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Stress Engineering in the Optimization of Next-Generation Hafnium-Based Ferroelectric Memory

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S1 The core-level spectra assigned to O 1s, the oxygen of hafnium-based thin film form deionized water

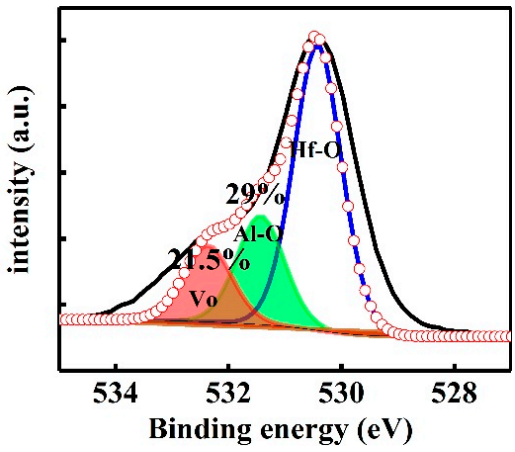


Figure S1. show the peal intensities of Al-O、Hf-O and oxygen vacancies in the O 1s spectrum with the Hf/Al cycle ratio of 34:1. We can see that the oxygen vacancy reach 21.5%.

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S2 C-V curves of the devices at 4 V

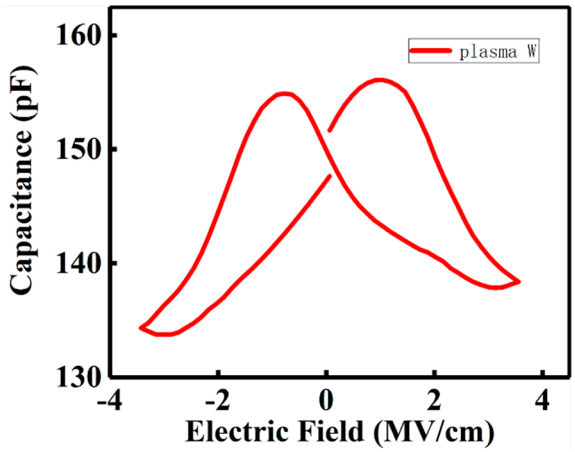


Figure S2. displays the C-V curves with bias voltages ranging from -4 to +4 V at 1KHZ.

S3 The P-E hysteresis curves of the hafnium-based thin films with 21.5% oxygen vacancies.

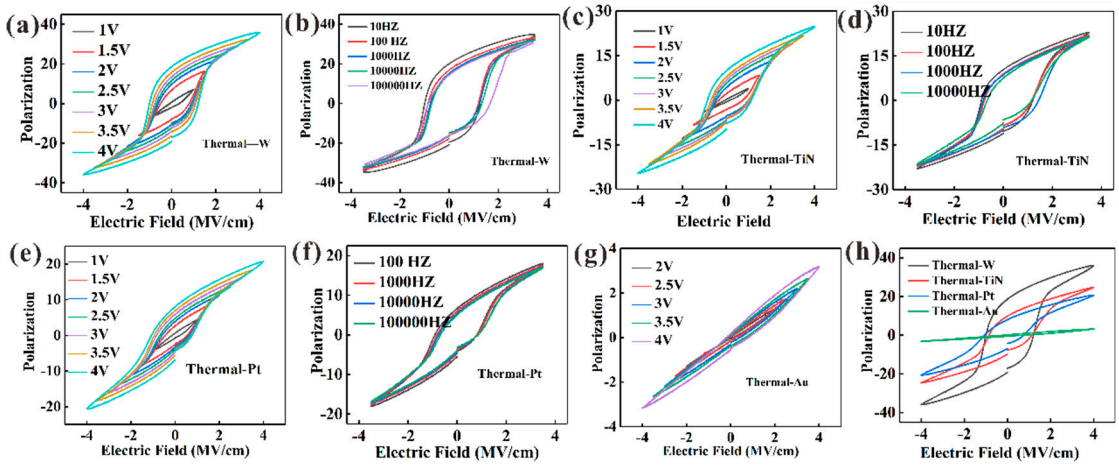


Figure S3. (a) shows the P-E hysteresis curves of the hafnium-based thin films of 21.5% oxygen vacancies with W top electrode under different voltage. FigS3 (b) shows the P-E hysteresis curves of the hafnium-based thin films of 21.5% oxygen vacancies with W top electrode under different frequency. FigS3 (c) shows the P-E hysteresis curves of the hafnium-based thin films of 21.5% oxygen vacancies with TiN top electrode under different voltage. FigS3 (d) shows the P-E hysteresis curves of the hafnium-based thin films of 21.5% oxygen vacancies with TiN top electrode under different frequency. FigS3 (e) shows the P-E hysteresis curves of the hafnium-based thin films of 21.5% oxygen vacancies with Pt top electrode under different voltage. FigS3 (f) shows the P-E hysteresis curves of the hafnium-based thin films of 21.5% oxygen vacancies with Pt top electrode under different frequency. FigS3 (g) shows the P-E hysteresis curves of the hafnium-based thin films of 21.5% oxygen vacancies with Au top electrode under different voltage. From the Figure S3(h), the devices with W top electrodes show the saturated P-E hysteresis curves, i.e., the remanent polarization of about 20 μC/cm^2.

S4 the remanent polarization and coercive field change with the top electrode changing

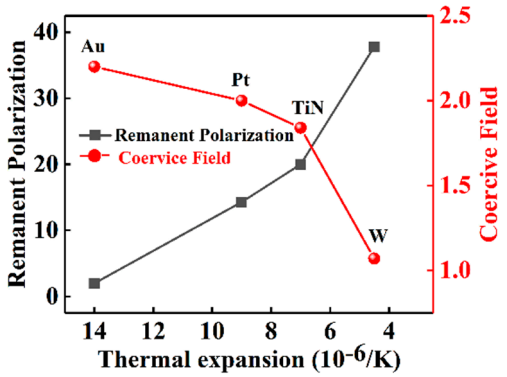


Figure S4. shows that the remanent polarization is increasing with the decreasing of thermal expansion. However, the coercive field is decreasing with the decreasing of thermal expansion.

S5The P-E hysteresis curves of the hafnium-based thin films with 14% oxygen vacancies.

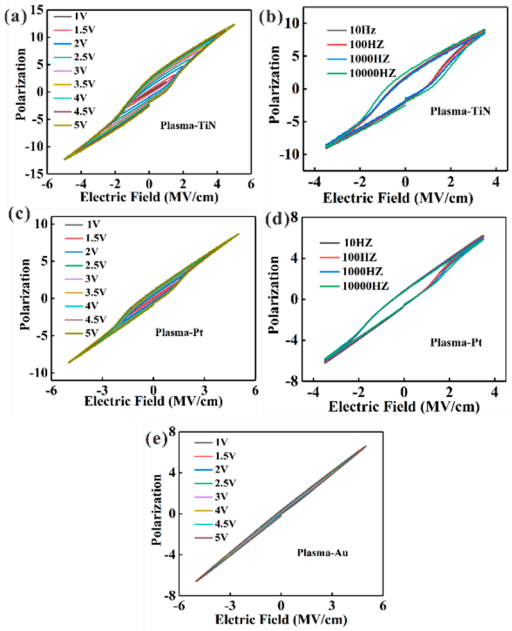


Figure S5. a) shows the P-E hysteresis curves of the hafnium-based thin films of 14% oxygen vacancies with TiN top electrode under different voltage. FigS5(b) shows the P-E hysteresis curves of the hafnium-based thin films of 14% oxygen vacancies with TiN top electrode under different frequency. FigS5 (c) shows the P-E hysteresis curves of the hafnium-based thin films of 14% oxygen vacancies with Pt top electrode under different voltage. FigS5 (d) shows the P-E hysteresis curves of the hafnium-based thin films of 14% oxygen vacancies with Pt top electrode under different frequency. FigS5 (e) shows the P-E hysteresis curves of the hafnium-based thin films of 14% oxygen vacancies with Au top electrode under different voltage.

S6 the retention characteristics test of hafnium-based thin films with 14% oxygen vacancies.

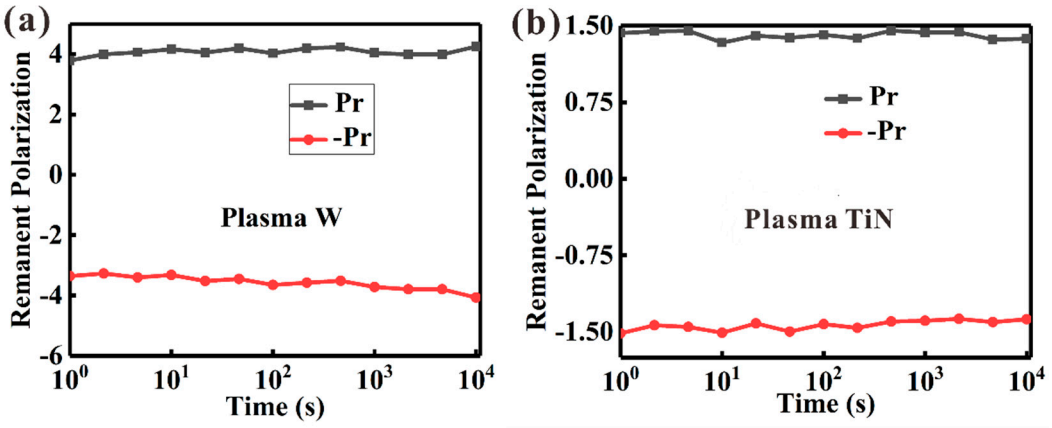


Figure S6. The retention time hold over 10^4 s for the ferroelectric devices with W top electrodes, as shown in Figure S6(a). Similarly, Figure S6(b) shows that the retention time is also over 10^4 s.