Sensitivity Analysis of Static Noise Margin in SRAM Cells with 65 nm CMOS devices

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***Abstract*—In this paper, a systematical method for sensitivity analysis of 6T SRAM cells with 65 nm planar CMOS devices is developed. Based on a design of experiment (DOE), a mixed-mode (i.e., coupled device and circuit) simulation, and a response surface model (RSM), performances of 6T SRAM cells are explored with respect to static noise margin (SNM). Taking device channel doping level, channel length, source/drain doping level, and thickness of gate oxide as significant variables, a SNM response surface model is constructed. With the developed SNM, the impact of channel length variation on SNM is evaluated. It is found that the variance of SNM is strongly affected by the critical dimension of the gate length. Besides exploring the SNM, this statistical technique can also be applied to study other electrical characteristics with respect to different device parameters.**

Keywords—6T SRAM, computational statistics, mixed-mode simulation, coupled simulation of device and circuit, static noise margin, sensitivity.

I. Introduction

Silicon-based CMOS devices have been a fundamental building block for SRAM cells. For SRAM cell design, the cell area and the stability of the cell are the most important factors [1]. The cell area determines about two-third of the total chip area. The cell stability determines the soft-error rate and the sensitivity of the memory to process tolerance and operating conditions. These two aspects are interdependent since designing a cell for improved stability invariably requires a larger cell area. With the scaling of conventional CMOS devices to sub-100 nm and beyond, the variations of the transistor characteristics due to local and nonlocal effects, such as the random dopants, the critical dimension of channel length, the interface roughness, and line edge roughness (LER) [2], [3] start to adversely affect the yield and functionality of the corresponding integrated circuits (ICs) [4]. The cell stability of a 6T SRAM using conventional nanoscale planar MOSFETs during read mode is explored [5].

In this paper, sensitivity of the static noise margin (SNM) for a 6T SRAM cell with 65 nm CMOS devices, shown in Fig. 1, is computationally explored with a mixed-mode (i.e., device-circuit) coupled simulation. To explore the sensitivity of SNM for the 65 nm SRAM, a computational statistics methodology is developed which consists of the design of experiment (DOE) and the second order response surface model (RSM). By considering the device doping level, channel length, gate oxide thickness, and the source/drain dopant as changing factors, according to the DOE, we construct a RSM for SNM of SRAM. The RSM highly explains the behavior of SNM for the investigated 65 nm SRAM cell. With a proper distribution, the model allows us to perform the sensitivity analysis of 65 nm SRAM with respect to aforementioned factors efficiently. Without loss of generality, we preliminarily focus on the impact of channel length variations on the 6T SRAM cells. It is found that the SNM increases when all channel lengths decrease simultaneously. Under a Gaussian distribution for the variation of the device length, there is a 2.75 mV increase of the standard deviation of SNM when the device channel length is at 61 nm. The increase of the standard deviation of SNM is mainly due to relatively large variation of driving current when the device channel lengths are simultaneously reduced. Compared with the results of a Gaussian distribution, the predicted variation significantly increases (about 2 times) when a uniform distribution is adopted. In Sec. II, we introduce the computational methodology. In Sec. III, simulation results are discussed. Finally, we draw conclusions.

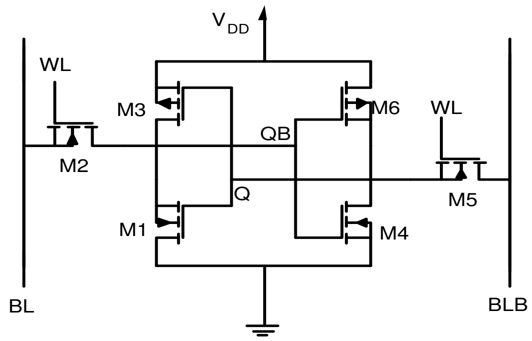

Fig. 1. A 6T SRAM cell with 65 nm planar CMOS devices in our mixed-mode simulation.

II. The Computational Methodology

A computational statistics methodology that accounts for the characteristic sensitivity is depicted in Fig. 2. Our simulation technique is mainly based on a mixed-mode simulation (i.e., the coupled simulation of device and circuit) for SRAM cells. It integrates DOE using the orthogonal matrix, running the experiment, extraction of SNM [6], and fitting the RSM for analyzing effects of aforementioned parameters' variation. The calculation of SNM is by computed the largest diagonal value shown in the inset of Fig. 2. Among many physical and process parameters, variable screening resulting four important factors, the channel length, the gate oxide thickness, the soure/drain doping concentration, and the channel doping concentration. They are systematically considered and modelled in this work. With a face centered cube DOE technique [7], the mixed-mode simulation is performed by solving a set of two-dimensional density-gradient-based drift-diffusion equations, which is simultaneously coupled with circuit nodal equations. Thus, all device and circuit characteristics are obtained without any devices' equivalent circuit models. The sensitivity of SNM then can be explored in

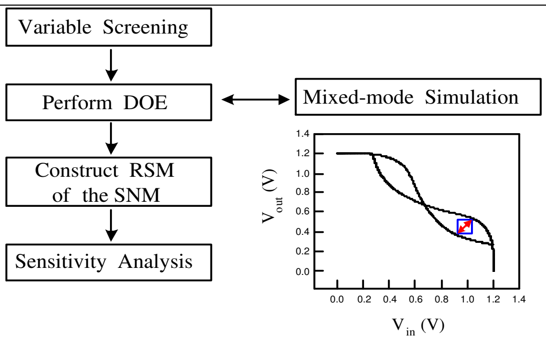

Fig. 2. A computational procedure for the method.

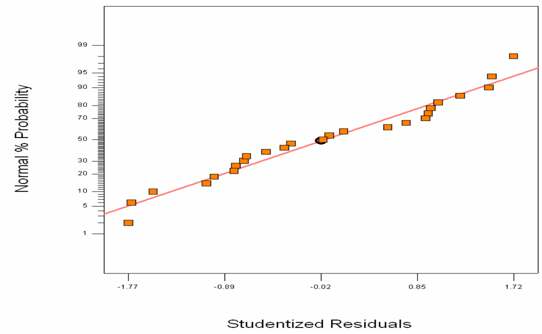

Fig. 3. Residuals and residual normal plot of SNM.

TABLE I

The upper and lower limits of the parameters, and the nominal recipes.

Parameters	Range	Nominal values
Gate oxide thickness (nm)	$[1.3, 1.7]$	1.5
Channel length (nm)	$[60, 70]$	65
Source/drain dose (cm^{-3})	$[8e+19, 1.2e+20]$	1e+20
Channel dose (cm^{-3})	$[7e+18, 1.2e+18]$	1e+18

a computationally cost-effective way. We note that this analysis technique not only can be used together with device and circuit simulation programs for theoretical prediction but also can analyze experimental measurement for realistic SRAM data. The input part of DOE, shown in Fig. 2, can be replaced with experimental measurement for a realistic diagnosis of process variation effects.

III. Results and Discussion

We model a second order RSM of the SNM for the 6T SRAM cells with 65 nm CMOS devices during the read mode. Operation bias is fixed at 1.2 V under room temperature. The model is in terms of the device channel length, the gate oxide thickness, the channel dopant, and the source/drain doping level

$$\begin{aligned} SNM &= 218.39 - 6.46x_1 - 19.64x_2 - 6.38x_3 \\ &+2.43x_4 - 1.00x_1^2 + 15.55x_2^2 + 0.73x_3^2 \\ &-1.00x_4^2 + 1.87x_1x_2 + 0.19x_1x_3 \\ &-0.28x_1x_4 - 0.32x_2x_3 - 1.66x_2x_4 + 1.66x_3x_4, \end{aligned} \tag{1}$$

where x_1 is the gate oxide thickness, x_2 is the channel length, x_3 is the source/drain dose, and x_4 is the channel dose. The coefficients are determined by the data obtained from the experiment. The upper and lower bounds of the process parameters are summarized in Table I. Residual normal plots are performed to verify the accuracy of the constructed model, shown in Fig. 3. This examination highly reflects the modelling functionality for the RSM of SNM. Table I summarizes the used factors for the studied 6T SRAM cell. The four factor levels are considered with respect to each parameter. The nominal (mean) values are also given in Table I. For each channel length being studied, Fig. 4 is the standard deviation (σ_{SNM}) of the SNM due to channel length variations of the 65 nm planar MOSFETs, where the cell ratio is set to be 1. It is found that the SNM increases when all channel lengths decrease simultaneously. Under a Gaussian distribution (with more than 1000 trails), there is a 2.75 mV increase of σ_{SNM} when the device channel length varies from 69 nm to 61 nm. The increase of σ_{SNM} is mainly due to relatively large variation of the driving current when

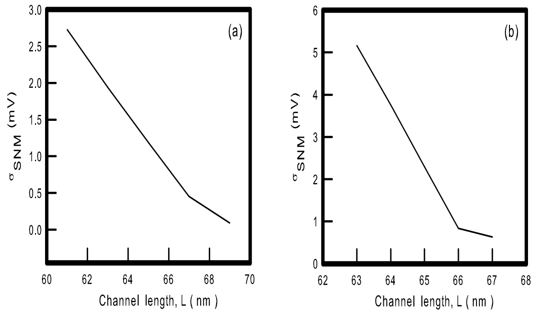

Fig. 4. Standard deviation of SNM versus channel length.

the device channel lengths are simultaneously reduced. As shown in Fig. 4b, the predicted variation significantly increases when a uniform distribution is adopted. We note that this estimation should be subject to further investigation by individually constructing RSM with respect to each transistor. Therefore, the individual behavior can be examined for the 65 nm SRAM cell.

IV. Conclusions

Based on the face centered cube DOE, RSM, and mixed-mode simulation, a method for SNM sensitivity analysis of 6T SRAM cells with respect to the device channel length has been presented. Preliminary results have shown the validity of method. This approach can be used to analyze other variation effects. We are currently performing the analysis and compare with measured data.

Acknowledgements

This work was supported in part by Taiwan National Science Council (NSC) under Contract NSC-94-2215-E-009-084 and Contract NSC-95-2752-E-009-003-PAE, by the MoE ATU Program under a 2006 grant, and by the Taiwan semiconductor manufacturing company under a 2004-2006 grant.

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