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Dielectric properties of $SrTiO_3$ thin films by RF magnetron sputtering.

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Dielectric $SrTiO_3$ thin films were prepared on various substrates using a rf-magnetron sputtering technique with a ceramic target. Its crystalline structure and dielectric properties were studied as functions of substrate temperature and lower electrode type. The X-ray diffraction peak intensities and the dielectric constant of the $SrTiO_3$ thin films increased with substrate temperature. The dielectric constant of the $SrTiO_3$ thin films deposited at 580℃ was 255. Strong bias voltage dependence and the maximum capacitance at -1V were observed in the films deposited on both the $Pt/SiO_2/Si$ and $Ru/SiO_2/Si$ substrates. The leakage current density of the 150nm thick films on $Pt/SiO_2/Si$ was $2.5 \times 10^{-8} A/cm^2$ at 5V.

1. INTRODUCTION

The strontium titanate ($SrTiO_3$) thin film has been attractive with respect to application in VLSI devices such as dynamic random access memories (DRAMs)[1-4]. Obtaining $SrTiO_3$ thin films with appropriate properties requires the reliable control of their stoichiometry and structure. RF magnetron sputtering is commonly used for deposition[1,3-4], however, this method involves difficulty in precisely controling film stoichiometry and damage to the substrate materials by bombardment of high-energy particles.

We have investigated the relations between substrate temperature, lower electrode type, crystal structure and dielectric properties of $SrTiO_3$ thin films prepared by RF magnetron sputtering.

2. EXPERIMENTAL

The $SrTiO_3$ thin films were prepared using a RF magnetron sputtering technique with a ceramic target under various conditions. The sputtering conditions of the $SrTiO_3$ thin films are summarized in Table 1. The sputtering target was a three-inch disk of stoichiometric $SrTiO_3$ ceramic. The substrates were (100)p-silicon wafers with a 1000nm thick oxidized layer. Lower electrodes were formed as follows. A platinum and a ruthenium film on the SiO_2/Si-wafer with a thickness of 500nm were prepared by sputtering in an argon atmosphere. A ruthenium oxide (RuO_2) and titanium nitride (TiN) film were formed by reactive sputtering in an atmosphere of argon/oxygen and argon/nitrogen gas mixture, respectively. From the results of our preliminary experiment, an oxygen partial pressure for the sputtering gas was set at 0.1Pa.[5] A typical thickness of the $SrTiO_3$ thin film was 500nm.

Film structure was analyzed by X-ray diffraction (XRD). For electrical measurements, Au thin films were deposited at room temperature as the upper electrode with a diameter of 0.9mm. Capacitances were measured using an impedance analyzer (YHP 4192A) at room temperature. The dielectric constant of the films was calculated from the capacitance measured without a bias voltage at a frequency of 100kHz. The current versus voltage was measured using an electrometer (Advantest TR8652).

3. RESULTS AND DISCUSSION

The dielectric constant of the $SrTiO_3$ thin films deposited on Pt/SiO_2/Si increased while the dielectric loss tangent decreased with substrate temperature, as shown in Fig.1. The X-ray peak intensities of the films increased and the lattice constant of the films decreased and approached to bulk value (3.905 Å). These results suggest that the crystallinity of the films increased with substrate heating, which led to improvement in the dielectric properties of the films.

Table 1. Sputtering conditions

Target	$SrTiO_3$ (99.9%)
Substrate temp.	240 ~ 580 ℃
Sputtering gas	$Ar:O_2$=9:1
Gas pressure	1Pa
RF input power	200W

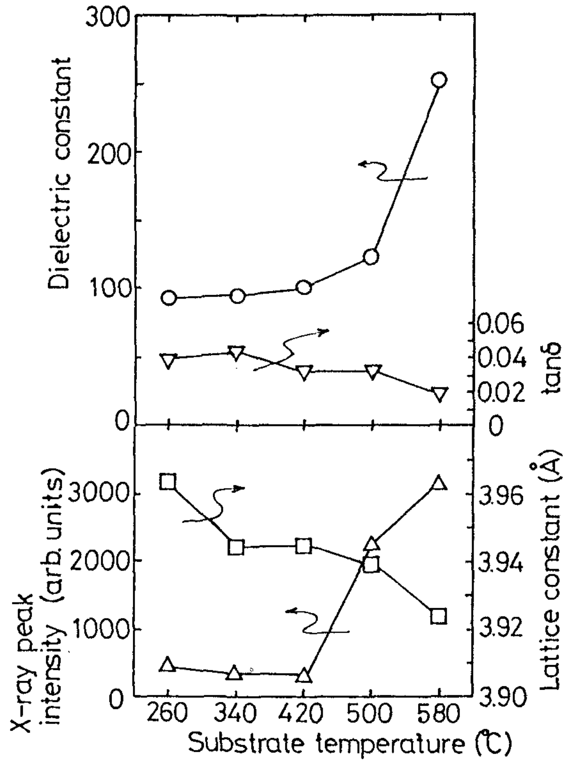

Figure 1. Substrate temperature dependence of dielectric constant, dielectric loss tangent, X-ray peak intensities and lattice constant of $SrTiO_3$ thin films.

Table 2. Dielectric properties of $SrTiO_3$ thin films on various substrate

Substrate	Lattice constant (Å)	X-ray peak intensity (arb. unit)	Dielectric constant	tan δ
$Pt/SiO_2/Si$	3.922	3171	255	0.022
$Ru/SiO_2/Si$	3.944	972	157	0.043
$RuO_2/Ru/SiO_2/Si$	3.941	1610	173	0.038
$RuO_2/SiO_2/Si$	3.941	1287	74	0.037
$TiN/SiO_2/Si$	3.927	1064	146	0.096
poly-Si/Si	3.949	446	85	0.061

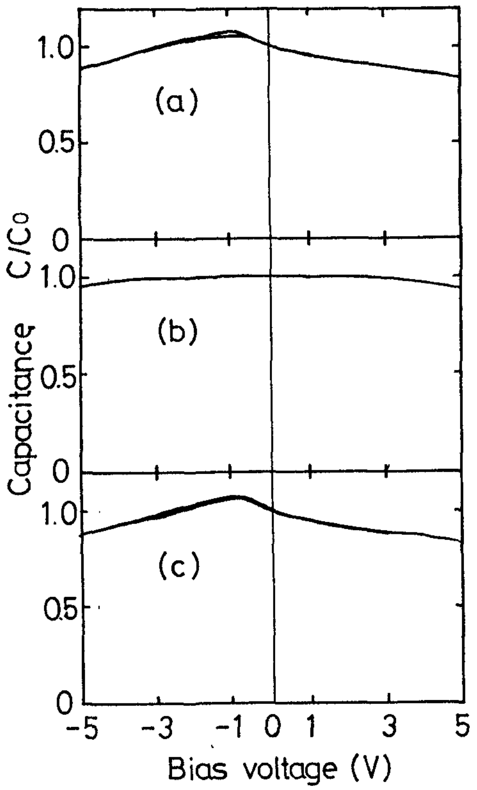

Figure 2. Dc bias voltage dependence of normalized capacitance, C/C_0, of $SrTiO_3$ thin films (150nm thick) deposited on (a) $Pt/SiO_2/Si$ at 580℃ (b) $Pt/SiO_2/Si$ at 420 ℃ and (c) $Ru/SiO_2/Si$ at 580 ℃. C_0 is the capacitance at bias voltage of 0V.

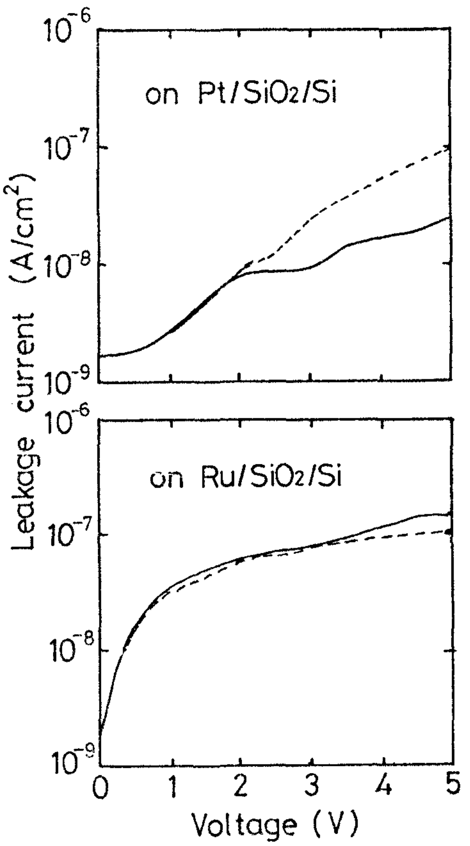

Figure 3. Leakage current of $SrTiO_3$ thin films (150nm thick) deposited on $Pt/SiO_2/Si$ and $Ru/SiO_2/Si$ at 580℃. — : positive, ··· : negative voltage application to the top electrode.

Dc bias voltage dependence of capacitance for $SrTiO_3$ thin films deposited on $Pt/SiO_2/Si$ at 580℃ and 420℃ are shown in Figs.2(a) and 2(b), respectively. Stronger bias dependence was observed in the films deposited at 580℃. It is considered that the degree of polarization saturation was larger in the film deposited at 580℃.

Dielectric properties, X-ray peak intensities and lattice constant of the $SrTiO_3$ thin films deposited on various substrates at 580 ℃ are summarized in Table 2. The highest dielectric constant achieved was for the films deposited on $Pt/SiO_2/Si$.

X-ray diffraction analyses revealed that RuO_2 appeared in addition to Ru and $SrTiO_3$ on the films deposited on $Ru/SiO_2/Si$. The color of the $Ru/SiO_2/Si$ changed to a purplish-silver with deposition. These results indicate that the RuO_2 layer was formed due to the reaction between Ru and $SrTiO_3$ at the interface.

Strong bias dependence and the maximum capacitance at -1V were also observed in the films deposited on $Ru/SiO_2/Si$, as shown in Fig.2(c). These results indicate that polarization saturation and the existence of an internal bias were not a unique phenomenon on the Pt substrate.

Current-voltage characteristics are shown in Fig.3. The leakage current density was 2.5×10^{-8}A/cm^2 on $Pt/SiO_2/Si$ and 1.6×10^{-7}A/cm^2 on $Ru/SiO_2/Si$ at 5V. The leakage current slightly depended on the polarity of the applied voltage.

4. CONCLUSIONS

Dielectric properties of $SrTiO_3$ thin films made by rf magnetron sputtering were varied with substrate temperature and lower electrode type. The highest dielectric constant of 255 was achieved with the films deposited on $Pt/SiO_2/Si$ at 580 ℃. Strong bias dependence and the maximum capacitance at -1V were also observed in the films deposited on $Ru/SiO_2/Si$. The leakage current density of the 150nm thick films on $Pt/SiO_2/Si$ was 2.5×10^{-8}A/cm^2 at 5V.

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