11th International Workshop on Computational Electronics
TU Wien, 25-27 May 2006

Random Dopant Fluctuation Analysis for Scaling Multi-Gate Device Structures

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INTRODUCTION

Multi-gate devices are extensively examined and expected to be one of the promising device structures beyond bulk MOSFETs. We have investigated basic characteristics of random dopant fluctuation for novel device structures, such as SG (Single Gate) SOI, DG (Double Gate) and tri-gate, by giving discrete dopant distribution[1] to the substrate. Moreover, we have calculated SNM (Static Noise Margin) for 6T-SRAM cell from hp45 to hp22 by a device simulator directly.

BASIC CHARACTERISTICS

Fig. 1 shows device parameters to see basic characteristics for hp45 SG, DG and tri-gate devices. Discrete dopant is distributed only in the substrate by an atomistic process simulator while SD regions are assumed to be uniform box profiles analytically. As for DG structures, thinner DG (A) devices fluctuate less than thicker DG (C). However, DG (A) devices are almost a half of SG at the same body thickness, Tsi, because of symmetrical layout of gates. Tri-gate devices with lower aspect ratios fluctuate much more than DG or tri-gate with higher aspect ratios. Table 1 shows device parameters to compare DG with bulk structures. Fig. 2 summarizes device characteristics fluctuation by σVth and sub-threshold factors. As for both DG and bulk structures, σVth will decrease with narrowing Tsi or junction depth Xj for bulk structures. However, DG structures reduce σVth remarkably with narrowing Tsi. As for sub-threshold factors, this is the same trend as σVth. This difference comes from floating body effect for DG or SG SOI.

SENSITIVITY TO PROCESS VARIATIONS

Assuming uniform dopant profiles, we have studied sensitivity to process variations. Fig. 3 shows device parameters to scale hp45 and hp22 technologies. Vth is calculated for these structures with process parameters ranging from –20 % to +20 %. However, continuous variation for Tsi is not acceptable because it varies by lattice constant, 0.54 nm, for Si.

Now Vth shift is calculated at the process variation by lattice constant for Lg, Tsi and Tfin (Fig.4). It is becoming very important to control Tsi for DG structures as well as Lg for future scaling. It is found that thinner Tsi and uniform thickness are key factors as well as Lg to control characteristics fluctuation.

6T SRAM WITH RANDOM DOPANT FLUCTUATION

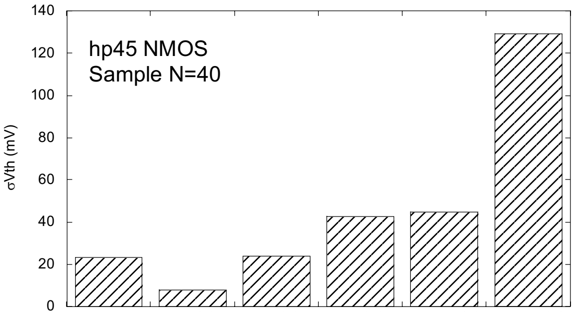
We have modeled SRAM with 6 DG transistors and calculated SNM from hp45 to hp22. Fig. 5 shows bird’s-eye view and boron concentration for this SRAM. In this calculation, discrete dopant distribution is applied to channel regions only. SNM distribution width is getting narrower with scaling because body thickness becomes thinner. However, SNM is observed to shift lower value. To keep SNM high, optimizations of device structure and cell layout should be done in the future devices.

CONCLUSION

We have investigated basic device characteristics fluctuation for novel device structures. DG structures are more sensitive to Tsi thickness than Xj for bulk structures and multi-gate devices with thinner Tsi and higher aspect ratios show less characteristics fluctuation. This finding suggests that multi-gate devices with thinner Tsi should be one of the preferable candidates in the view of characteristics fluctuation.

REFERENCES

[1] N. Sano, K. Matsuzawa, M. Mukai, and N. Nakayama, *Role of Long-Range and Short-Range Coulomb Potentials in Threshold Characteristics under Discrete Dopants in Sub-0.1μm Si-MOSFETs,* IEDM Tech. Dig., pp.275-278, 2000.



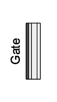
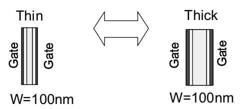
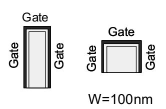
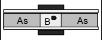
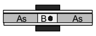
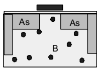
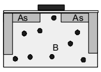
Lg (nm)	25	25	25	25	25	25
Tsi (nm)	5	5	10	15	15	30
Tfin (nm)	50	50	50	50	50	35
Tox (nm)	1.0	1.0	1.0	1.0	1.0	1.0
Na (cm^{-3})	5 × 10^{18}	5 × 10^{18}	5 × 10^{18}	5 × 10^{18}	5 × 10^{18}	5 × 10^{18}
Vdd (V)	1.0	1.0	1.0	1.0	1.0	1.0
Tfin/Tsi( )	10	10	5	3.33	3.33	1.16
Geometry						

Fig. 1. Device parameters and σVth with random dopant fluctuation in the Si body.

Table 1. Device parameters to compare DG, SG and bulk structures.

hp45	DG (C)	DG (D)	SG (D)	Bulk (A)	Bulk (B)
Lg (nm)	25	25	25	25	25
Tox (nm)	1.0	1.0	1.0	1.0	1.0
H (nm)				60	60
Tsi/Xj (nm)	15	8	8	15	8
W (nm)	100	100	50	50	50
N_{Xj} (cm^{-3})	10^{20}	10^{20}	10^{20}	5x10^{19}	5x10^{19}
N_{SD} (cm^{-3})	10^{20}	10^{20}	10^{20}	10^{20}	10^{20}
N_a (cm^{-3})	5x10^{18}	5x10^{18}	5x10^{18}	5x10^{18}	5x10^{18}
Vdd (V)	1.0	1.0	1.0	1.0	1.0
Geometry					

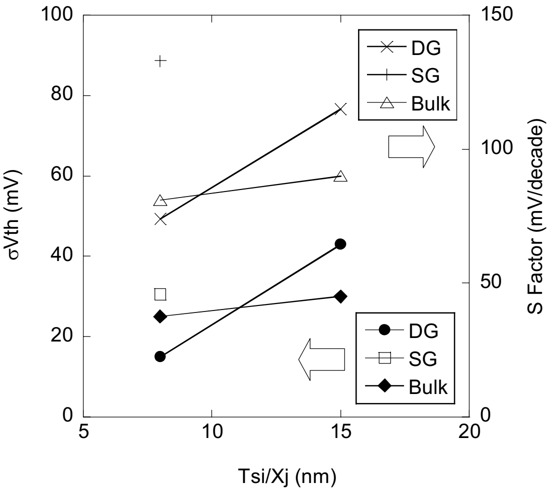


Fig. 2. σVth and S factors for various device structures.

		Lg (nm)	Tsi (nm)	Tox (nm)	Tfin (nm)	Na (cm^{-3})	Vdd (V)
hp22	DG (A)	13	8	0.7	26	1x10^{18}	0.8
	DG (B)	13	8	0.7	26	5x10^{18}	0.8
hp45	DG (C)	25	15	1.0	50	5x10^{18}	1.0

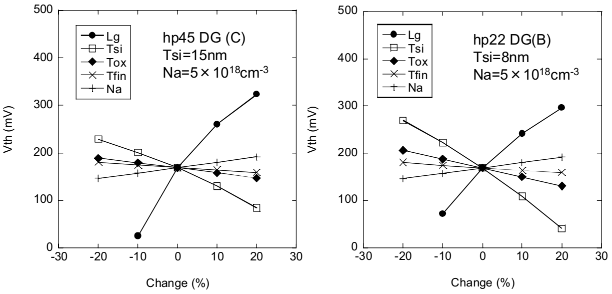


Fig. 3. Sensitivity analysis by giving process variations and channel dopant concentration for hp45 and hp22 technologies.

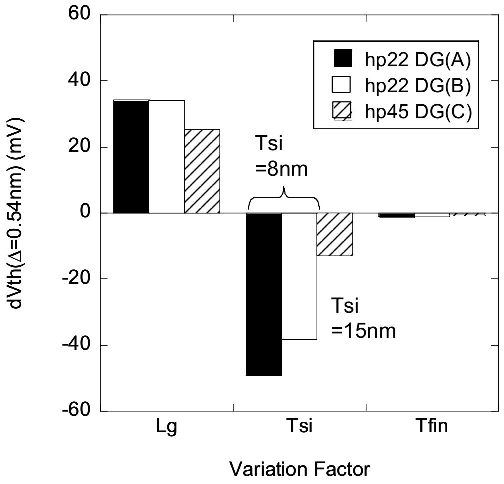


Fig. 4. Vth shift with process variations by lattice constant.

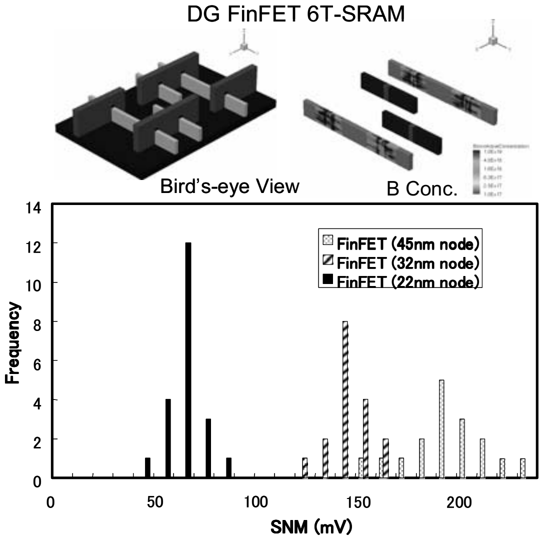


Fig. 5. SNM frequency distribution for DG 6T-SRAM with scaling.