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Comparison and Statistical Analysis of Four Write Stability Metrics in Bulk CMOS SRAM Cells

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Abstract

The commonly used four metrics for write stability are measured and compared based on the same set of 2k 6T-SRAM cells by the 65nm bulk technology. Four metrics show themselves effective in evaluation of worst cell. Bit-line and word-line margins have good normality as well as almost perfect correlation, which proves both of them preferred write stability metrics than butterfly curve and N-curve.

Introduction

Continued increase in variability is perceived to be a major challenge to future technology scaling, which is especially pronounced in large memory arrays due to utilization of minimum sized transistors.[1] The variation has a great impact on both read and write stability of SRAM cells.[2,3] Though a long-term emphasis has been focused on read stability generally, we have also to consider write stability for SRAM cells' whole stability since both stabilizing conditions always work in opposition.[4] In order to evaluate the write stability in the worst cell and estimate the yield, a good metric characterizing write stability is critically important.

Besides (i) write static noise margin (WSNM) from traditional butterfly curve[5], (ii) N-curve I_W[6], (iii) bit-line margin (BLM)[7] and (iv) combined word-line margin (CWLM)[8] have also been proposed for the write stability characterization. Both simulations[9,10] and experiments[1] have given some basic conclusions for preference of the write metric. However, no experimental work has given a thorough comparison among these four metrics based on the same set of SRAM cells.

In this work, 2k bulk SRAM cells are intensively measured using DMA-TEG[11,12]. Four write stability metrics are compared and correlated. It is found that BLM and CWLM show good normality and perfectly correlate with each other. On the other hand, the demerits of WSNM and I_W as write stability metrics are discussed.

Measurement Strategy

SRAM DMA TEG[11,12] with bulk FETs was fabricated by the 65nm technology. Terminals for V_{DD}, V_{WL}, V_{BLL}, V_{BLR}, and two storage nodes (VL and VR) can be accessed (Fig. 1). During a write operation ("0" write as an example), voltages (V_{DD}, 0) are applied to (V_{BLL}, V_{BLR}) with access transistors (TaL, TaR) turned on to flip the SRAM cell from "1" state to "0" state – (VL, VR) from (0, V_{DD}) to (V_{DD}, 0). Fig. 2 shows measured waveforms for the four metrics for "0" write at V_{DD}=0.9V for 2k SRAM cells. Testing parameters are shown in insets and (i) "0" WSNM, (ii) "0" I_W, (iii) "0" BLM, and (iv) "0" CWLM are defined as red double headed arrows.

Results

Fig. 3 shows cumulative plots for four write metrics at V_{DD}=0.9V for 2k SRAM cells. WSNM, I_W, BLM, CWLM are defined as the minimum of "0" and "1" write. I_W, BLM, and CWLM show good normality up to approximately ±3σ. On the other hand, WSNM shows large deviation from normal distribution, which should arrive at misleading estimation of yield.

To investigate the correlations among these four metrics, scatter plots are generated among the four metrics measured for the same set of SRAM cells at V_{DD}=0.9V as shown in Fig. 4. All values have been normalized to σ. Relatively poor correlations are found between WSNM and other three metrics (Fig. 4a-c). On the other hand, I_W shows better correlations with BLM and CWLM (Fig. 4d-e), and the best correlation is found between BLM and CWLM (Fig. 4f). Moreover, all four metrics predict the same worst stable cell (indicated by red circle).

Fig. 5 shows both butterfly curve and write N-curve in "0" write case for the same SRAM cell at 0.9V (stable) and 0.6V (fail). Interestingly, VR values for three intersection points (indicated by blue circle) in butterfly curve and N-curve at 0.6V are exactly the same. This is because the intersection points in butterfly curve correspond to stable or meta-stable points where current flow through nodes is just zero. But the correlation between WSNM and I_W (Fig. 4a) is not as good as expected.

With a good normality as well as being the simplest metric which requires only I-V curve test, I_W shows itself a good metric. However, in both cases of WSNM and I_W, the nodes' voltage is forcefully changed, which cannot reflect actual write process. On the contrary, during sweeping bit-line or word-line in BLM and CWLM measurements, the nodes' voltage actually flips at some critical point. Additionally, BLM and CWLM show good normal distribution and are almost perfectly correlated, indicating that BLM and CWLM are preferred write stability metrics.

Conclusion

Systematic measurements of 2k SRAM cells are performed for a comprehensive comparison among four commonly used write stability metrics. With a large deviation from normal distribution, WSNM from butterfly curve is not a good candidate for yield estimation. I_W from N-curve is also excluded since it does not reflect actual write process. On the contrary, with a good normal distribution as well as perfectly correlated, both BLM and CWLM prove to be better write stability metrics. Future work could be focused on distribution analysis extended to 6σ variation.

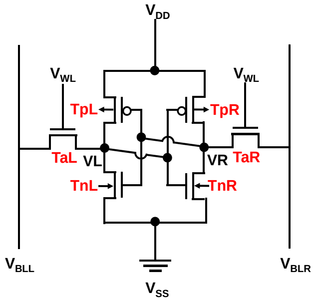


Fig. 1. Schematic of 6T SRAM.

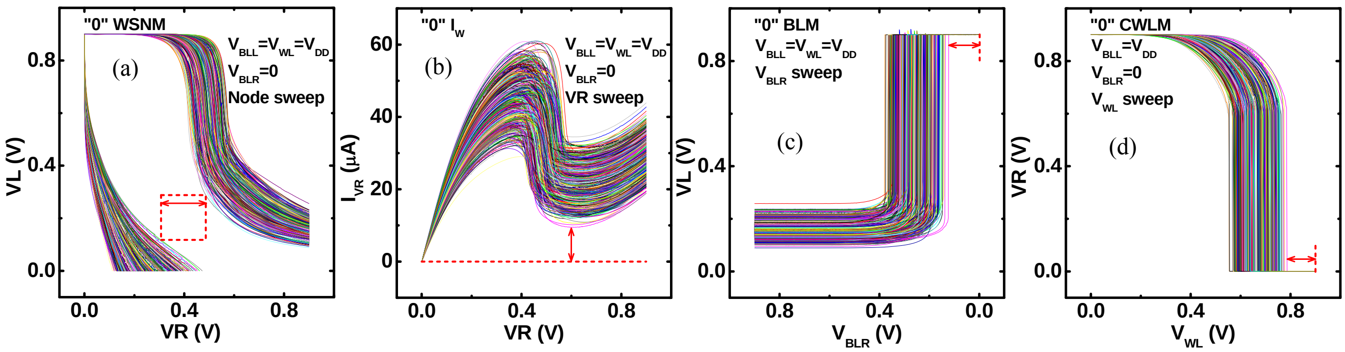


Fig.2. Measured waveforms for "0" write at V_{DD}=0.9V for 2k SRAM cells. Definitions of (a) "0" WSNM from butterfly curves, (b) "0" I_W from write N-Curve, (c) "0" BLM from using BLR sweep, and (d) "0" CWLM from using WL sweep are shown by red arrows.

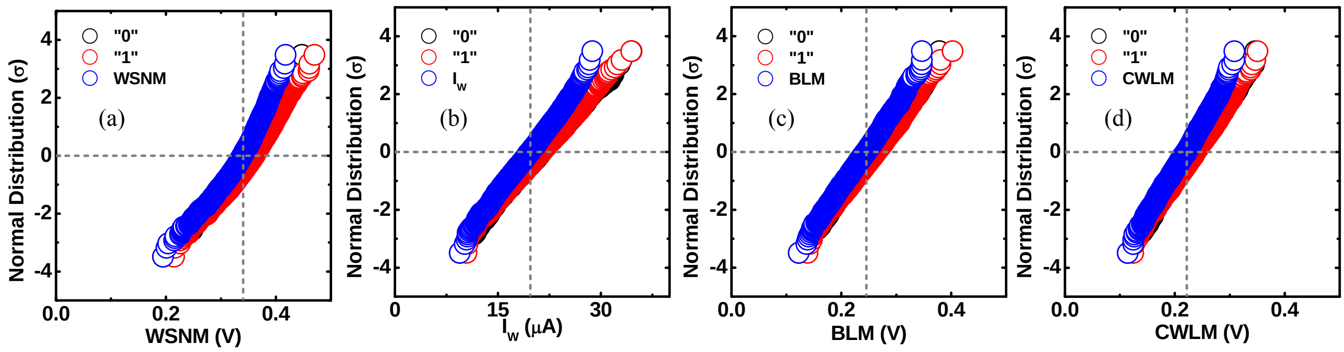
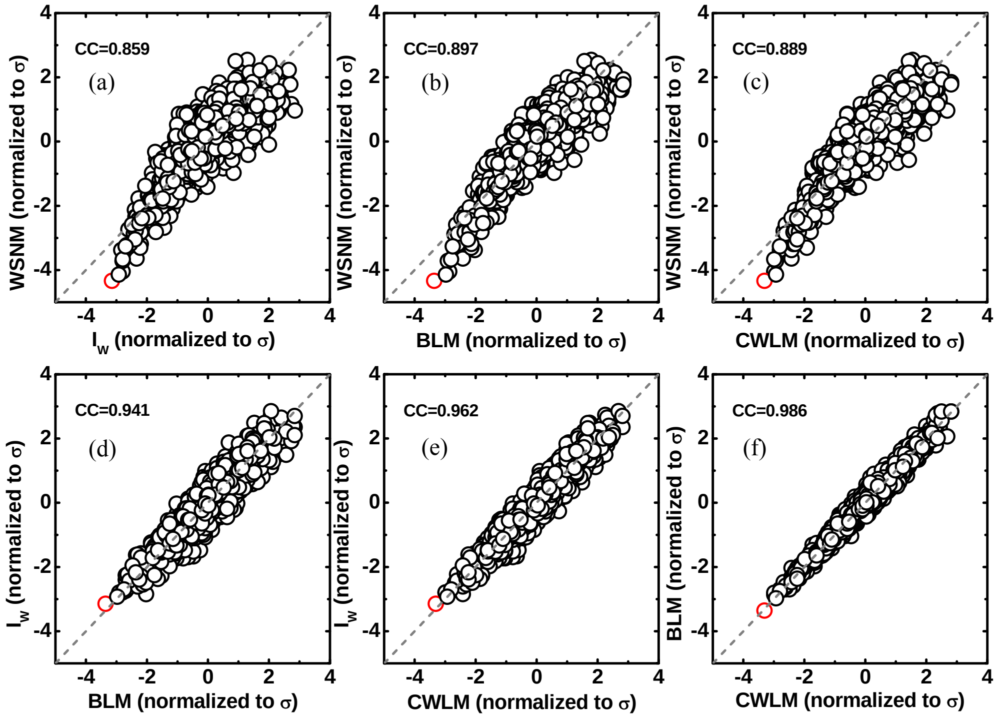


Fig.3. Cumulative plot for (a) WSNM, (b) I_W, (c) BLM, and (d) CWLM at V_{DD}=0.9V for 2k SRAM cells. WSNM, I_W, BLM, CWLM are defined as the minimum of "0" and "1" write. The intersection point of both grey dashed lines indicates average value μ.



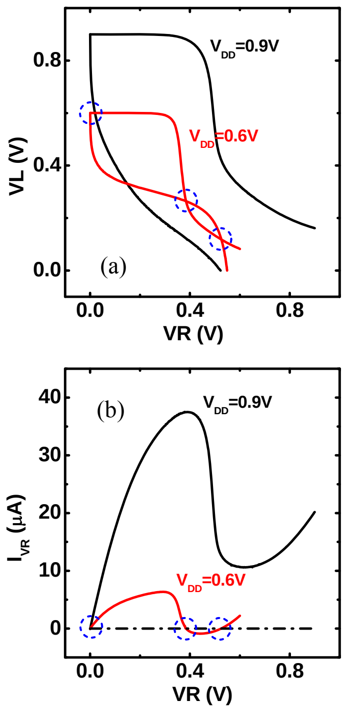


Fig.4. Scatter plots of (a) WSNM vs. I_W, (b) WSNM vs. BLM, (c) WSNM vs. CWLM, (d) I_W vs. BLM, (e) I_W vs. CWLM, and (f) BLM vs. CWLM for 2k SRAM cells at V_{DD}=0.9V.

Fig.5. (a) Butterfly curve and (b) N-curve of one specific SRAM cell at V_{DD}=0.9V and 0.6V.

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