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Characterization of BLT thin films using MgO buffer layer for MFIS-FET

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Abstract

The BLT thin film and MgO buffer layer were fabricated using a metalorganic decomposition method and the DC sputtering technique. The MgO thin film was deposited as a buffer layer on SiO_2/Si and $Bi_{3.25}La_{0.75}Ti_3O_{12}$ (BLT) thin films were used as a ferroelectric layer. The electrical of the metal ferroelectric insulator semiconductor (MFIS) structure were investigated by varying the MgO layer thickness. Transmission electron microscopy (TEM) shows no interdiffusion and reaction that suppressed by using the MgO film as a buffer layer. The width of the memory window in the *C–V* curves for the MFIS structure decreased with increasing thickness of the MgO layer. Leakage current density decreased by about three orders of magnitude after using MgO buffer layer. The results show that the BLT and MgO-based MFIS structure is suitable for non-volatile memory FETs with large memory window.

Keywords: MFIS; BLT; MgO; Memory window

1. Introduction

Memory device using ferroelectric may be categorized into ferroelectric random access memory (FRAM), dynamic random access memory (DRAM), and metal-ferroelectric-semiconductor field-effect-transistors (MFS-FETs), where a ferroelectric film is used as a gate insulator [1]. Ferroelectric thin films such as Bi-based layered perovskite ($SrBi_2Ta_2O_9$ (SBT), $Bi_4Ti_3O_{12}$ (BTO), $Bi_{3.25}La_{0.75}Ti_3O_{12}$ (BLT), etc.) and $Pb(Zr,Ti)O_3$ (PZT) thin films have been extensively investigated for non-volatile FRAM devices. The PZT films have some serious problem such as the imprint, retention and fatigue which ferroelectric properties are degraded by repetitive polarization switching. The SBT films have fatigue-free characteristic. However it has a high processing temperature of above 800 °C and a low remanent polarization [2,3]. Among them, BLT thin films have advantages such as highly fatigue resistant characteristic, low processing temperature, and large remanent polarization. In this respect, BLT films are considered for the MFS-FETs. Because non-volatile memories using MFS-FETs make non-destructive operation possible, rewriting for destroyed information is not needed [4,8].

However, the MFS-FETs that ferroelectric film deposited directly on Si substrate without inserting an electrode have been some problems such as the formation of an amorphous SiO_2 layer with a low dielectric constant at the ferroelectric film/Si interface and interdiffusion between the ferroelectric film and Si substrate [5,9]. To suppress them, a metal-ferroelectric-insulator-semiconductor (MFIS) structure has been subjected. The most important thing in developing a MFIS structure is to find a good insulator that acts as a buffer between the Si substrate and the ferroelectric material. The insulating buffer layer such as MgO, ZrO_2, and Y_2O_3 have relative high dielectric constants of 10–20 ranges, low leakage current, good interface characteristics, and compatibility [6,10]. Among them, the MgO is used as an insulating buffer layer because of its refractory nature and ferroelectric film can be grown highly oriented on MgO-buffered substrates [7].

In this paper, the MgO and BLT film were fabricated using a sputtering method and metalorganic decomposition method (MOD), respectively. The MgO was deposited as a buffer layer on Si substrate, and BLT thin films were used as a ferroelectric layer. In order to show that the BLT-based MFIS structure is suitable for non-volatile memory FETs

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with large memory window, the electrical properties of the MFIS structure were investigated by varying the MgO layer thickness.

2. Experimental

p-Si substrates to deposit the MgO film were cleaned by RCA in order to eliminate the native silicon oxide. MgO thin films were prepared on the Si substrates using the DC sputtering technique. BLT thin films were prepared using the MOD method. Precursors of bismuth (III) acetate [$Bi(CH_3CO_2)_3$], lanthanum-acetate hydrate [$(CH_3CO_2)La \cdot xH_2O$], and titanium (IV) iso-propoxide {$Ti[OCH(CH_3)_2]_4$} and solvents of an acetic acid [CH_3CO_2H] and 2-methoxyethanol [$CH_3OCH_2CH_2OH$] were used.

The MgO films were deposited using the sputtering technique. The deposition conditions of MgO thin film are shown in Table 1. The MgO films were adjusted in a range from 5 to 30 nm. The BLT films were deposited using spin-coated onto Si substrates and the MgO/Si substrates at room temperature, dried at 400 °C for 10 min to remove organic material, respectively. The final thickness of BLT film was 200 nm. In order to crystallize, the MgO and pre-baked BLT film were annealed at 400 and 650 °C for 1 h in oxygen ambient, respectively. Pt as the top electrode material of 300 μm diameter was sputtered through a shadow mask on the BLT films.

X-ray diffraction (XRD) was used to determine the phase of the BLT thin. The interface structures of the BLT and the MgO layers were investigated by transmission electron microscopy (TEM). The polarization–electric field (P–E) hysteresis of the BLT and the BLT/MgO structure was measured using a workstation ferroelectric tester (Radiant Technologies, USA). The high frequency capacitance–voltage characteristics of the MgO/Si and the BLT/MgO/Si were measured using a HP 4192 impedance analyzer with 1 MHz and the sweep speed was 0.2 V/s. The current–voltage characteristics of the BLT/Si and the BLT/MgO/Si were measured using a semiconductor parameter analyzer (Agilent 4156C).

3. Result and discussion

Fig. 1 represents the XRD patterns of BLT films deposited on MgO/Si. As shown in Fig. 1, the BLT film deposited on the MgO/Si shows the typical XRD patterns of

Table 1
Sputtering conditions for deposition of MgO thin film on Si substrate

Target	MgO
Sputtering pressure	1.2×10^{-5} Torr
RF power	100 W
Target distance	15 cm

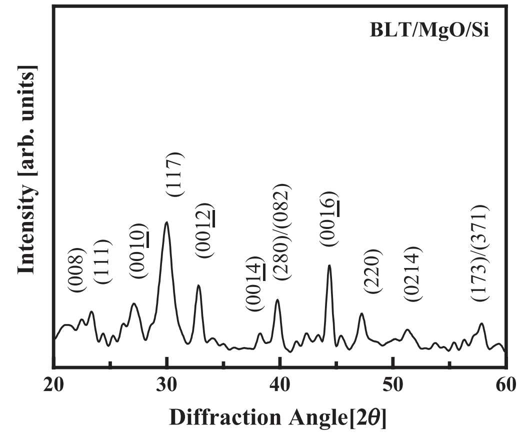

Fig. 1. XRD patterns of the BLT thin film.

BTO layered perovskite polycrystalline structure with diffraction peak of strong (117), and the secondary phase or the preferred orientation was not observed.

In order to observe the effect of MgO insulating buffer layer on the polarization voltage characteristics of the BLT film, a metal ferroelectric insulator metal (MFIM) and metal ferroelectric metal (MFM) structures were fabricated on the Pt/Ti/SiO_2/Si substrate. The P–E hysteresis loops of Pt/BLT/Pt are compared with Pt/BLT/MgO/Pt structures in Fig. 2. These characteristics were measured by applying voltage of ±1 V, ±3 V, ±5 V, ±7 V, and ±10 V. In P–E hysteresis loops of Pt/BLT/Pt and Pt/BLT/MgO/Pt structures, the remanent polarization ($2P_r$) and coercive voltage (E_c) increase as an applied voltage increases from 1 to 10 V. At applied voltage of ±10 V, the remanent polarization of BLT film was 24.24 μC/cm^2. P–E hysteresis loops is saturated for the Pt/BLT/Pt structure due to the ferroelectric characteristic of BLT film but P–E hysteresis loops of Pt/BLT/MgO/Pt structure is not saturated due to the para-electric characteristic of MgO film and show small remanent polarization. On the other hand, Pt/BLT/MgO/Pt structure improves the electrical properties of ferroelectric gate because the coercive voltage is larger than that of Pt/BLT/Pt structure. The large coercive voltage using MgO film lead

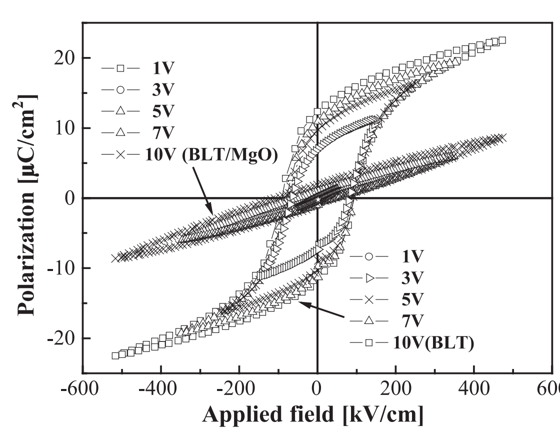

Fig. 2. P–E hysteresis of Pt/BLT/Pt and Pt/BLT/MgO/Pt structure.