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The effect of annealing temperature on the electrical properties of metal-ferroelectric ($PbZr_{0.53}Ti_{0.47}O_3$)-insulator (ZrO_2)-semiconductor (MFIS) thin-film capacitors

P. C. Juan [a,b], J. D. Jiang [a], W. C. Shih [a], J. Y. M. Lee [a,*]

[a]*Department of Electrical Engineering and Institute of Electronic Engineering, Tsing-Hua University, Hsinchu 300, Taiwan, Republic of China*
[b]*Department of Materials Engineering, Mingchi University of Technology, Taipei 243, Taiwan, Republic of China*

Abstract

Metal-ferroelectric-insulator-semiconductor (MFIS) thin-film structures using $PbZr_{0.53}Ti_{0.47}O_3$ (PZT) as the ferroelectric layer and zirconium oxide (ZrO_2) as the insulator layer were fabricated in this work. The leakage current and the C-V memory window were measured for MFIS capacitors with the PZT layer annealed at temperatures of 400^0C, 500^0C, 600^0C, 700^0C. The dominant conduction mechanism of Al/PZT(290 nm)/ZrO_2(15 nm)/Si structure is Poole-Frenkel emission in the temperature range of 300-425 K. Under a sweep voltage of 6 V, the largest memory window of 1.31 V was obtained for 500^0C-annealed samples. The memory window as a function of insulator thickness was also discussed. More serious charge injection is observed when the voltage was swept from negative to positive.

Keywords: ferroelectric memory; zirconium oxide; memory window; conduction mechanism

1. Introduction

Ferroelectric memory field-effect transistors (FEMFETs) with a metal-ferroelectric-insulator-semiconductor (MFIS) structure have emerged as promising nonvolatile memory devices [1]. The purpose of the insulator layer is to prevent the reaction and interdiffusion between the ferroelectric layer and silicon substrate as well as to improve the retention properties [2]. The purpose of using high-κ materials as the insulator layer is to apply sufficient electric field across the ferroelectric layer. The theoretical memory window, $\Delta W \sim 2d_f E_C$ [3], increases with increasing electric field due to the increase in coercive field (E_C) [4]. Zirconium oxide (ZrO_2) is an attractive insulator due to several

* Corresponding author. Tel.:+ *886-3-5731157; fax: 886-3-5715971.*
*E-mail address:*ymlee@ee.nthu.edu.tw (J. Y. M. Lee)

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outstanding characteristics including a large band gap (5.16-7.8 eV) [5], a relatively high dielectric constant (~25) [6] and a high breakdown electric field (>5 MV/cm) [7]. In the literature, Park et al. [8] fabricated the MFIS structure with SBT as the ferroelectric layer and ZrO_2 as the insulator layer and the memory window is as large as 1.6 V under ± 5 V applied voltages. It implies that ZrO_2 acts as a good barrier between the ferroelectric layer and silicon. In this work, MFIS thin-film capacitors with ($PbZr_{0.53}Ti_{0.47}O_3$) (PZT) ferroelectric layer and ZrO_2 insulator layer were fabricated. The electrical properties such as leakage current and C-V memory window were measured. The size of the memory window and the effect of charge injection were characterized under different annealing temperatures and insulator thicknesses.

2. Experiment

P-type, (100)-orientation, 4-in.-diameter silicon wafers (6.5-8 Ω-cm) were used as the starting substrates. The ZrO_2 films were deposited by RF magnetron sputtering. The purity of the ZrO_2 target is 99.9%. A standard oxide clean ($HF:H_2O$=1:10) was performed before film deposition. The PZT target was $Pb_{1.1}(Zr_{0.53}Ti_{0.47})O_3$. The excess Pb was used to compensate for the volatile PbO. A thermal treatment (RTA) was performed in pure O_2 at 400^0C, 500^0C, 600^0C and 700^0C, respectively. The thickness of the PZT thin films was determined by ellipsometry. The crystalline phase of the PZT was identified by x-ray diffraction. Aluminum was used for the top electrode by using a lift-off process. Post-metallization annealing (PMA) was performed at 400^0C in N_2 ambience for 30 s. The C-V characteristics of MFIS capacitors were measured with a HP4284B LCR meter.

3. Results and discussion

Fig.1 shows the current density versus voltage (J-V) characteristics of Al/PZT(290 nm)/ZrO_2(15 nm)/p-Si (MFIS) structure at the annealing temperatures of 400^0C, 500^0C, 600^0C and 700^0C, respectively. The leakage current increases with increasing annealing temperature. Although the current density is lowest with 400^0C annealing, the X-ray diffraction patterns indicate that no PZT crystalline phase was observed (not shown here). The I-V curves were measured as a function of temperature (300-475 K) under positive and negative applied voltages in Fig.2. Under positive biases, the current density strongly depends on the temperature. The J-E curves can be fitted with Poole-Frenkel emission at the electric field range of 0.3-0.5 MV/cm. Fig.3 shows that the log(*J/E*) versus $E^{1/2}$ plot is a straight line in this field range and the slope gives the dielectric constant. The dynamic dielectric constant is calculated to be from 10.6 to 3.6 in the temperature range of 300-425 K. This is consistent with the optically measured refractive index of about 1.9 to3.2, since $\varepsilon_r = n^2 = 2.6^2 = 6.76$.

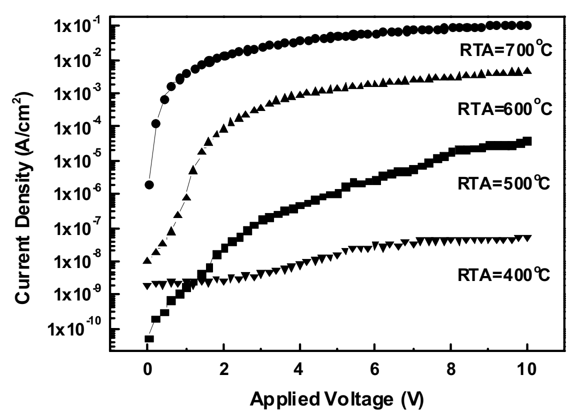

Fig. 1. J-V characteristics of Al/PZT(290 nm)/ZrO_2(15 nm)/p-Si structure at the annealing temperatures of 400^0C, 500^0C, 600^0C and 700^0C, respectively.

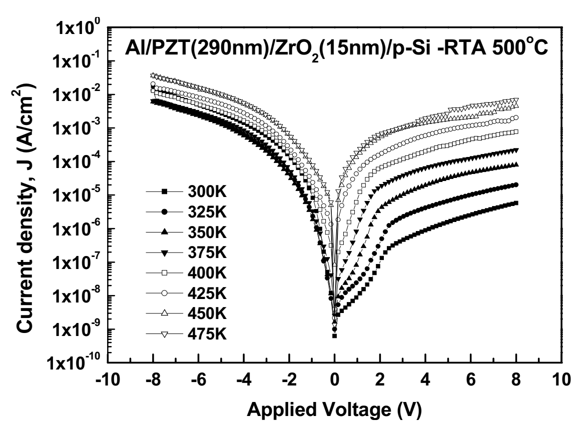

Fig. 2. J-V characteristics of Al/PZT/ZrO_2/p-Si structures in the temperature range from 300 to 475K under positive and negative biases.