Lowering Effective Dielectric Constant of Ferroelectric $Hf_{0.5}Zr_{0.5}O_2$ Film with an Ultra-Thin Al_2O_3 Intermediate Layer

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Ferroelectricity in HfO_2-based thin films has been one of the most active research topics in the semiconductor device area in recent years. HfO_2-based films offer several advantages including compatibility with complementary metal-oxide-semiconductor (CMOS) technology, stability of ferroelectricity at sub-10 nm thickness, sufficiently large coercive field, and ease of large-scale integration[1-3]. However, the HfO_2-based ferroelectric layer deposited directly on a semiconductor substrate as a gate insulator of MOS field effect transistor (MOSFET) can degrade the device performance due to the charge injection from the semiconductor substrate[4,5]. Therefore, it is necessary to insert an insulating (dielectric) layer between the ferroelectric layer and the semiconductor substrate to serve as a blocking layer. In the gate stack of metal-ferroelectric-metal-insulator-silicon (MFMIS) structure, a significant difference in dielectric constant between the ferroelectric layer and the insulating layer raises another issue. The much larger dielectric constant of the ferroelectric layer leads to insufficient voltage drop across the layer, necessitating a higher voltage to induce the electric field required for reversing the polarization direction, compared to metal-ferroelectric-silicon (MFS) structure. From the perspective of the insulating layer, the voltage drop across it will be quite excessive to increase the charge trapping probability[4]. These trapped charges interfere the field effect generated by the surface polarization charges of the ferroelectric layer, leading to the retention deterioration[6]. In order to resolve these issues, a HfO_2-based ferroelectric film with a reduced dielectric constant is highly preferential. In this study, we demonstrate an experimental method for reducing the dielectric constant of HfO_2-based film while maintaining its robust ferroelectric properties. The key idea is to incorporate a thin Al_2O_3 intermediate layer within a $Hf_{0.5}Zr_{0.5}O_2$(HZO) ferroelectric layer to form a tri-layer structure (HZO/Al_2O_3/HZO) with precisely controlled thicknesses by using atomic layer deposition (ALD). We also investigate how the processing conditions of sputtered TiN layer affect the ferroelectric and dielectric properties of the tri-layer structure and a single-layer HZO grown on it. It is found that the tri-layer structure grown on the TiN layer sputtered under Ar-rich environments exhibits an effective dielectric constant lower than that of a single-layer HZO while its ferroelectricity remains almost intact.

References
[1] T. B€oscke *et al.*, Appl. Phys. Lett. 99, 102903 (2011).
[2] J. Müller *et al.*, Nano Lett. 12, 4318 (2012).
[3] S. E. Reyes-Lillo *et al.*, Phys. Rev. B 90, 140103(R) (2014).
[4] Tian F *et al.*, IEEE Trans Electron Devices, 68: 5872–5878 (2021).
[5] Xiao W *et al.*, Nanoscale Res Lett, 2019, 14: 254 (2019).
[6] T. P. Ma and J.-P. Han, IEEE Electron Device Letters **23**, 386-388 (2002).

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