x}$T$_{1-x}$/Pt/Ti/SiO$_2$/Si capacitors from 0 to 40 V was measured with an HP 4156 B semiconductor parameter analyzer at 0.2 V dc stair step voltage, 5 s holding time, 20 s delay time, and 25 °C measurement temperature. A 1 nF mica capacitor was used to detect the amount of stored charge.

III. RESULTS AND DISCUSSION

A. Crystal structure and microstructure of the BZ$_{x}$T$_{1-x}$ thin film

The XRD profiles of the BZ$_{0.3}$T$_{0.7}$ thin films sputtered at 130 W rf power; 5.0×10$^{-3}$ Torr working pressure; O$_2$/(O$_2$ + Ar) ratio of 1/10; and 300, 400, and 500 °C substrate temperatures, are shown in Fig. 1. BZ$_{0.3}$T$_{0.7}$ phases in the (h00) reflections and Pt (111) reflection were observed. The preferred orientation of BZ$_{0.3}$T$_{0.7}$ in the (h00) reflections indicated that the BZ$_{0.3}$T$_{0.7}$ thin film consisted of a single BaZr$_x$Ti$_{1-x}$O$_3$ phase epitaxially grown onto the substrate. The crystallinity of the BZ$_{0.3}$T$_{0.7}$ phase increased with increasing substrate temperature. This was caused by an increase in kinetic energy in the sputter-ejected species with increasing substrate temperature, leading to enhanced BZ$_{0.3}$T$_{0.7}$ thin film crystallization.

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TABLE I. Chemical composition of the stoichiometric ceramic targets for the preparation of the Ba(Zr$_x$Ti$_{1-x}$)$_2$O$_3$ (BZ$_{x}$T$_{1-x}$) thin films.

<table>
<thead>
<tr>
<th>Starting material</th>
<th>BZ$<em>{0.1}$Ti$</em>{0.9}$</th>
<th>BZ$<em>{0.2}$Z$</em>{0.8}$</th>
<th>BZ$<em>{0.3}$T$</em>{0.7}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaZrO$_3$</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>BaTiO$_3$</td>
<td>90</td>
<td>80</td>
<td>70</td>
</tr>
</tbody>
</table>

TABLE II. Rf magnetron sputtering parameters for the preparation process of the Ba(Zr$_x$Ti$_{1-x}$)$_2$O$_3$ (BZ$_{x}$T$_{1-x}$) thin films.

<table>
<thead>
<tr>
<th>Target diameter (cm)</th>
<th>5.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target–substrate distance (cm)</td>
<td>3.6</td>
</tr>
<tr>
<td>Background pressure ($10^{-3}$ Torr)</td>
<td>2</td>
</tr>
<tr>
<td>Working pressure ($10^{-3}$ Torr)</td>
<td>5–15</td>
</tr>
<tr>
<td>Sputtering gas</td>
<td>Ar or (O$_2$ + Ar) gas</td>
</tr>
<tr>
<td>RF power (W)</td>
<td>100–160</td>
</tr>
<tr>
<td>Substrate temperature (°C)</td>
<td>300–500</td>
</tr>
<tr>
<td>Deposition time (min)</td>
<td>60</td>
</tr>
<tr>
<td>Film thickness (nm)</td>
<td>500</td>
</tr>
</tbody>
</table>
An amorphous BZ$_{0.3}$T$_{0.7}$ thin film was obtained when the film was prepared at 130 W rf power, $5.0 \times 10^{-3}$ Torr working pressure, and an O$_2$/(O$_2$ + Ar) ratio of 0, as shown in Fig. 2. The crystallinity of the BZ$_{0.3}$T$_{0.7}$ thin films increased with increasing O$_2$/(O$_2$ + Ar) ratio, as indicated by curves (b) and (c) in Fig. 2. The oxygen partial pressure played a crucial role in the film’s growth process.20 Oxygen addition to the sputtering gas, enhancing indium tin oxide film crystallization, was reported by Buchanan et al.21

The SEM micrograph of the BZ$_{0.3}$T$_{0.7}$/Pt/Ti/SiO$_2$/Si structure prepared at 130 W rf power, $5.0 \times 10^{-3}$ Torr working pressure, 500 °C substrate temperature, and an O$_2$/(O$_2$ + Ar) ratio of 1/10 is shown in Fig. 3. A dense and crack-free BZ$_{0.3}$T$_{0.7}$ film was fabricated on the top of the substrate. The film thickness was 500 nm and columnar grains were observed from the BZ$_{0.3}$T$_{0.7}$ film cross section.

**B. Dielectric constant of the BZ$_{x}$T$_{1-x}$ thin film**

Figures 4–6 show the dielectric constants of the BZ$_{x}$T$_{1-x}$ thin films ($x = 0.1$–$0.3$) at different measurement temperatures. When BZ$_{0.1}$T$_{0.9}$ thin films were deposited at 100 W rf power with a substrate temperature of 300 °C, the maximum dielectric constant was obtained at 120 °C, as shown in Fig. 4. The Curie temperature was close to the Curie temperature of the BT structure because it had only 10 mol % Zr in the BZ$_{x}$T$_{1-x}$ film. When the BZ$_{0.1}$T$_{0.9}$ thin film was deposited at 160 W rf power and a substrate temperature of 300 °C, variations in the film dielectric constant at the Curie temperature, 120 °C, were not quite pronounced. The Curie temperature of the BZ$_{x}$T$_{1-x}$ thin films became less obvious when the films had a ZrO$_2$ content greater than 20 mol %, as shown in Figs. 5 and 6. This indicated that BZ$_{0.3}$T$_{0.7}$ thin films sputtered at 100 W rf power and a substrate temperature of 300 °C were amorphous. Diffuse phase transition behaviors were observed with increasing Zr content in BZ$_{x}$T$_{1-x}$ thin films. The dielectric constants of BZ$_{x}$T$_{1-x}$ thin films deposited at 300 and 500 °C increased with increasing deposition temperature and Zr content, as revealed in Figs. 4–6. The maximum dielectric constants of the BZ$_{x}$T$_{1-x}$ thin films were obtained from samples prepared using 130 W rf power. Resputtering lead to decreased crystallinity of the BZ$_{x}$T$_{1-x}$ thin films with the rf power increasing from 130 to 160 W, which might cause a decrease in the film dielectric constant. The dielectric constant of the BZ$_{x}$T$_{1-x}$ thin films increased with increasing Zr content at the same deposition rf power.

Figure 7 shows the relationships between the frequency and capacitance of Pt/BZ$_{x}$T$_{1-x}$/Pt/Ti/SiO$_2$/Si capacitors deposited at different substrate temperatures. The capacitance decreased with increasing frequency. Each sample’s capaci-
 Capacitance decreased at the measuring frequencies from 1 k to 40 kHz. The capacitance of the films reached equilibrium values when the frequency was greater than 40 kHz. Each curve had a depression at various frequencies caused by capacitor resonance leading to decreased dielectric constant. The capacitance decreased with decreasing substrate temperature when measured at the same frequency. As revealed from Fig. 1, a better BZ$_x$T$_{1-x}$ phase crystallinity was observed from samples deposited at higher substrate temperatures. This caused the film capacitance to be higher.

The capacitances of Pt/BZ$_{0.3}$T$_{0.7}$/Pt/Ti/SiO$_2$/Si capacitors deposited at 130 W rf power, 5.0$\times$10$^{-3}$ Torr working pressure, and an O$_2$/(O$_2$+Ar) ratio of 1/10 at different bias voltages are shown in Fig. 8. The electric charge storage of BZ$_{0.3}$T$_{0.7}$ thin films at 300 °C had consistent capacitance values at different bias voltages. This indicated the films linear dielectric behavior. In Waser’s investigation,$^{23}$ superparaelectric behavior was obtained from ferroelectric BT thin films due to their small grain size. Variations of the capacitances of BZ$_{0.3}$T$_{0.7}$ thin films deposited at 400 and 500 °C at 4 V bias voltage were greater than 20 pF. The electric charge storage of those films decreased with increasing bias voltage. Nonlinear dielectric properties were observed from 400 and 500 °C deposited BZ$_{0.3}$T$_{0.7}$ thin films. As discussed previously, the crystallinity and grain size of BZ$_{0.3}$T$_{0.7}$ thin films increased with increasing substrate temperature from 300 to 500 °C. Due to the larger grain size, BZ$_{0.3}$T$_{0.7}$ thin films deposited onto 400 and 500 °C substrates exhibited nonlinear dielectric behavior.

C. Leakage current density of the Pt/BZ$_{x}$T$_{1-x}$/Pt/Ti/SiO$_2$/Si capacitors

The influences of the electric field and Zr content on the leakage current density of the Pt/BZ$_{x}$T$_{1-x}$/Pt/Ti/SiO$_2$/Si capacitors are shown in Fig. 9. The leakage current density of the Pt/BZ$_{x}$T$_{1-x}$/Pt/Ti/SiO$_2$/Si capacitors at 1 kV/cm is about 1.0$\times$10$^{-7}$ A/cm$^2$ ($x=0.1–0.3$). The leakage current densities of the BZ$_{0.3}$T$_{0.7}$ capacitors were lower than other BZ$_{x}$T$_{1-x}$ capacitors. Similar electric field versus leakage cur-
rent density characteristics were observed from different Zr
content capacitors at applied electric fields between 150 and
400 kV/cm. BZ0.3 T 0.7 thin films had a higher crystallinity.
This gave the films the lowest leakage current density among
the films prepared in this study. The leakage current ($I_{lc}$) of
the Pt/BZ$_x$T$_{1-x}$/Pt/Ti/SiO$_2$/Si capacitors can be expressed as:

$$I_{lc} = I_{sc} + I_t + I_{th},$$

where $I_{sc}$ is the current flow using the Schottky emission, $I_t$
is the tripping current, $I_{th}$ is the detripping current, and $I_{th}$
is the thermally generated current.

The Schottky-barrier limited current flow was reported
as the most favored mechanism for the leakage current in ST
and (Ba,Sr)TiO$_3$ thin films.\textsuperscript{11,13,25,26} The height of the barrier
is in the general field and temperature dependent. The
Schottky effect quantifies the field effect on the energy bar-
rier for the electron emission from a metal into a semicon-
ducting or insulating bulk materials.\textsuperscript{27} The temperature de-
pendence ($T$) and electric field ($E$) on the leakage current
density ($J_{ld}$) can be expressed as:

$$J_{ld} = A^* T^2 \exp \left( -\frac{q \phi_B}{kT} \right) \exp \left[ \frac{q \phi_B}{kT} \left( \frac{qE}{4\pi\epsilon_0} \right)^{1/2} \right].$$

FIG. 6. Dielectric constants of (a) 300 °C and (b) 500 °C deposited BZ$_{0.3}$Ti$_{0.7}$
thin films as a function of the measured temperatures. Deposition conditions
of these films were 100, 130, and 160 W rf power, 5.0×10^{-3} Torr working
pressure, and an O$_2$/(O$_2$+Ar) ratio of 1/10.

FIG. 7. Capacitance vs. frequency of Pt/BZ$_{0.3}$Ti$_{0.7}$/Pt/Ti/SiO$_2$/Si capacitors
sputtered at 130 W rf power, 5.0×10^{-3} Torr working pressure, and an O$_2$/(O$_2$+Ar) ratio of 1/10.

FIG. 8. Bias voltage vs capacitance of the Pt/BZ$_x$T$_{1-x}$/Pt/Ti/SiO$_2$/Si capacitors sputtered at 130 W rf power, 5.0×10^{-3} Torr working pressure, and an O$_2$/(O$_2$+Ar) ratio of 1/10.

FIG. 9. Leakage current densities of Pt/BZ$_x$T$_{1-x}$/Pt/Ti/SiO$_2$/Si capacitors at different applied electric fields. Dielectric layers of the capacitors were prepared at 130 W rf power, 5.0×10^{-3} Torr working pressure, an O$_2$/(O$_2$+Ar) ratio of 1/10, and 500 °C substrate temperature.
where $A^*$ is the effective Richardson constant, $T$ is the absolute temperature, $q$ is the electron charge, $\phi_B$ is the barrier height, $E$ is the electric field, $\varepsilon_i$ is the insulator dynamic dielectric constant, and $k$ is the Boltzmann constant.

In this case, the charge carriers were thermally excited over an energy barrier at the ceramic–metal interface. This barrier was created using the equilibration of the charge carrier energy in the ceramic and metal. The equilibration value at zero applied field was adjusted by field-dependent lower-energy barriers at ceramic–metal interfaces. The equilibration charge carriers made the capacitor leakage current densities increase with increasing sputtering temperature.

In Fig. 9, the electric field effect on the leakage current density was divided into four regimes. Electric fields smaller than 20 kV/cm were located in regime I (Ohmic regime). At this regime, the thermally generated carriers in both directions were only slightly affected by the external field. The electric fields from 20 to 150 kV/cm belonged to regime II, where the voltage-independent forward current led to a saturation current. Regime III had electrical fields from 150 to 400 kV/cm. In this regime the barrier became lower due to the Schottky emission effect. Electric fields larger than 400 kV/cm were attributed to regime IV. Murphy and Good pointed out that neither the Schottky emission nor the Fowler–Nordheim tunneling approximation works in this regime.

The electric field and substrate temperature effects on the leakage current density of the Pt/BZ$_{0.3}$T$_{0.7}$/Pt/Ti/SiO$_2$/Si capacitors are shown in Fig. 10. The leakage current densities of the capacitors increased with increasing substrate temperatures. This result was caused by Ti$^{4+}$ reduced to Ti$^{3+}$, and the oxygen vacancies generated at elevated substrate temperatures. The oxygen vacancies act as doubly ionized donors and contribute, at maximum, two electrons to the electrical conductivity as shown in the following equation:

$$\text{O}_2^2- \rightarrow \text{V}_O^- + 2e^- + \frac{1}{2}\text{O}_{2(g)}.$$

The interface between the Pt electrode and the BZ$_{0.3}$T$_{0.7}$ thin film was also associated with the field-enhanced thermal excitation charge carriers from the traps due to the increasing substrate temperature. These thermal excitation charge carriers made the capacitor leakage current densities increase with increasing sputtering temperature.

Figure 11 shows the effects of the electric field and $\text{O}_2/(\text{O}_2+\text{Ar})$ ratio on the leakage current densities of the Pt/BZ$_{0.3}$T$_{0.7}$/Pt/Ti/SiO$_2$/Si capacitors. The leakage current densities decreased with increasing $\text{O}_2/(\text{O}_2+\text{Ar})$ ratio. This was caused by oxygen vacancy dissipation, leading to a decrease in resistivity. Ovadyahu et al. found dendritic growth in indium oxide films when the partial oxygen pressure was lower than the nominal pressure. The indium oxide films with dendritic structures had poor electrical properties. Thilakan and Kumar reported that a few oxygen vacancies acted as charge carriers in films at high oxygen partial pressure. The critical role of oxygen partial pressure on sputtering gas is the conflicting requirements for introducing enough oxygen vacancies without creating too many grain boundaries in the process.

Figure 12 shows the polarization versus electric field ($P-E$) hysteresis loops in BZ$_x$T$_{1-x}$ thin films. The BZ$_x$T$_{1-x}$ thin film with $x=0.1$ (10 mol% of Zr) exhibited a square hysteresis loop and remnant polarization ($P_r$) of 21 $\mu$C/cm$^2$. When the film had 20 mol% Zr, the remnant polarization of the BZ$_{0.2}$T$_{0.8}$ thin film decreased to 10 $\mu$C/cm$^2$. The $P-E$ characteristics of BZ$_{0.3}$T$_{0.7}$ thin films exhibited linear relationships. These films had a paraelectric behavior. The paraelectric characteristics of the BZ$_{0.3}$T$_{0.7}$ thin films were consistent with previous discussions on temperature and bias field dependences of dielectric constants.

**IV. CONCLUSIONS**

BZ$_x$T$_{1-x}$ thin films with various Zr contents were successfully fabricated from stoichiometric targets using rf magnetron sputtering. BZ$_x$T$_{1-x}$ thin films deposited on Pt-coated Si substrates had preferred orientation in the (100) reflection. The Curie temperatures of the BZ$_x$T$_{1-x}$ thin films were not
pronounced when the Zr content of the films increased. Diffuse phase transformation was observed in the prepared films. Due to the better \( \text{BZ}_x\text{T}_{1-x} \) phase crystallinity formed in the film, the dielectric constant of the \( \text{BZ}_x\text{T}_{1-x} \) thin films increased with increasing deposition temperatures and Zr content. Linear dielectric behaviors were obtained from \( \text{BZ}_{0.3}\text{T}_{0.7} \) thin films deposited onto 300 °C Pt-coated Si substrates. When the substrate temperatures increased, the dielectric of the \( \text{BZ}_{0.3}\text{T}_{0.7} \) thin films became nonlinear. The leakage current density at 1 kV/cm was about 1.0 \( \times 10^{-7} \) A/cm\(^2\) for 0.1 \( \leq x \leq 0.3 \). The leakage current density increased with increasing substrate temperature but decreased with increasing \( \text{O}_2/(\text{O}_2 + \text{Ar}) \) ratio. The hysteresis loops in the polarization versus electric field plots indicated that the \( \text{BZ}_{0.3}\text{T}_{0.7} \) thin films had paraelectric properties at room temperature.

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