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Temperature Dependence of Off-Current in Bulk and FD SOI MOSFETs

Kousuke Miyaji, Masumi Saitoh, Toshiharu Nagumo, and Toshiro Hiramoto

Institute of Industrial Science, University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
Phone: +81-3-5452-6264 E-mail: k-miyag@nano.iis.u-tokyo.ac.jp

1. Introduction

The increase in power dissipation in VLSI circuits due to aggressive scaling leads to high temperature operation. As the temperature (T) rises, subthreshold current increases exponentially, and this leads to further increase in power dissipation and T. It is essential to re-examine the T dependence in scaled high-performance MOSFETs from the viewpoint of off-current (I_{off}). Extensive research works have been done on the T dependence of threshold voltage (V_{th}) [1-3], and it has been reported that FD SOI MOSFETs have a better T dependence than bulk MOSFETs [3]. However, their device dimensions were much larger than recent advanced devices and short channel effect (SCE) was not considered. Moreover, they focused only on T dependence of V_{th}, and T dependence of I_{off} was not discussed.

In this paper, we investigate T dependence of I_{off}, instead of V_{th}, from 0.25μm node to 65nm node, comparing bulk to FD SOI MOSFETs. Analytical modeling and 2D device simulations [4] are performed. It is found that, although the advantage of FD SOI MOSFETs remains when the SCE can be neglected, it diminishes when SCE is dominant as the technology node advances.

2. Method

We compare I_{off} at 25℃ and 100℃, and pay attention to the ratio of $I_{off@100℃}/I_{off@25℃}$. It is found that $I_{off@100℃}/I_{off@25℃}$ consists of two components: $I_{off@100℃}/I_{off@25℃}$ caused by the degradation of S factor (S component) and that caused by the decrease in V_{th} (V_{th} component) as shown in Fig. 1. The two components are analytically expressed as,

$$\frac{I_{off@HT}}{I_{off@RT}} = 10^{-V_{th@RT}\left(\frac{1}{S_{@HT}}-\frac{1}{S_{@RT}}\right)} \quad (1)$$

$$\frac{I_{off@HT}}{I_{off@RT}} = 10^{-\left(\frac{V_{th@HT}-V_{th@RT}}{S_{@RT}}\right)} \quad (2)$$

The V_{th} component largely depends on T dependence of V_{th} (dV_{th}/dT). Expression of dV_{th}/dT for long channel bulk MOSFETs is approximately expressed as [3],

$$\frac{dV_{th\_bulk}}{dT} = \frac{d\phi_B}{dT}\left[1+\frac{\sqrt{\varepsilon_{Si}qN_a/\phi_B}}{C_{ox}}\right] \quad (3)$$

where $d\phi_B/dT$ results from the T dependence of intrinsic carrier concentration and can be improved by increasing N_a. In the case of FD SOI MOSFETs, dV_{th}/dT is roughly equal to $d\phi_B/dT$, since there is no variation of the depletion charge in the channel region. To examine the T characteristics, we develop a new figure with vertical axis of $I_{off@100℃}/I_{off@25℃}$ and horizontal axis of $I_{off@25℃}$. Primary device parameters are shown in Table 1 [5].

3. Long Channel Devices

Fig. 2 shows analytical calculation results for long channel bulk and FD SOI MOSFETs from 0.25μm node to 65nm node. L_g is fixed to 1μm to examine long channel case. N_a is changed to vary $I_{off@25℃}$. It should be noted that exponential relation between $I_{off@100℃}/I_{off@25℃}$ and $I_{off@25℃}$ is obtained. Fig. 3 presents $I_{off@100℃}/I_{off@25℃}$ at different nodes at $I_{off@25℃} = 10^{-10}$(A) from simulation, which agrees well with analytical calculation. It is found that FD SOI is superior to bulk MOSFETs at every node by 20%~30%. Figs. 4 and 5 show the S component and V_{th} component, respectively. The S components are similar in all devices, and the total $I_{off@100℃}/I_{off@25℃}$ is mainly determined by the V_{th} component. Fig. 6 presents the N_a dependence of analytical dV_{th}/dT. N_a is varied to meet the same $I_{off@25℃}$ range for each nodes. dV_{th}/dT of FD SOI agrees well with $d\phi_B/dT$. In bulk MOSFETs, on the other hand, dV_{th}/dT is larger than $d\phi_B/dT$ due to the N_a term in eq. (3). As the node advances and C_{ox} increases, dV_{th}/dT of bulk MOSFETs improves according to eq. (3). However, to achieve the same range of $I_{off@25℃}$, FD SOI must be doped more heavily than bulk, result in better dV_{th}/dT in FD SOI. As a result, FD SOI MOSFETs maintain the advantage at every node in long channel case.

4. Short Channel Devices

Short channel effects must be considered in T dependence for high-performance devices. For bulk MOSFETs, it is reported that dV_{th}/dT improves by charge sharing [6]. Fig. 7 shows simulated L_g dependence of V_{th} component for 0.25μm node at V_{ds}=0.1V and V_{ds}=2.5V. Parameters are set so that both bulk and FD SOI MOSFETs have nearly the same V_{th} roll-off. It is obvious that the V_{th} component of bulk MOSFETs rolls off and approaches that of FD SOI MOSFETs at V_{ds}=0.1V due to the charge sharing. At V_{ds}=2.5V, the V_{th} component increases in shorter devices with SCE. This results in roll-up characteristics in FD SOI and flat characteristics in bulk MOSFETs. We have found that DIBL affects the T dependence of V_{th} defined by constant current due to further degradation of S. Therefore, regardless of V_{ds}, the V_{th} component of bulk MOSFETs approaches that of FD SOI MOSFETs, and the advantage of FD SOI diminishes in advanced short channel devices.

5. Conclusions

Systematic study has been performed on T dependence of I_{off} for both bulk and FD SOI MOSFETs from 0.25μm node to 65nm node. Simulation results showed that if SCE is negligible, FD SOI MOSFETs maintain the advantage over bulk MOSFETs. When SCE is considerable, T characteristics of bulk MOSFETs improve due to charge sharing and approaches that of FD SOI MOSFETs.

Acknowledgements

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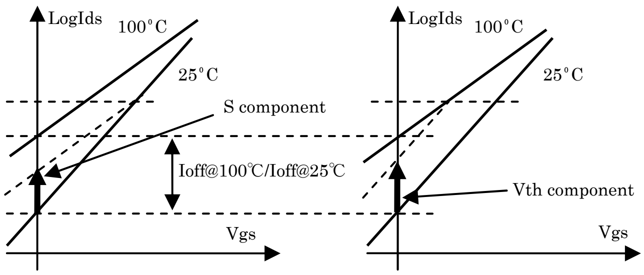

Fig. 1 Schematics of T dependence of I_{off}. The S component and V_{th} component are shown.

Table 1 Device parameters for calculations and simulations.

Tech. Node (nm)	250	180	130	90	65
L_g (nm)	250	140	65	37	25
Electrical tox (nm)	5	3.3	2.3	2.0	1.3
V_{dd} (V)	2.5	1.8	1.2	1.2	1.1
t_{SOI} (nm)	60	35	16	9.0	6.5
t_{BOX} (nm)	400	225	100	75	50

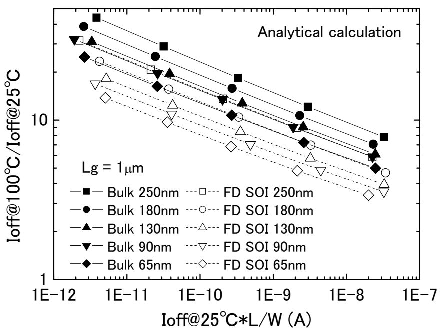

Fig.2 $I_{off@100℃}/I_{off@25℃}$ as a function of $I_{off@25℃}$ in long channel bulk and FD SOI MOSFETs (analytical calculation).

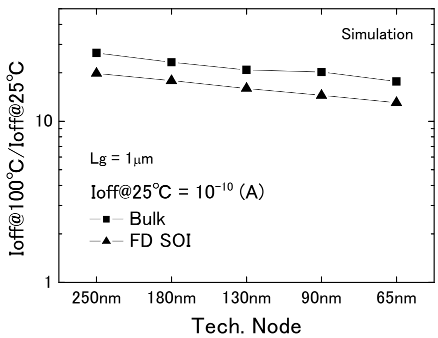

Fig. 3 Technology node dependence of $I_{off@100℃}/I_{off@25℃}$ in bulk and FD SOI MOSFETs (simulation).

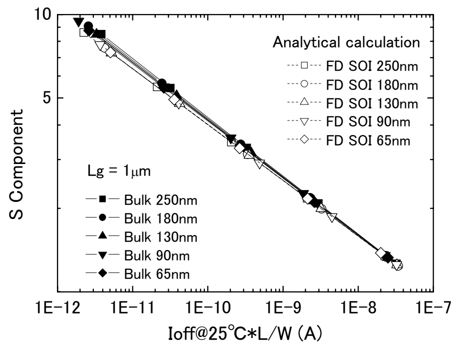

Fig. 4 The S component as a function of $I_{off@25℃}$ in long channel bulk and FD SOI MOSFETs (analytical calculation).

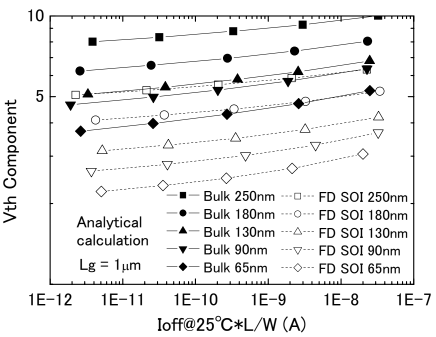

Fig. 5 The V_{th} component as a function of $I_{off@25℃}$ in long channel bulk and FD SOI MOSFETs (analytical calculation).

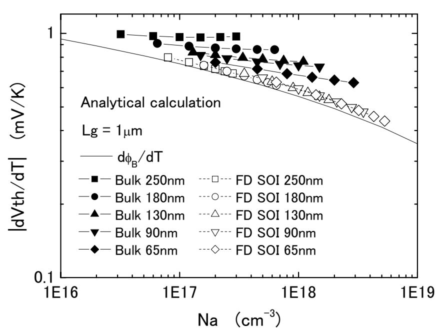

Fig. 6 dV_{th}/dT as a function of N_a in long channel bulk and FD SOI MOSFETs (analytical calculation).

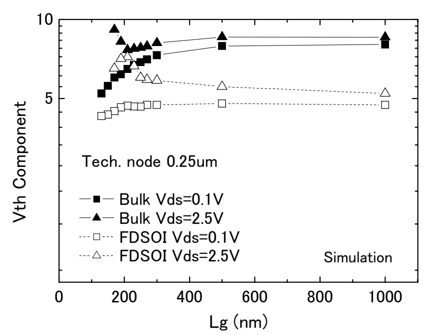

Fig. 7 L_g dependence of the V_{th} component in bulk and FD SOI MOSFETs (simulation).