Integration and Characterization of Linear and Non-linear HfO2-Based Thin Films for Nanocapacitor Applications

Doctorant·e

GARCIA RAMIREZ Emmanuel Armando

Direction de thèse

LÜDERS ULRIKE (Directeur·trice de thèse)

Date de la soutenance

13/09/2024 à 10:00

Lieu de la soutenance

Grenoble

Rapporteurs de la thèse

ALLARD BRUNO Professeur des universités INSA Lyon
VILQUIN BERTRAND Maître de conférences HDR ECOLE CENTRALE LYON

Membres du jury

ALLARD BRUNO, Professeur des universités, INSA Lyon
COQ Rosine, Professeur des universités, Université de Caen Normandie
LÜDERS ULRIKE, Directeur de recherche au CNRS, ENSICAEN
SYLVESTRE ALAIN, Professeur des universités, UNIVERSITE GRENOBLE 1 JOSEPH FOURIER
VILQUIN BERTRAND, Maître de conférences HDR, ECOLE CENTRALE LYON
VOIRON FRÉDÉRIC, Ingénieur de recherche, Murata Integrated Passive Solutions

Abstract

This research investigates the use of hafnium oxide (HfO2)-based thin films in nanocapacitors, focusing on both their linear and non-linear electrical properties to meet the growing demands of high-performance and miniaturized electronic devices. Starting with the fundamental physics of energy storage capacitors, the investigation highlights the essential characteristics of effective dielectric materials, such as a high dielectric constant and a substantial band gap. Hafnium-based materials are particularly promising due to their compatibility with Atomic Layer Deposition (ALD), which allows for precise and uniform thin-film deposition—crucial for ensuring reliable performance in electronic devices. To understand the potential of these materials, various fabrication and characterization techniques were employed. This includes specific deposition processes to create the thin films and morphological tests to study the physical structure of the capacitors. Electrical testing plays a key role in evaluating critical parameters like dielectric constant, breakdown voltage, and overall energy storage capacity. By analyzing these factors, a comprehensive view of how both linear and non-linear hafnium-based dielectrics perform is provided. When exploring linear, amorphous hafnium-based dielectrics, HfO2 is combined with aluminum oxide and silicon dioxide to enhance dielectric properties. Different configurations, such as nanolaminates and solid solutions, are tested to find the optimal balance. The goal is to achieve materials that maintain a high dielectric constant and resist voltage breakdown, thereby improving their ability to store energy efficiently. On the other hand, a detailed look into non-linear, crystalline dielectrics examines the effects of doping hafnium oxide with elements like zirconia and silicon. Different deposition and annealing temperatures are assessed for their impact on crystalline structure and polarization behavior, revealing complex ferroelectric and antiferroelectric behaviors that could offer high energy density and stability. The findings suggest that while ferroelectric materials might not be suitable for applications requiring linear capacitance due to their sensitivity to voltage variations, antiferroelectric materials show promise. However, they still face challenges related to electrical efficiency and thermal management. Finding materials that can effectively stabilize voltage variations is crucial, as capacitors are increasingly used to manage these fluctuations in modern electronics. A significant challenge identified is the variability in the dielectric constant, which can limit the use of these materials in applications demanding stable capacitance, such as signal filtering. To address this issue, solid solutions and laminated materials, which provide consistent linear capacitance, are prioritized. Although these materials are effective up to a certain permittivity threshold, exploring non-linear phases opens the door to potentially higher performance under specific conditions. In summary, understanding of HfO2-based thin films and their role in nanocapacitors is advanced by this research. By examining both linear and non-linear dielectric materials, insights into how to optimize fabrication techniques and material compositions to improve dielectric properties are provided. Ongoing research into issues like material endurance, electrical efficiency, and thermal management is essential for developing reliable and high-performing capacitors that meet the evolving demands of modern electronic technologies