High- κ TiO_xN_y based MFIS Structure for Next Generation FeRAM Applications

A Thesis

Submitted by

Deepak Kumar Sharma (S12027)

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MASTER OF SCIENCE

(By RESEARCH)

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To my Family
and
To the Calmness of Himachal

Declaration

I hereby declare that the entire work reported in this thesis is the result of investigations carried out by me in School of Computing and Electrical Engineering (SCEE), Indian Institute of Technology (IIT), Mandi H.P under the supervision of Dr. Satinder Kumar Sharma. The contents of this Thesis, in full or in parts, have not been submitted to any other institute or university for the award of any Degree or Diploma.

IIT Mandi, Himachal Pradesh,
India
Date: Deepak Kumar Sharma

THESIS CERTIFICATE

This is to certify that the thesis titled **"High- κ TiO_xN_y based MFIS Structure for Next Generation FeRAM Applications"**, submitted by **Deepak Kumar Sharma**, to the Indian Institute of Technology Mandi, for the award of the degree of **Master of Science (M.S) (by Research)**, is a bonafide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other institute or university for the award of any degree or diploma.

Dr. Satinder Kumar Sharma
(Supervisor)

School of Computing and Electrical Engineering (SCEE)
Indian Institute of Technology (IIT)- Mandi
MANDI-175001(Himachal Pradesh), India
Email: satinder@iitmandi.ac.in

Date: …………..

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Deepak Kumar Sharma

Abstract

Nonvolatile memories using the ferroelectric material has been studied for many years. Ferroelectric Field effect (FeFET) transistors using Metal Ferroelectric Insulator Semiconductor (MFIS) structure offers non-destructive read out and utilizes ferroelectric layer to alter the channel conductivity of semiconductor thereby producing a shift in flat band voltage whose difference is known as memory window (MW). But the ferroelectric layer used in MFIS capacitor in the past utilizes thick ferroelectric layer with a minimum thickness of the order of ~60 nm. The thickness limitation is due to higher voltage drop across the lower κ buffer layer due to which ferroelectric material is unable to polarize fully at lower gate voltages. Also, the MFIS structures reported in the literature unable to meet the long data retention requirements. In this work, we used high dielectric constant (κ) Titanium oxynitride (TiO_xN_y) as a buffer layer between Ferroelectric layer and silicon. Taking advantages of high κ of TiO_xN_y comparable voltage will be available across PZT ($Pb(Zr_{0.52}Ti_{0.48})O_3$) therefore the minimum thickness of PZT which shows sufficient polarization is used in this study.

PZT act as ferroelectric layer and high-κ titanium oxynitride (TiO_xN_y) as insulating buffer layer of various thicknesses on p-Si (100) substrate was deposited by RF magnetron sputtering technique for non-volatile ferroelectric field effect transistors (FeFETs). The best Capacitance Voltage (C-V) characteristics were obtained at 6 nm of TiO_xN_y with memory window of ~1.05 V was obtained at cyclic sweep voltage of ± 5 V. Memory window found to be dependent on sweep voltage and increases from 0.2 V at sweep voltage of ±2 V to 1.25 V at sweep voltage of ± 6V indicating multilevel data storage. On further increasing sweep voltage memory window found to decrease due to charge injection. The fabricated structure possesses excellent data retention upon extrapolating to 15 years. The proposed system exhibited excellent TiO_xN_y-Si interface, incomparable high breakdown field strength ~11.15 MV/cm and low leakage current density (J) ~5 μA/cm^2 at +4 V. Further Effect of constant voltage stress (CVS) on electrical characteristics of MFIS structure was investigated to study the reliability of fabricated devices. The experimental results showed trivial variation in memory window (ΔW) from 1.05 to 1V under CVS of 0 to 15V (5.76 MV/cm) at sweep voltage of ±5V. Also, leakage current density reduced from 5.57 to 1.94 μA/cm^2 under CVS of 5.76 MV/cm, supported by the energy band diagram. It signifies highly reliable TiO_xN_y buffer layer for Ferroelectric Random Access Memory.

Furthermore, AFM analysis shows the surface roughness of ultrathin TiO_xN_y and thin PZT films are ~2.54 nm and ~1.85 nm, respectively and result the uniform interface between substrate and metal. Micro-Raman analysis of the proposed systems confirmed the existence of TiO_xN_y along with rutile phase and perovskite phase of PZT thin films. Microstructures analysis of XRD reveals the formation of (100) and (111) orientation of PZT and TiO_xN_y, respectively.

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