Statistical Analysis of Four Write Stability Metrics in Fully Depleted Silicon-on-Thin-BOX (SOTB) SRAM Cells at Low Supply Voltage Down to 0.4V

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[Introduction] Voltage scaling assumes significance for realizing low-power highly scaled devices, since energy has a square dependence on the supply voltage (V_{DD}). However, the variation induced by random dopant fluctuation (RDF), especially at low supply voltage, has a great impact on write stability of SRAM cells.[1] As a good candidate, fully depleted (FD) SOTB[2] SRAM cell proves itself operable at low V_{DD}.[3] In order to find the good candidate for characterizing write stability, in previous work[4], four write stability metrics (WSNM from butterfly curve, N-curve I_W, bit-line margin (BLM), and combined word-line margin (CWLM)) have been compared based on bulk SRAM cells at relatively high V_{DD}. Then, in this work[5], the four metrics at low V_{DD} down to 0.4 V based on SOTB SRAM cells are investigated.

[Method] SRAM DMA-TEG[6] with SOTB FETs was fabricated by the 65 nm technology. All measurement was performed based on 1k SOTB SRAM cells with substrate bias: V_{bsn} = -1 V, V_{bsp} = 1 V.

[Results] Fig. 1 shows cumulative plots for BLM, CWLM, WSNM and I_W at V_{DD} = 0.8 V, 0.6 V and 0.4 V. Both BLM and CWLM follow normal distribution not only at high V_{DD}, similar to the results of bulk SRAM cells[4], but also when V_{DD} is scaled down to 0.4 V. This proves both of them good candidates for write stability characterization. Conversely, I_W and WSNM show normality at high V_{DD} while deviate from normal distribution at low V_{DD}. Particularly, WSNM shows "two-mode" distribution, which has been discovered for the first time. Fig. 2 shows measured butterfly curves in "0" write operation at V_{DD} = 0.8 V, 0.6 V and 0.4 V. Clearly, the tails of bottom transfer curves appear at low V_{DD}. To clarify the two modes, two specific cells are also compared (Fig. 3). Different from cell-A (V_{thc}_TaR = 0.34 V, V_{thc}_TpR = 0.37 V), cell-B is a unbalanced cell (V_{thc}_TaR = 0.42 V, V_{thc}_TpR = 0.36 V). It is TaR in cell-B operating in near- or sub-V_{thc} region that pulls up VR's voltage to V_{DD}, resulting in the transition from mode-I to mode-II.

[Conclusion] BLM and CWLM always show good normality even at low V_{DD}.

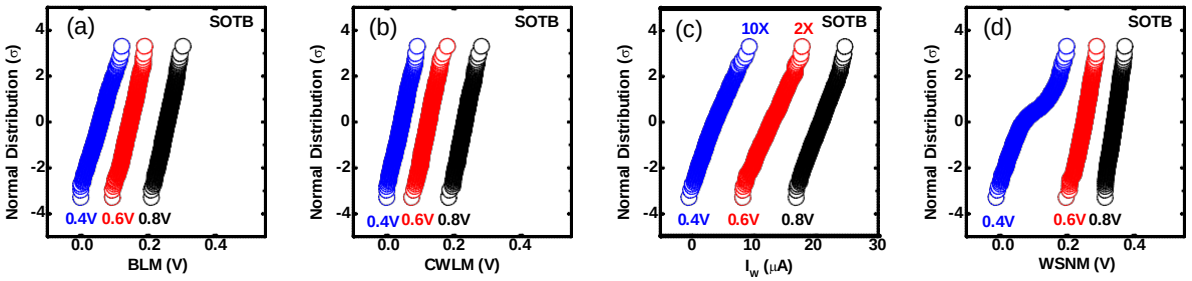

Fig. 1. Cumulative plots for (a) BLM, (b) CWLM, (c) I_W, and (d) WSNM at V_{DD} = 0.8 V, 0.6 V, 0.4V, respectively.

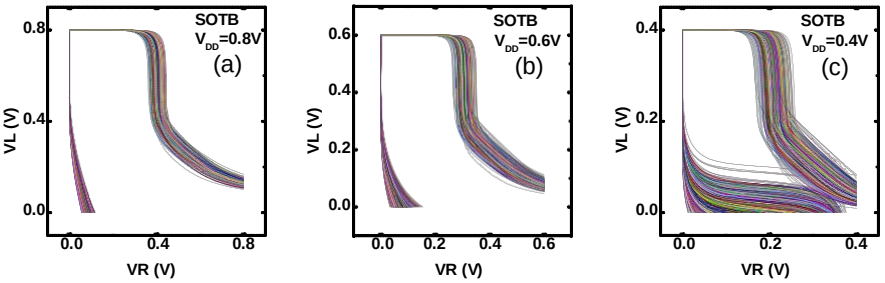

Fig. 2. Measured butterfly curves at (a) V_{DD} = 0.8 V, (b) V_{DD} = 0.6 V, and (c) V_{DD} = 0.4 V.

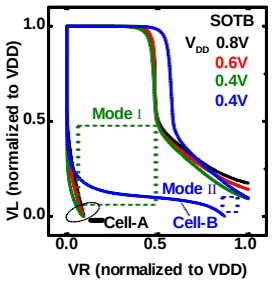

Fig. 3. Normalized butterfly curve of cell-A (balanced) at V_{DD}=0.8V (black), 0.6V (red), 0.4V (green), and cell-B (unbalanced) at V_{DD}=0.4V (blue).

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[References] [1] Z. Guo et al., VLSI, p. 42, 2008. [2] R. Tsuchiya et al., IEDM, p. 631, 2004. [3] Y. Yamamoto et al., VLSI, p. 212, 2013. [4] H. Qiu et al., SSDM, p. 848, 2014. [5] H. Qiu et al., ICSICT, 2014. [6] T. Hiramoto et al., IEEE TED, p. 2249, 2011.