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# Comprehensive Analysis of Low-frequency Noise Variability Components in Bulk and FDSOI (SOTB) MOSFETs

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**Abstract**

**Low-frequency noise (LFN) variability in bulk MOSFETs and FDSOI MOSFETs with SOTB (Silicon on Thin Box) technology was investigated. The random telegraph noise (RTN) and random dopant fluctuation (RDF) in channel were strongly affected to LFN variability in bulk NMOSFETs compared to SOTB MOSFETs with channel dopant-less structure. In case of SOTB MOSFETs, not only median of but also variability of LFN in PMOS were reduced by applied forward back gate voltage because the centroid of carrier flow goes away from front-gate. These results indicated the LFN variability in SOTB PMOSFETs also was mainly explained by the carrier number fluctuations with correlated mobility fluctuations.**

## 1.Introduction

The LFN of MOSFETs is one of the limiting factors for low-voltage operation of analog circuits in SOC and for integrity of noise-sensitive devices such as CMOS image sensor (CIS). LFN typically shows a flicker noise component ($\propto$ 1/f) but in some frequency range, LFN contain signal Lorentzian components ($\propto 1/f^2$) by RTN due to the trapping and de-trapping of carrier at the gate insulator/silicon substrate interface [1]. The recent research indicates that the amplitude of RTN was related with RDF [2, 3]. Threshold voltage (*Vth*) variability in SOTB MOSFETs, which has FDSOI structure, has been reported to be much smaller than bulk MOSFETs because of channel dopant less structure [4], which makes SOTB to be a powerful solution for low voltage operation of digital circuits. There are few experimental reports, however, about LFN variability, although it is crucial for low voltage operation of analog circuits. In this paper, we comprehensively investigated LFN variability in bulk and SOTB MOSFETs, and discuss its relationship to RTN and RDF.

## 2.Experiment

LFN characteristics are measured with MOSFETs of 65nm-node conventional bulk process and SOTB process. Fig. 1 shows typical cross-section TEM image in SOTB MOSFETs. Poly-Si gate and oxide dielectric structure is almost same in bulk and SOTB MOSFETs [4]. Gate length (*Lg*) and width (*Wg*) for evaluation are 0.4 μm and 0.14 μm, respectively. Relaxed *Lg* is selected aiming for analog usage. LFN measurements using spectrum analyzer are performed in linear region (*Vd*=0.1 V) at room temperature.

## 3.Results and Discussion

Fig. 2 shows the cumulative frequency distribution of normalized *Vth* of bulk and SOTB NMOSFETs. Normalized *Vth* is defined as the difference from each median value. *Vth* variability in SOTB NMOSFETs was about one third of bulk, which is consistent with data already reported [4]. Fig. 3 shows the cumulative frequency distribution of normalized current noise intensity ($Sid/Id^2$) at 10, 100, and 1kHz; (a) weak inversion state and (b) strong inversion state. The main dispersion of *Sid* in SOTB MOSFETs is improved by 30% as compared to bulk MOSFETs at weak inversion state. The similar results were obtained for PMOS as well. In the case of bulk MOSFETs, there are some tail distributions in weak inversion state, and this tendency was remarkable for low frequency. Figs. 4 and 5 show the time dependence of drain current (*Id*) and 1/f noise characteristics for various gate voltage conditions; (a) and (b) are typical and tail sample data in bulk MOSFETs and (c) is typical sample data in SOTB MOSFETs. For the tail sample, the Lorentzian-like behaviors with $1/f^2$ characteristics and RTN-like current sampling behavior are observed in specific frequency and gate voltage around *Vth*. These results indicate that the relative incidence of RTN in SOTB MOSFETs considerably decreases with compared to bulk MOSFETs and the root cause of tail components is RTN.

In order to exclude $1/f^2$ characteristics in several LFN data, *Sid* was smoothed along 1/f slope as shown in fig.6. Fig.7 shows the correlation of *Id* and Sid at Vg=Vth; (a) and (b) are after and before smoothed *Sid* along 1/f slope in bulk MOSFETs, respectively. The smoothed *Sid* was clearly correlated to *Id* regardless of frequency. Fig. 8 shows the correlation between interface trap density (*Nit*) and the smoothed *Sid* along 1/f slope. There was no obvious correlation between *Sid* and *Nit*. Fig. 9 shows *Id* dependence of *Sid* variability at 10Hz in bulk and SOTB NMOSFETs. From *Vth* to *Gm_max* region, the *Sid* variation in SOTB MOSFETs is clearly reduced with compared to the smoothed *Sid* variation in bulk MOSFETs. These results indicate that the carrier number fluctuation with correlated RDF strongly affects to the LFN variability in bulk NMOSFETs.

Flicker noise in FDSOI structure is reported to be affected not only from front-gate oxide but also from back-gate buried oxide [5]. Fig.10 shows *Id* dependence of *Sid* variability with several back-gate voltages in SOTB N- and P-MOSFETs. FBB and RBB are forward and reverse bias (±1V), respectively. In case of NMOS, *Sid* variability on same drain current was almost independent of back-gate voltage. On the other hands, *Sid* variability of PMOS was decreased between *Vg=Vth* and *Gm_max* by applied FBB. Fig.11 shows *Id* dependence of normalized *Sid* with several back-gate voltages in SOTB PMOSFETs. Normalized *Sid* also was clearly decreased in case of FBB. It is considered that the centroid of carrier flow goes away from front-gate by applied FBB. The LFN of bulk MOSFETs were explained by the carrier number fluctuations with correlated mobility fluctuations model [6]. These results indicated the LFN variability of SOTB PMOSFETs also was limited by the carrier number fluctuations with correlated mobility fluctuations.

## 4.Conclusions

LFN variability in bulk and SOTB MOSFETs was comprehensively studied. The RTN and RDF in channel were affected LFN variability in bulk NMOSFETs. The LFN variability in SOTB PMOSFETs was mainly explained by the carrier number fluctuations with correlated mobility fluctuations.

## References

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[3] T. Hiramoto, SDM2011-97 pp1-4.
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[6] E.G. Ioannidis, et al., IEDM2011 pp449-452

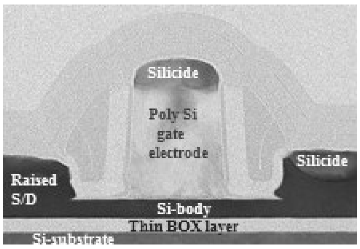



Fig. 1. Cross-sectional TEM image of SOTB MOSFET.

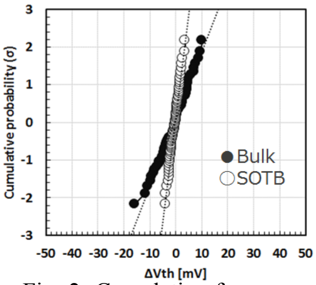



Fig. 2. Cumulative frequency distribution of normalized *Vth* in bulk and SOTB MOSFETs.

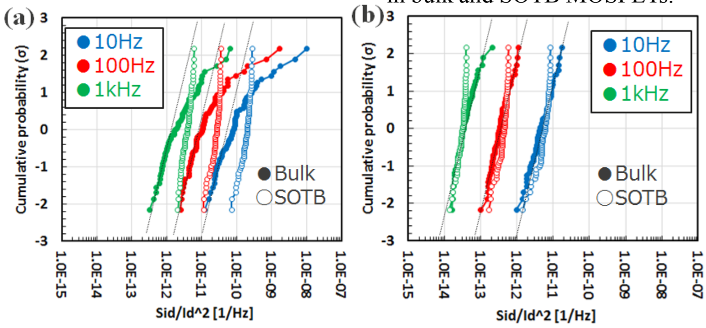



Fig. 3. Cumulative frequency distribution of normalized current noise intensity (*Sid/Id*) in bulk and SOTB MOSFET; (a) weak inversion state, (b) strong inversion state.

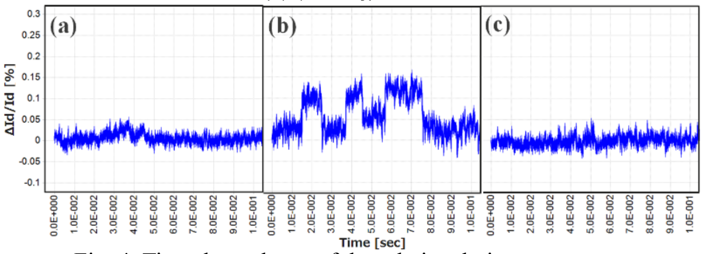
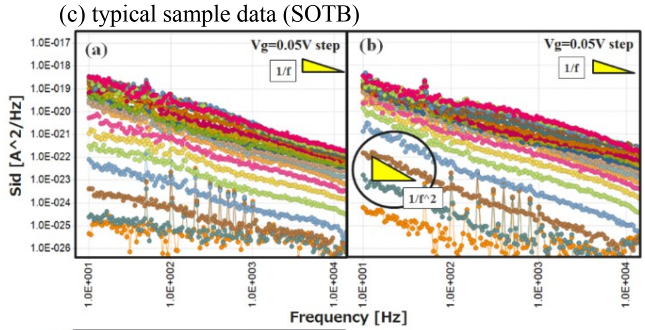



Fig. 4. Time dependence of the relative drain current
(a) typical sample data (bulk), (b) tail sample data (bulk)
(c) typical sample data (SOTB)



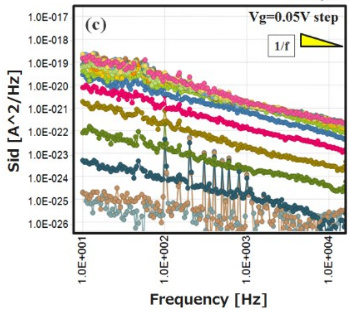




Fig. 5. 1/f noise characteristics for various gate voltage condition.
(a) typical sample data (bulk)
(b) tail sample data (bulk)
(c) typical sample data (SOTB)

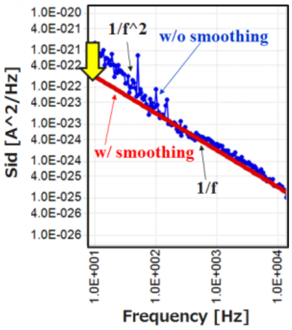



Fig. 6. Current noise intensity with and without smoothing along 1/f slope.

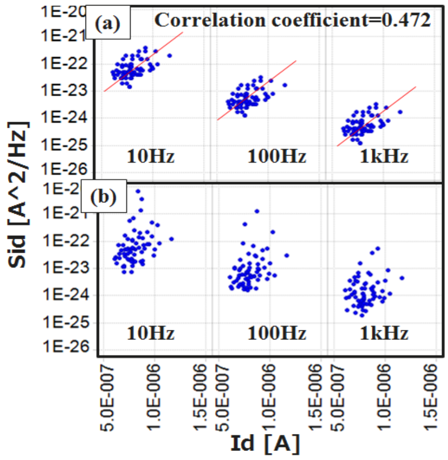



Fig. 7. The correlation of Id and Sid at Vg=Vth ; (a) wi smoothed Sid, (b) w/o smoothed Sid.

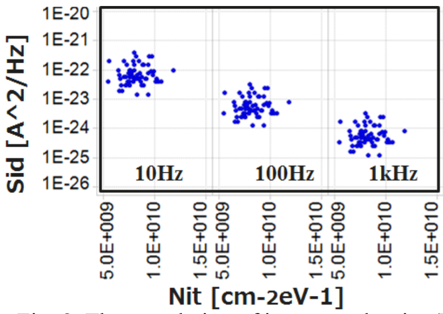



Fig. 8. The correlation of inter trap density (Nit) and Sid at Vg=Vth

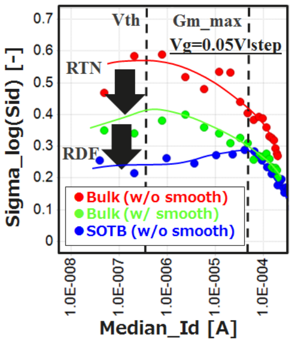



Fig. 9. Id dependence of Sid variability in NMOSFETs at 10Hz.

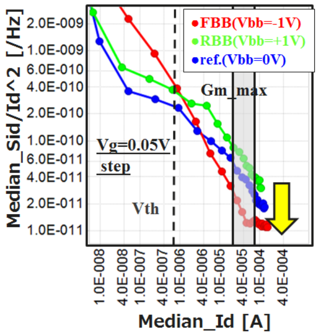



Fig. 11. Id dependence of Sid in SOTB PMOSFETs at several back-gate voltages at 10Hz.

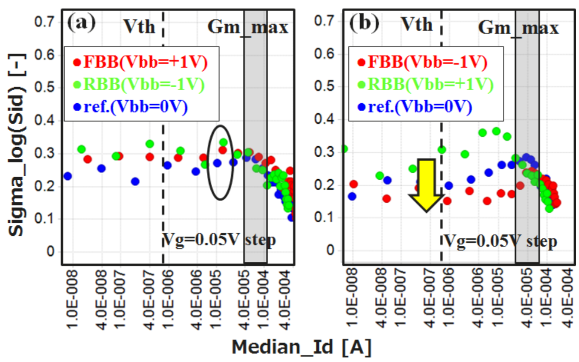



Fig. 10. Id dependence of Sid variability in SOTB MOSFETs at several back-gate voltages at 10Hz;
(a)NMOSFETs and (b) PMOSFETs