Process-Driven Enhancement of Ferroelectric Properties in HZO Films via Dual-Plasma ALD

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Hafnium–zirconium oxide ($Hf_{0.5}Zr_{0.5}O_2$, HZO) has emerged as a promising ferroelectric material for next-generation non-volatile memory (NVM) due to its excellent compatibility with CMOS processes and its low-power, non-volatile characteristics. However, practical implementation is hindered by the formation of oxygen vacancy layers or interfacial dead layers at the TiN/HZO interface, which significantly degrade the remanent polarization and interfacial quality [1].

High-quality HZO thin films are typically fabricated using plasma-enhanced atomic layer deposition (PEALD). This technique can be categorized into direct plasma (DP) ALD, in which reactive ions and radicals are directly delivered to the substrate surface, and remote plasma (RP) ALD, in which only chemically activated radicals reach the surface while the plasma generation region is spatially separated [2].

To enhance interfacial and electrical properties while suppressing ion bombardment-induced damage, a dual plasma-assisted ALD method was employed, in which remote plasma ALD (RPALD) and direct plasma ALD (DPALD) were operated simultaneously. During HZO deposition, the RP plasma power was fixed at 2.6 kW, while the DP plasma power was varied from 25 W to 125 W. Electrical characterization of TiN/HZO/TiN capacitors fabricated under these conditions revealed a well-defined ferroelectric hysteresis loop at a DP power of 100 W, with a remanent polarization ($2P_r$) value of 38.6 $\mu C/cm^2$. In contrast, an anti-ferroelectric double hysteresis loop was observed at a DP power of 25 W. X-ray diffraction (XRD) analysis further indicated that increasing the plasma power enhanced the crystallization of the orthorhombic phase (o-phase) in HZO, consistent with the observed electrical characteristics. Although anti-ferroelectric films are generally known for superior fatigue endurance, the reduced energy input at lower DP power likely induced a higher density of defects, leading to degradation in fatigue performance. This degradation could potentially be mitigated through optimized plasma treatments and post-deposition annealing processes.

In this study, we demonstrated that the crystallographic phase and electrical performance of HZO capacitors can be effectively controlled by optimizing and combining remote plasma ALD (RPALD) and direct plasma ALD (DPALD). Furthermore, it is anticipated that alternating the stacking of ferroelectric and anti-ferroelectric layers to form engineered interfaces that suppress defect migration could further enhance polarization characteristics and device reliability [3]. Detailed results related to this approach will be presented in a forthcoming conference.

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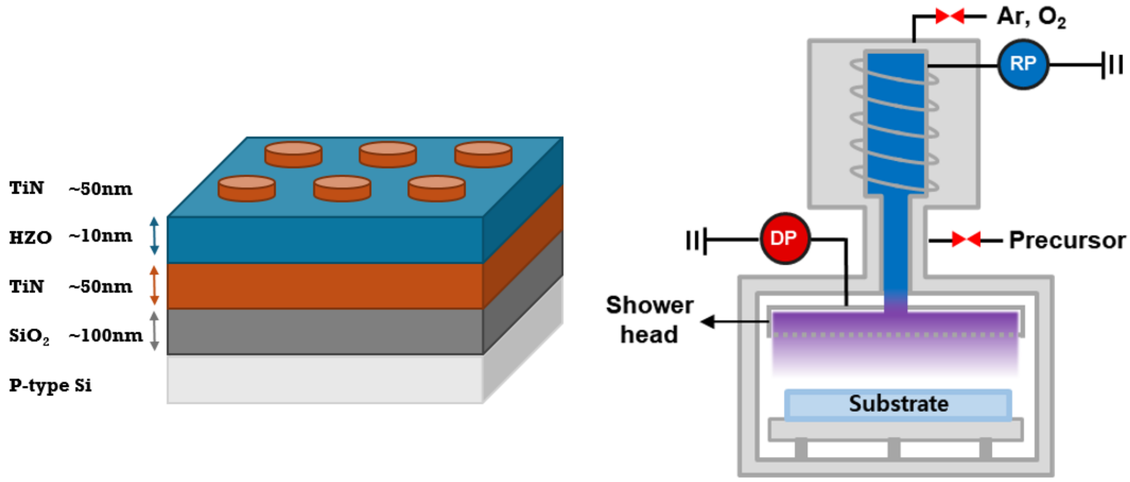

Fig. 1. (a) Schematic illustration of the ferroelectric capacitor used in this study (not to scale). (b) Conceptual diagram of the dual plasma-assisted ALD chamber employing both direct and remote plasma simultaneously.

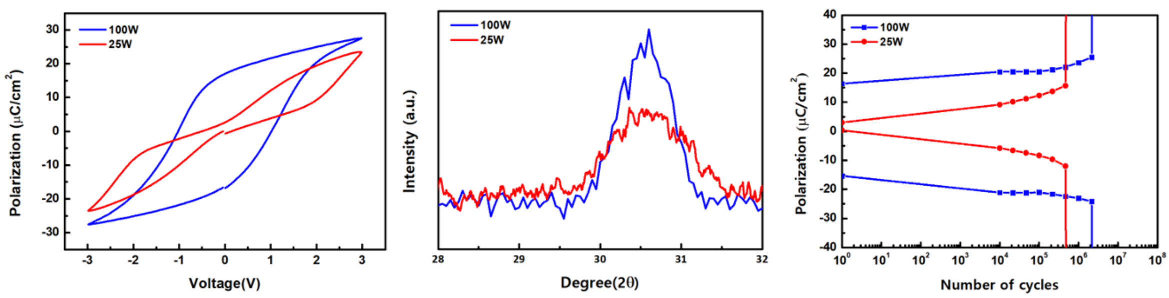

Fig. 2. (a) Polarization–electric field (P–E) hysteresis loops, (b) GIXRD patterns, and (c) fatigue endurance characteristics of HZO thin films deposited by dual plasma-assisted ALD under varying direct plasma power conditions.