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 (VDD). However, the variation induced by random dopant fluctuation (RDF), especially at low supply voltage, has a great impact on write stability of SRAM cells. As a good candidate, fully depleted (FD) SOTB[2] SRAM cell proves itself operable at low VDD.[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 IW, bit-line margin (BLM), and combined word-line margin (CWLM)) have been compared based on bulk SRAM cells at relatively high VDD. Then, in this work[5], the four metrics at low VDD 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: Vbsn = -1 V, Vbsp = 1 V.

[Results] Fig. 1 shows cumulative plots for BLM, CWLM, WSNM and IW at VDD = 0.8 V, 0.6 V and 0.4 V. Both BLM and CWLM follow normal distribution not only at high VDD, similar to the results of bulk SRAM cells[4], but also when VDD is scaled down to 0.4 V. This proves both of them good candidates for write stability characterization. Conversely, IW and WSNM show normality at high VDD while deviate from normal distribution at low VDD. 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 VDD = 0.8 V, 0.6 V and 0.4 V. Clearly, the tails of bottom transfer curves appear at low VDD. To clarify the two modes, two specific cells are also compared (Fig. 3). Different from cell-A (Vthc_TaR = 0.34 V, Vthc_TpR = 0.37 V), cell-B is a unbalanced cell (Vthc_TaR = 0.42 V, Vthc_TpR = 0.36 V). It is TaR in cell-B operating in near-or-sub-Vthc region that pulls up VR’s voltage to VDD, resulting in the transition from mode-I to mode-II.

[Conclusion] BLM and CWLM always show good normality even at low VDD.

Fig. 1. Cumulative plots for (a) BLM, (b) CWLM, (c) IW, and (d) WSNM at VDD = 0.8 V, 0.6 V, 0.4 V, respectively.

Fig. 2. Measured butterfly curves at (a) VDD = 0.8 V, (b) VDD = 0.6 V, and (c) VDD = 0.4 V.

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

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