Mechanisms of Reverse-DIBL and NDR Observed in Ferroelectric FETs

IIS, Univ. of Tokyo ○(D)Chengji Jin, Takuya Saraya, Toshiro Hiramoto, and Masaharu Kobayashi

E-mail: cjjin@nano.iis.u-tokyo.ac.jp

1. Introduction: Ferroelectric FET (FeFET) with steep subthreshold slope (SS) becomes one of the most promising transistor solutions for low-power computing [1]. Since the mechanism of steep SS is based on negative capacitance (NC) effect of ferroelectric (FE), it is also called NCFET. While NCFET is originally proposed by the quasi-static NC (QSNC) theory, recently, it is reported that steep SS can be explained by the transient NC (TNC) theory with dynamics of polarization reversal as well [2-4]. In this work, we show the previously reported reverse drain-induced barrier lowering (R-DIBL) and negative differential resistance (NDR) can be explained by the TNC theory. Their mechanisms are also discussed.

2. Simulation Methods: Transient characteristics (I_d-V_g and I_d-V_d) of FeFET are simulated considering 2-D electrostatics, drift-diffusion carrier transport mechanism, and dynamic Preisach model of FE self-consistently [5]. Both of FeFET and reference MOSFET are simulated (Fig. 1). The only difference between them is the additional FE layer in FeFET. Before transient I_d-V_g or I_d-V_d simulation, quasi-static (QS) sweep is used to initialize certain polarization states (FE history) and bias conditions (Fig. 2).

3. Result and Discussion: Fig. 3 plots simulated transient I_d-V_g. FeFET shows counter-clockwise hysteresis in I_d, and prominent sub-60 SS and R-DIBL in reverse sweep. Fig. 4 plots DIBL as a function of gate length (L_g). Negative DIBL due to TNC is observed for FeFET in reverse sweep. As L_g decreases, DIBL gradually increases due to short channel effect (SCE). Fig. 5 and Fig. 6 plot simulated transient I_d-V_d for FeFET with $\pm P_s$ (low/high V_{th}) initialization, respectively. NDR is observed only in forward sweep with $+P_s$ (low V_{th}) initialization, which is consistent with experimental results shown in Ref. [6]. Fig. 7 shows I_d-V_d in forward sweep at V_g=0.3 V for FeFET with different L_g. The reciprocal of differential resistances ($1/r_d=g_d=dI_d/dV_d$) are calculated and show L_g dependence. NDR gradually disappears as L_g decreases because of the dominant SCE. Fig. 8 summarizes the mechanisms of NDR and R-DIBL due to TNC and drain-to-gate coupling. TNC boosts decreasing of charge in the channel (Q_{ch}) near the drain as V_d increases, leading to NDR and R-DIBL.

4. Conclusion: Transient characteristics of FeFET are investigated by simulation with FE model without traversing the S-curve based on QSNC theory. The results show TNC theory can explain previously reported sub-60 SS, R-DIBL, and NDR in NCFET.

References

[1] S. Salahuddin and S. Datta, Nano Lett. 8(2) 405 (2008). [2] B. Obradovic, et al., VLSI Technol., 2018, p. 51–52. [3] C. Jin et al., JEDS, 7, p. 368-374 (2019). [4] C. Jin et al., in IEDM Tech. Dig., 2018, p. 723-726. [5] C. Jin et al., VLSI Technol., 2019, p. 220–221. [6] M. Jerry, et al., DRC, 2018, p. 1-2.

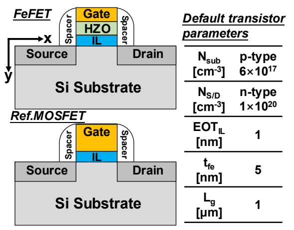

Fig. 1. Simulated device structures and default parameters. The only difference between FeFET and Ref. MOSFET is the additional FE layer.

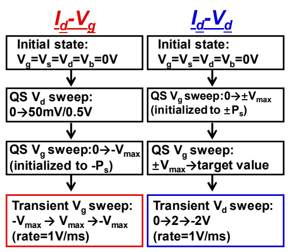

Fig. 2. FETs simulation flow. Before transient I_d-V_g and I_d-V_d simulation, QS sweep is used to initialize polarization states and certain bias conditions.

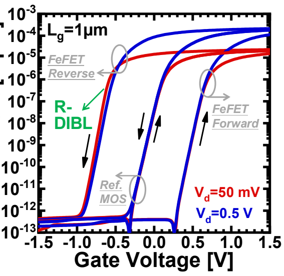

Fig. 3. Simulated transient I_d-V_g. Prominent sub-60 SS and R-DIBL are observed for FeFET in reverse sweep.

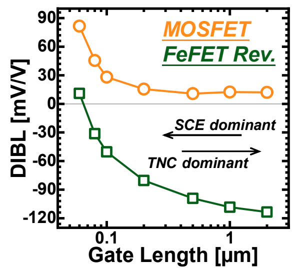

Fig. 4. Simulated DIBL as function of L_g. In short channel case, DIBL becomes positive even for FeFET because of the dominant SCE.

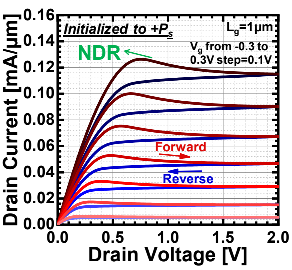

Fig. 5. Simulated transient I_d-V_d for FeFET with $+P_s$ (low V_{th}) initialization. NDR is observed only in forward V_d sweep.

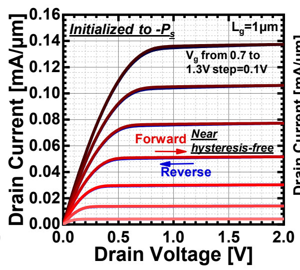

Fig. 6. Simulated transient I_d-V_d for FeFET with $-P_s$ (high V_{th}) initialization. No NDR is observed and hysteresis is negligible.

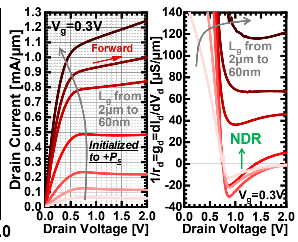

Fig. 7. Simulated transient I_d-V_d and the reciprocal of differential resistances ($1/r_d=g_d=dI_d/dV_d$) in forward sweep at V_g=0.3 V for FeFET with different L_g.

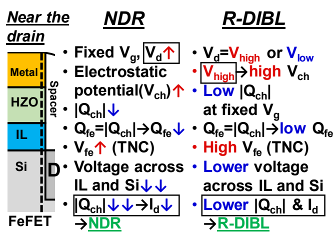

Fig. 8. Summary for the mechanisms of NDR and R-DIBL due to TNC and drain-to-gate coupling. TNC boosts the decreasing of charge in the channel (Q_{ch}) near the drain as V_d increases.