Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp263-264

P-3-4

Source/Drain Doping Induced V_{th} Variation in Nano-scale UTB SOI MOSFET

Linfeng Du[1] and Shengdong Zhang[1,2]

[1] Institute of Microelectronics, Peking University, Beijing 100871, PRC
[2] Shenzhen Graduate School, Peking University, Shenzhen 518055, PRC
Phone: +86755-2603-5356 E-mail: zhangsd@szpku.edu.cn

1. Introduction

Random dopant fluctuation (RDF) effect in small-size bulk MOSFETs has been extensively investigated via 2D/3D simulations [1]–[4]. It has been shown that the RDF effect is one of the major challenges to extremely scaling MOSFETs [5, 6]. On the other hand, ultra thin body (UTB) SOI devices even with un-doped body can exhibit strong short channel effect (SCE) immunity, good electrostatic integrity and high electrical performance [7]. Theoretically, using an un-doped or very lightly-doped body as device channel in the UTB device is an effective solution to suppressing the RDF effect. Therefore, the UTB SOI device with un-doped or lightly-doped body seems to be a promising candidate for sustaining the devices scaling in nano-scale regions [8]. However, the lateral dopant penetration caused by source/drain (S/D) doping will very likely make the "nominally" un-doped body significantly doped when the gate length is short enough. Therefore, the RDF effect in ultra-small UTB devices even with un-doped body is still a concern and needs to be addressed.

2. Simulation approach

Fig. 1 shows the device structure used in our simulation. L_g, t_{OX}, t_{si}, t_{BOX} and t_{SUB} are the channel length, the gate oxide thickness, the channel body thickness, the buried oxide thickness and the substrate thickness, respectively. The channel is "nominally" un-doped. The S/D doping induced dopant distribution in the channel is assumed to be continuous and follow Gaussian function. The dopant concentration *C(X)* in the channel is defined as,

$$C(x) = C_p \exp[-\frac{1}{2}\frac{(\frac{L_g}{2}-|x|)^2}{\delta^2}] \qquad (1)$$

where C_p and δ are the peak concentration and the S/D doping abruptness, respectively. Fig. 2 shows *C(X)* in the device with L_g = 22 nm. The average dopant number in half of the channel is computed by the equation below,

$$n = 10^{-12}\int_{-Lg/2}^{0}[C(x)\cdot W\cdot t_{si}]dx \qquad (2)$$

From Eq. (1) and Eq. (2), we have

$$n = 5\times10^{7}\sqrt{\frac{\pi}{\ln 10}}\cdot(W\cdot t_{si}\cdot\delta) \qquad (3)$$

In order to investigate RDF effect, it is necessary to quantify not only the average dopant number, but also its variation. The variation of dopant number, $\sigma(n)$, is given by,

$$\sigma(n) = \sqrt{n} \qquad (4)$$

It is assumed that the statistical dopant number follows the normal distribution [9]. Therefore, a set of statistical dopant numbers can be derived by only using the average dopant number (n). It is also assumed that the S/D doping induced dopant profile in the channel, even considering RDF effect, always follow Gaussian function and the RDF directly results in the fluctuation of S/D doping abruptness. From Eq.(3), we know that there exists a one-one correspondence between n and δ with MOSFETs of definite dimension (W, t_{si}). Therefore a set of statistical dopant number can be transformed to a set of different doping abruptness, thus obtaining microscopically different MOSFETs which are samples for investigating RDF effect. Fig.3 shows the process for obtaining the statistical samples. The device simulation is implemented with the simulator DESSIS [10].

3. Results and Discussion

According to ITRS [11], the total allowable threshold voltage variation (ATVV, $3\sigma V_{th}$) is 3% of the power supply voltage (V_{dd}). V_{dd} = 1 V is assumed, so the allowed standard deviation of V_{th} (σV_{th}) is 10 mV. The threshold voltage (V_{th}) variation is assumed to be completely induced by statistical dopant number fluctuation. Fig. 4 shows the histogram of V_{th} distribution of devices with L_g = 16, 22 nm, t_{si} = 8 nm, W = 50 nm, and δ = 1.07 nm/dec. The V_{th} approximately follows the Gaussian distribution. The σV_{th} is 12.3 mV for L_g = 16 nm and 3.9 mV for L_g = 22 nm. It can be seen that the V_{th} variation could become unacceptable for the device with L_g = 16 nm, t_{si} = 8 nm, W = 50 nm, and δ = 1.07 nm/dec. Fig. 5 shows σV_{th} versus L_g. It can be seen that, for the device with δ = 1.23 nm/dec, the σV_{th} increases from 5.78 mV to 36.5 mV when L_g reduces from 24 nm to 16 nm, whereas for the device with δ = 0.548 nm/dec, the σV_{th} increases from 0.39 mV to 5.47 mV. Fig. 6 shows σV_{th} versus W. For the device with L_g = 16 nm and W = 50 nm, an abruptness of 0.85 nm/dec will results an unacceptable σV_{th} of 10.77 mV. Fig. 7 shows σV_{th} versus the impurity number (n). For the L_g = 22 nm device, the allowable impurity numbers in channel are 18 if W = 30 nm, and 28 if W = 50 nm. Fig. 8 shows V_{th} versus δ. The V_{th} for device with L_g = 16 nm substantially reduces when the abruptness value increases over 0.8 nm/dec. Fig. 9 shows the allowed abruptness versus channel width for devices at 20 nm. The ranges of the allowed abruptness values are less than 0.48, 0.49 and 0.73 nm/dec for W = 30, 40, and 50 nm, respectively. A 0.73 nm/dec abruptness is needed to suppress RDF for the device with L_g = 16 nm, W = 30 nm, t_{si} = 10 nm, and a 1.55 nm/dec abruptness for the device with L_g = 22 nm, W = 50 nm, t_{si} = 8 nm. For these devices, it is shown that the δ value is required to be around 1 nm/dec, which seems too difficult to obtain in the present or near future technologies.

4. Conclusion

We have investigated the source/drain induced V_{th} variations in UTB SOI devices. A simulation method for quantifying the RDF effect is described. It is shown that devices, even with "nominally" un-doped body, also suffer from RDF. The maximum allowed values of abruptness is given. It is concluded that it is fairly difficult to get rid of the RDF effect in the present or near future technologies.

Acknowledgements

This work is supported by NSFC of China under Project 60676023 and 60736030.

References

[1] Yuri Yasuda, et al., TED, **47** (2000) 1838–1842
[2] Yiming Li, et al., TED, **55** (2008) 1449-1455
[3] Asen Asenov, et al., TED, **48** (2001) 722–729
[4] Yiming Li, et al., phys. Stat. sol. (a) **205** (2008) 1505–1510.
[5] G. Roy, et al., TED, **53** (2006) 3063–3070.
[6] Tanaka T, et al., IEDM, (2000) 271-274.
[7] K. Samsudin, et al., Solid-State Electronics, **51**(2007) 611.
[8] B. Cheng, et al., Solid-State Electronics, **53** (2009) 767.
[9] T. Mizuno, et al., TED, **41** (1994) 2216-2221.
[10] DESSIS Technical Manual for ISE TCAD Release 10.0.
[11] ITRS. Available http://public.itrs.net

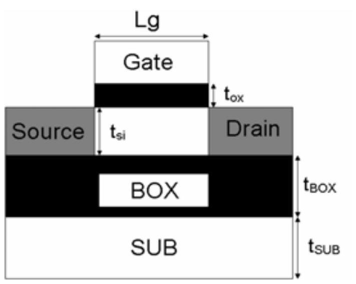

Fig. 1. Device structure of UTB SOI MOSFETs used in the simulation.

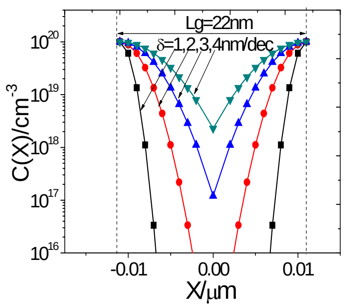

Fig. 2. Gaussian S/D doping profiles with L_g = 22 nm.

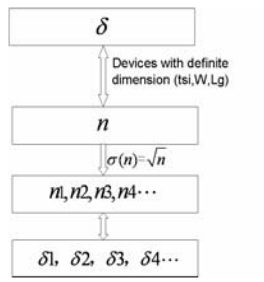

Fig. 3. Process for obtaining statistical samples.

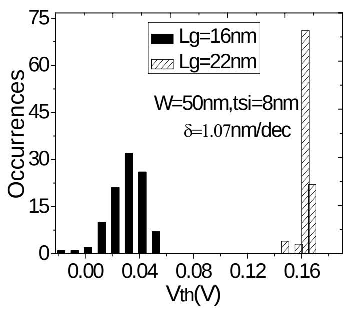

Fig. 4. V_{th} distribution for the devices with L_g = 16 nm and 22 nm.

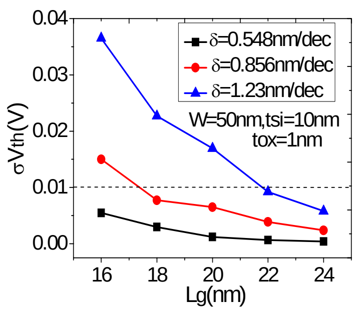

Fig. 5. Standard deviation of V_{th} versus channel length.

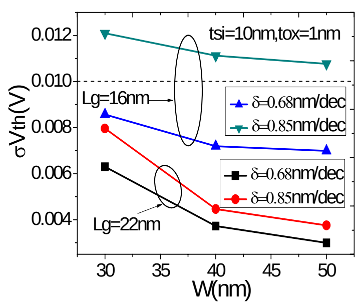

Fig. 6. Standard deviation of V_{th} versus channel width.

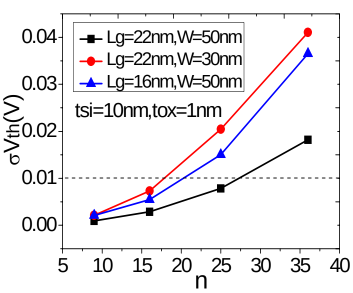

Fig. 7. Standard deviation of V_{th} versus impurity number.

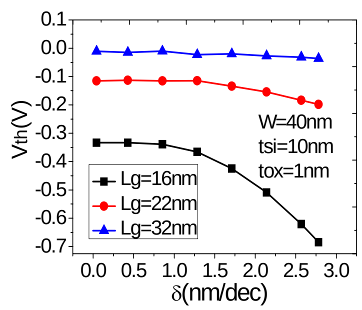

Fig. 8. V_{th} versus the S/D doping abruptness.

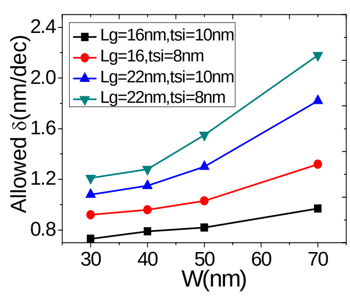

Fig. 9. Allowed abruptness versus channel width for devices at 20nm.