E-6-2

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Statistical Analysis of Subthreshold Swing in Fully Depleted Silicon-on-Thin-BOX (SOTB) MOSFETs and Bulk MOSFETs

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Abstract

The variability of subthreshold swing (SS) in fully depleted (FD) silicon-on-thin-BOX (SOTB) MOSFETs is measured and compared with conventional bulk MOSFETs. It is newly found that SS variability is small enough in deep subthreshold region (small drain current I_{ds}) while it increases as increasing I_{ds} due to the effect of current-onset voltage (COV) variability. Since SOTB FETs have small COV variability thanks to intrinsic channel, SS variability is much smaller than bulk FETs, which is a great advantage of FD SOTB in terms of I_{on}/I_{off} ratio.

1. Introduction

Random variability in scaled transistors is one of the most serious issues for further device scaling and supply voltage reduction [1-4]. It is well recognized that the main cause of random V_{TH} variability in bulk FETs is random dopant fluctuation (RDF) [2,4]. Drain current (I_{ds}) variability has also been intensively analyzed and it has been found that COV largely affect I_{ds} variability [5] and COV originates from random potential distributions along channel width direction caused by RDF [6-7].

On the other hand, FD SOI FETs or SOTB FETs are attractive for low power applications [8-9]. It has been shown that SOTB FETs with intrinsic channel has much smaller V_{TH} and I_{ds} variability than bulk MOSFETs due to the absence of RDF and small COV variability [10-11].

Subthreshold swing (SS) is an influential parameter that determines I_{off} and I_{on}/I_{off} ratio in scaled FETs. Despite its importance, however, very little work has been reported so far on SS variability [12-13]. In design of high performance circuits with suppressed standby power, basic understanding of SS variability is indispensable.

In this study, SS variability in FD SOTB FETs is intensively measured using device-matrix array (DMA) TEG and compared with that in bulk FETs. It is newly found that SS variability largely depends on I_{ds} range due to COV variability and FD SOTB FETs have much smaller SS variability thanks to smaller COV variability.

2. Measurements

FD nFETs with intrinsic channel were fabricated on SOTB substrate by 65nm technology [14]. T_{SOI} is 13nm, T_{BOX} is 10nm, and T_{INV} is 2.8nm. For reference, conventional bulk nFETs were also fabricated. The variability of 1k transistors was measured using DMA TEG and SS variability of bulk and SOTB transistors were compared.

Fig. 1 shows the definitions of SS and COV. SS9, SS8, SS7, and SS6 are defined by SS at I_{ds} = $1\text{x}10^{-9}$ W/L [A], $1\text{x}10^{-8}$ W/L [A], $1\text{x}10^{-7}$ W/L [A], and $1\text{x}10^{-6}$ W/L [A] in this study, respectively (SS7' is SS at $3\text{x}10^{-7}$ W/L [A]). COV is defined by V_{THEX}–V_{THC} [5-7], where V_{THEX} is the extrapolated V_{TH} and V_{THC} is subthreshold constant current V_{TH}. Fig. 2 shows nFETs with smallest SS7 and largest SS7 among 1k bulk and SOTB nFETs, indicating that SS values have large variations.

Figs. 3 and 4 show cumulative distributions of SS in linear and saturation regions, respectively. It is clearly found that the absolute values of SS and their variability increases as increasing I_{ds} in both bulk and SOTB FETs. It is also shown that, while SS in bulk and SOTB FETs is very similar in deep subthreshold region, (SS9 and SS8), SOTB FETs have much smaller SS variability in high I_{ds} region.

3. Origin of SS Variability

To clarify these behaviors, correlations of SS with other parameters are examined. SS has very small correlation with V_{THC} (Fig. 5). On the other hand, it is newly found that SS in high I_{ds} (SS7, SS7' and SS6) is strongly correlated with COV while SS8 and SS9 have only a slight correlation with COV (Fig. 6). SS8-SS9 and SS6-SS7 (where I_{ds} is close) are well correlated, while SS6-SS9 (where I_{ds} is very different) is not correlated (Fig. 7). SS in linear and saturation regions are well correlated (Fig. 8).

These results indicate that the origins of SS variability are different in deep subthreshold region and high I_{ds} region. It has been considered that SS is varied mainly due to RDF [12] and random distribution of interface traps [13]. Although these models may apply to deep subthreshold region, SS variability is dominated by COV variability in high I_{ds} region. In transistors with worse current onset, SS in high I_{ds} region is degraded resulting in degraded I_{on}. Because SOTB FETs have smaller COV variability than bulk FETs thanks to intrinsic channel, SOTB FETs also have smaller SS variability. This is a great advantage of SOTB FETs in terms of I_{on}/I_{off} ratio.

4. Conclusions

SS variability in SOTB and bulk FETs are compared. SOTB FETs have much smaller SS variability which originates from COV variability thanks to intrinsic channel.

Acknowledgements

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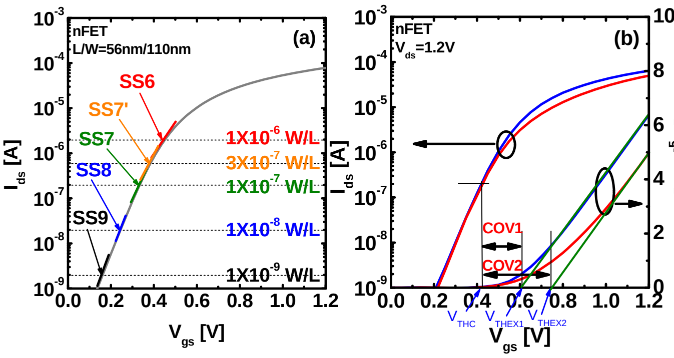

Fig.1. (a) Definitions of SS9, SS8, SS7, SS7’, and SS6. (b) Definition of COV. COV is defined by $V_{THEX} - V_{THC}$.

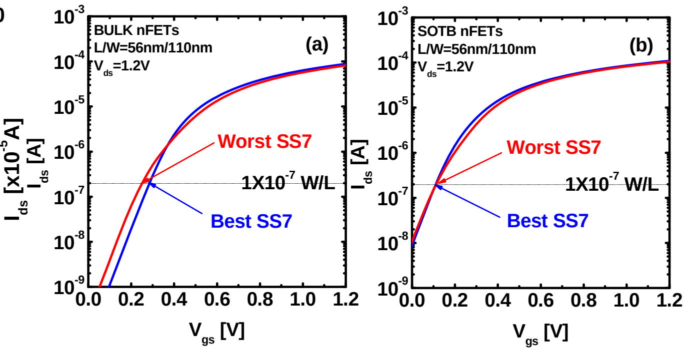

Fig.2. Ids - Vgs characteristics with the smallest SS7 and the largest SS7 among 1k nFETs. (a) Bulk nFETs. (b) SOTB nFETs.

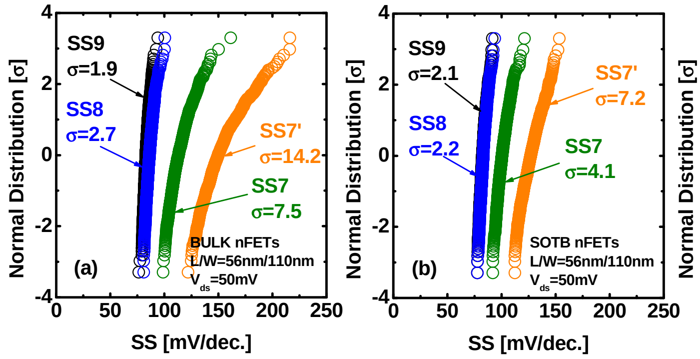

Fig.3. Cumulative distributions of SS9, SS8, SS7, and SS7’ in linear region. (a) Bulk nFETs. (b) SOTB nFETs.

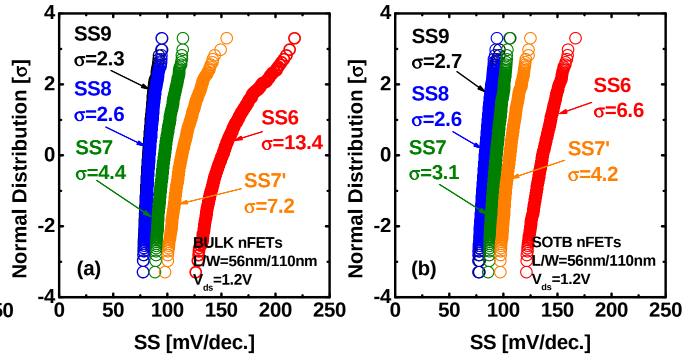

Fig.4. Cumulative distributions of SS9, SS8, SS7, SS7’, and SS6 in saturation region. (a) Bulk nFETs. (b) SOTB nFETs.

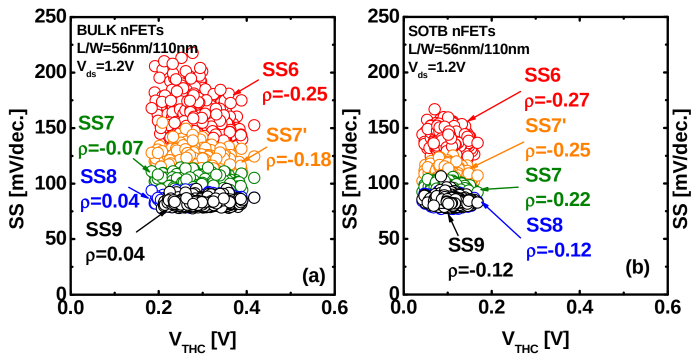

Fig.5. Correlations between SS and V_{THC} in saturation region. (a) Bulk nFETs. (b) SOTB nFETs.

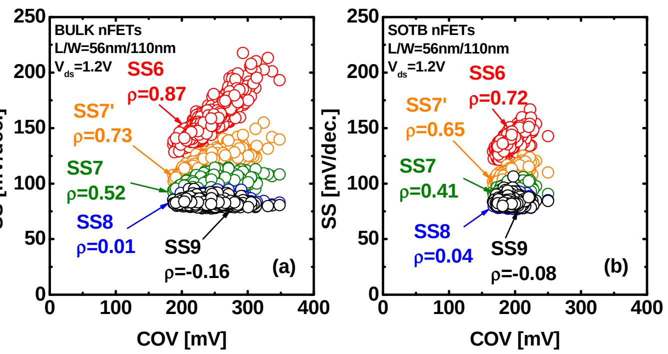

Fig.6. Correlations between SS and COV in saturation region. (a) Bulk nFETs. (b) SOTB nFETs.

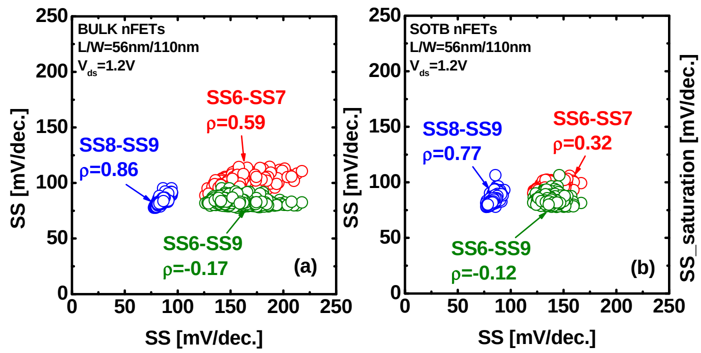

Fig.7. Correlation between SS8 and SS9, correlation in SS6 and SS7, and correlation between SS6 and SS9. (a) Bulk nFETs. (b) SOTB nFETs.

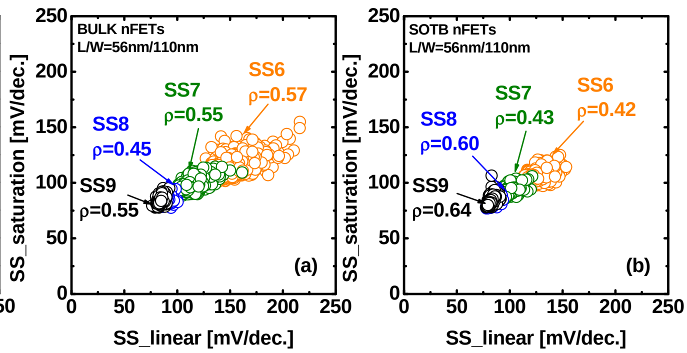

Fig.8. Correlations of SS9, SS8, SS7, SS7’, and SS6 between saturation region and linear region. (a) Bulk nFETs. (b) SOTB nFETs.