# Discrete Polarization Switching in Nanoscale BEOL FE-FETs

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**Introduction:** Ferroelectric $HfZrO_2$ (FE-HZO) has emerged as a strong candidate for non-volatile memory (NVM) [1]. Understanding FE domain structures and domain switching mechanisms in FE-HZO is crucial. In this abstract, we report discrete domain polarization switching in nanoscale back-end-of-the-line (BEOL) metal-oxide ferroelectric field-effect transistors (FE-FETs). Leveraging this unique device platform, we further study important anomalies in FE-HZO, including wake-up and fatigue, down to the single domain level.

**Experimental:** Two generations of FE-FETs with different device structures and metal-oxide channels were studied [Figs. 1(a) and (b)]. Details have been reported elsewhere [2,3]. Intrinsic dimensions of scaled devices approach FE-HZO domain size (~30-40 nm).

**Results and Discussion:** Fig. 1(c) shows the memory behavior of a representative ITO-channel device with a large memory window (MW) of 2.2 V @ 1 μA/μm. Pulsed-*I*-*V* measurements on a nanoscale $In_2O_3$-channel device using the scheme in Fig. 1(d) with a pulse width as narrow as 20 ns shows two and only two quantized current states [Figs. 1(f) and (g)], indicating a single domain under active switching [Fig. 1(e)]. Note that the device had been woken up by one cycle of DC $I_d$-$V_{gs}$, and a clear MW was observed (data not shown here). Wake-up (fatigue) is commonly seen in FE-HZO, in which remnant polarization increases (decreases) with voltage cycling in early (late) cycling stages. Our nanoscale single/few-domain devices provide us with a unique view on these processes. Experiments on an $In_2O_3$-channel FE-FET reveal discrete domain wake-up [Figs. 2(a)-(c)]. The device initially displayed three conductance levels, indicating two active FE domains. After several sweep cycles, two additional states with higher conductance emerged as two more domains woke up. Eventually, the switching behavior fully stabilized into a repeatable pattern. We also studied domain fatigue in ITO-channel devices. We carried out repeated double-direction DC $I_d$-$V_{gs}$ measurements. Fig. 2(d) shows the upward sweeps and the inset shows the extracted threshold voltage ($V_t$) for each upward sweep. Quantized negative $V_t$ shift was clearly observed as the device aged. We further carried out pulsed measurements on a similar nanoscale device. Again, discrete domain switching was observed. The incomplete “Erase” after complete “Program” indicates domain pinning of a few domains [Fig. 2(e)] underlying fatigue in this device structure.

**Conclusions:** We have demonstrated discrete domain switching in scaled BEOL oxide-channel FE-FETs. In this unique device platform, we have uncovered that FE domain depinning (pinning) leads to wake-up (fatigue) in HZO. These findings provide valuable insight into fundamental HZO switching behavior of relevance in future NVM applications.

**References**

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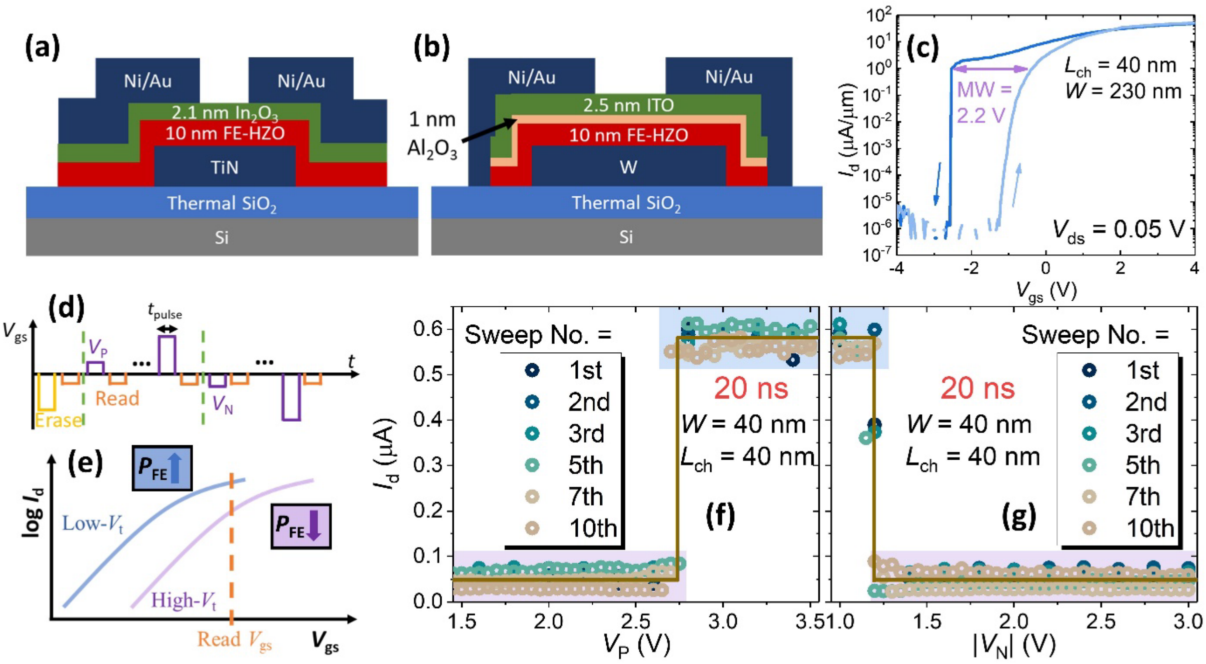


Fig. 1. Device structures and demonstration of single domain switching. (a),(b) $In_2O_3$- and ITO-channel BEOL metal-oxide FE-FETs. (c) Memory characteristics of ITO-channel device with a large memory window (MW) of 2.2 V. (d) Pulse scheme. (e) Schematic subthreshold behavior for a single-domain device. (f),(g) Drain current read at a constant $V_{gs}$ = -0.4 V from a nanoscale $In_2O_3$-channel device versus $V_P$ and $|V_N|$ pulses using the pulse sequence in (d). Single-domain switching is demonstrated.

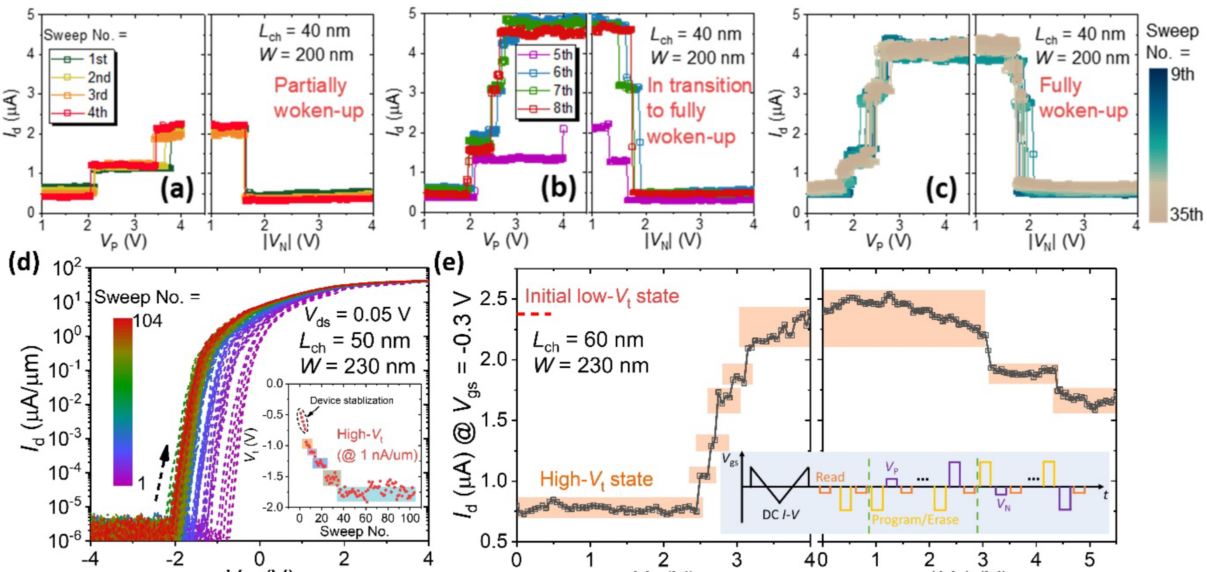


Fig. 2. Discrete-domain wake-up and fatigue. (a)-(c) Pulsed measurements on an $In_2O_3$-channel FE-FET using the scheme in Fig. 1(d) with a total of 35 repeated sweep cycles, showing discrete domain wake-up. (d) Evolution of DC $I_d$-$V_{gs}$ curves in the upward sweep as a function of sweep number for an ITO-channel device. Inset: Extracted $V_t$ (defined at 1 nA/μm) in the upward sweep as a function of sweep number, showing initial discrete $V_t$ negative shift and final $V_t$ saturation. (e) Evolution of $I_d$ @ $V_{gs}$ = -0.3 V vs. $V_P$ (left) and $|V_N|$ (right) in a FE-FET with $W_{ch}/L_{ch}$ = 230/60 nm using pulse scheme shown in the inset for device fatigue characterization. Discrete domain pinning is demonstrated.