Effect of Tungsten Insertion Layer on the Electrical Properties of PEALD HZO Thin Films for Semiconductor Memory Applications

Ha Jeong Kim, Jea Hyuk Choi, and Hee Chul Lee*

Department of Advanced Materials Engineering, Tech University of Korea, Siheung-city,
Gyeonggi-do, Republic of Korea, eechul@tukorea.ac.kr*

Hafnium-zirconium oxide ($Hf_XZr_{1-X}O_2$, HZO)-based thin films exhibit ferroelectricity even at sub-nanometer thicknesses, making them a promising candidate for next-generation non-volatile and low-power semiconductor memory applications. Atomic Layer Deposition (ALD) offers excellent thickness uniformity and compatibility with Complementary Metal-Oxide-Semiconductor (CMOS) processes, enabling high device integration. However, defects such as oxygen vacancies within the HZO film can degrade its ferroelectric properties, necessitating further studies on electrode materials and processing conditions to o

In this study, Co-Plasma ALD (CPALD) was employed to deposit HZO films, and the effects of a tungsten (W) insertion layer on the electrical properties of TiN/HZO/TiN capacitors were systematically investigated. The thickness of the tungsten insertion layer was varied (0, 5, 10, and 20 nm) to examine its influence on the structural, electrical, and chemical characteristics of the HZO films. Analysis of the polarization-electric field (P-E) hysteresis curves revealed that introducing the tungsten insertion layer significantly suppressed the wake-up effect, with the highest remanent polarization (2Pr) value of 61.0 $\mu C/cm^2$ observed. Additionally, leakage current analysis confirmed that the tungsten insertion layer had minimal impact on electrical reliability.

X-ray diffraction (XRD) analysis demonstrated that introducing the tungsten insertion layer enhanced the formation of the orthorhombic (o-) phase, which is responsible for ferroelectricity. When the tungsten insertion layer thickness increased up to 10 nm, the o-phase fraction rose from 59.1% to 81.1%, while the tetragonal (t-) phase proportion decreased. This finding strongly correlates with the observed improvement in ferroelectric performance. Furthermore, X-ray photoelectron spectroscopy (XPS) analysis indicated that incorporating the tungsten insertion layer at the bottom interface reduced oxygen vacancies and improved the crystallinity of the HZO film by decreasing the proportion of sub-stoichiometric Hf 4f and Zr 3d oxide states.

A comparative analysis of electrode configurations revealed that inserting the tungsten layer at the bottom electrode resulted in superior ferroelectric properties compared to the top electrode configuration. The bottom tungsten insertion layer significantly reduced oxygen vacancies, minimizing the wake-up effect and enhancing device reliability. The highest 2Pr value was obtained when tungsten was inserted at both the top and bottom electrodes, indicating optimal ferroelectric performance.

This study demonstrates that the tungsten insertion layer plays a crucial role in improving the ferroelectric characteristics of HZO films, particularly by mitigating oxygen vacancy-related defects at the electrode interface. The electrode configuration and processing conditions proposed in this research are expected to serve as a valuable foundation for next-generation semiconductor memory technology advancements.

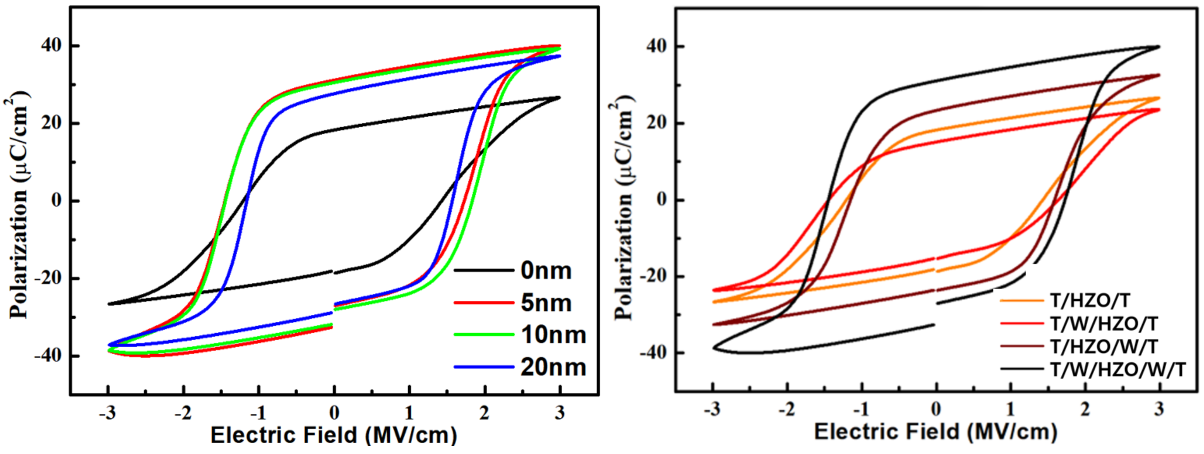

Fig. 1. Polarization hysteresis curves of (a) TiN/W/HZO/W/TiN ferroelectric capacitors with varying tungsten insertion layer thicknesses, and (b) ones with different electrode configurations incorporating a tungsten insertion layer

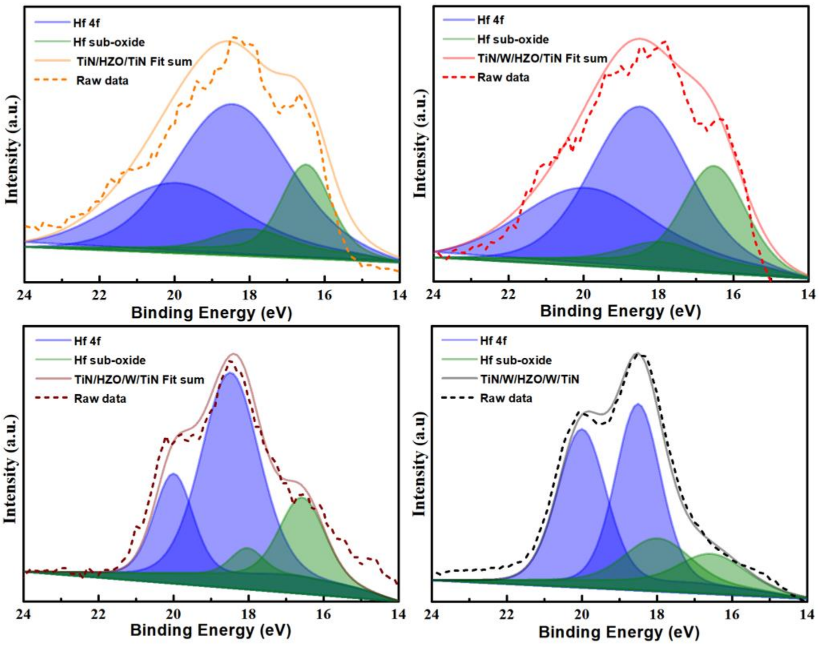

Fig. 2. Hf 4f XPS narrow scan spectra of HZO films with different electrode configurations.

Acknowledgment: This work was supported by K-CHIPS (Korea Collaborative & High-tech Initiative for Prospective Semiconductor Research) (2410000308, RS-2023-00237030, 23027-15FC) funded by the Ministry of Trade, Industry & Energy (MOTIE, Korea).