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Improvement of Device Characteristics Variation by using a Body-Bias Controlling Technology Based on a Hybrid Trench Isolated SOI

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1. Introduction

With an aggressive CMOS device scaling, it becomes difficult to achieve low-voltage and high-speed operation, especially for low standby power (LSTP) devices, because the threshold voltage cannot be reduced due to increase of subthreshold leakage current. Moreover, the device variability becomes crucial problem for further scaled devices, and intensive investigations for the issue have been performed [1]-[3].

An SOI technology is one of the solutions for low-power and high-speed operation. We proposed a body-tied SOI device which can offer stable operations without floating body effect [4]-[5]. Although the bulk device has great difficulty using a forward body-bias due to a latch-up problem, the body-bias controlling device with a hybrid trench isolation (HTI) is latch-up free and is effective to increase drive current using a forward body-bias [6].

In this paper, we evaluate the performance of transistors and ring oscillators fabricated with an actively body-bias controlled (ABC) SOI technology. In the ABC SOI structure, body-bias effect influenced by the body resistance is inversely proportional to gate length. Therefore, the ABC SOI shows a self-regulating effect that reduces the variations of transistor characteristics and the delay time.

2. Device Structure

Fig.1 shows a schematic diagram of the ABC SOI MOSFET with the HTI. The SOI layer under the partial trench isolation (PTI) oxide remains only in the area that connects the body contact region with the body of the MOSFET. The full trench isolation (FTI) is used for other isolation regions to reduce the peripheral parasitic junction capacitance of the S/D regions. In this structure, we can control the body potential at each transistor separately.

3. Transistor characteristics of the ABC MOSFET

Fig. 2 shows the Id-Vg characteristics, and Table 1 summarizes the transistors characteristics. High-Vth and Middle-Vth transistors were fabricated to estimate the channel dose dependence of body-bias effect.

Fig. 3 shows the forward body-bias dependence of Vth and Ids. By applying forward body-bias, the Vth decreases and the Ids increases. High-Vth transistors realize the same Ids of Middle-Vth transistors with forward body-bias of 0.4V - 0.6V. At |VB|=0.4V, Ids of NFET with Lg=85nm increases about 10% and 7% for High-Vth and Middle-Vth, respectively. For PFET, increases of Ids are about 26% and 18% at High-Vth and Middle-Vth, respectively. Ids change of PFET is larger than NFET, because a resistance between a body contact region and a channel region of PFET is smaller than that of NFET.

Fig. 4 shows the gate length dependence of Id increase due to the forward body-bias. Effect of body-bias becomes larger when the gate length is longer. This behavior is considered to be caused by the gate length dependence of body resistance. In ABC SOI structure, body resistance is inversely proportional to gate length. Therefore, Ids increase of transistor with longer gate length is bigger than that of transistor with shorter gate length. It means that the ABC SOI structure shows self-regulating effect that reduces the Id variation due to the gate length fluctuation.

Moreover, Fig. 4 shows the Vth dependence of Id increase. Effect of body-bias becomes larger when the channel dose is higher. Therefore, Ids increase of transistor with higher channel dose is larger than that of transistor with lower channel dose. This means that the ABC SOI structure is also effective to suppress the Id variation due to the channel dose fluctuation.

Fig.5 shows the forward body-bias dependence of Id variation. The variation of Id decreases with higher body-bias.

Fig. 6 shows Id variations of transistors with various cases that are shorter gate length, lower threshold voltage and forward body-bias. To achieve the same Ids, the variation of the forward body-bias case is smaller compared to other cases.

Fig.7 shows the body-bias dependence of threshold voltage variations. The variations of threshold voltage were also suppressed by applying forward body-bias.

From these results, ABC SOI technology can realize high performance transistors with small characteristics variations.

4. Ring Oscillator Results

We demonstrated the ABC SOI MOSFET advantages using the ring oscillators. Fig. 8 shows delay times of inverter ring oscillators and their variations as a function of forward body-bias. Applying 0.4V forward body-bias, the delay time and its variation are improved by about 20% and 31% at VCC=1.2V. To reduce the supply voltage, the improvement rate of delay times and their variations become large. For example, the delay time and its variation are improved by about 27% and 41% at VCC=1.0V. Moreover, the same delay time of VCC=1.2V can be obtained at VCC=1.05V with smaller variation. Fig. 9 shows the body-bias dependence of the delay time and its variation. For the High-Vth transistors, the improvement rate of both delay time and its variations are larger compared with Middle-Vth transistors. The difference of delay time and its variation between High-Vth and Middle-Vth becomes smaller with higher forward body-bias. Applying the 0.4V forward body-bias to High-Vth device, it achieves the same delay time as Middle-Vth condition with small delay time variation.

Fig. 10 shows the power consumption of ring oscillators at High-Vth transistors. At the same supply voltage, the power consumption is almost the same in the condition of |VB|=0V~0.6V. The power consumption of VCC=1.05V with |VB|=0.4V is about 25% lower than that of VCC=1.2V with |VB|=0V under the same delay time condition.

5. Conclusion

We demonstrated the advantages of ABC SOI CMOS technology. A forward body-bias of 0.4V enhances High-Vth transistors drive current about 10% and 26% for NFET and PFET, respectively. The ABC SOI MOSFET achieves not only to increase the Ids but also to decrease the variations of the transistor characteristics. Especially, it is effective to suppress the variations due to the gate length and the channel dope fluctuations.

For the ring oscillator, delay time and its variation were improved about 20% and 31% by applying 0.4V forward body-bias, respectively. Improvements of the delay time and its variation are more prominent with lower supply voltages.

These results indicate that the ABC SOI CMOS technology is promising for low-power consumption and high-speed operation applications, especially for LSTP devices.

References

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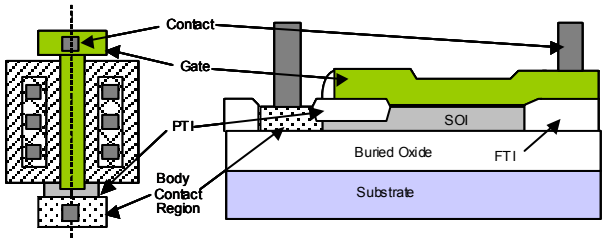


Fig.1 Schematic diagram of ABC SOI MOSFET.

Table 1 Transistor characteristics.(VCC=1.2V,VB=0V,@ RT)

	NMOS FET		PMOS FET	
Vth	Middle	High	Middle	High
|Ion|(μA/μm)	530	455	263	210
|Ioff|(pA/μm)	137	26	106	26

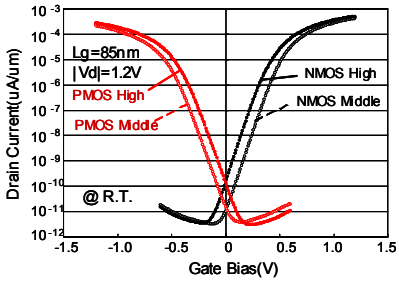
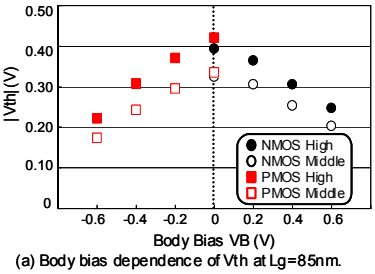
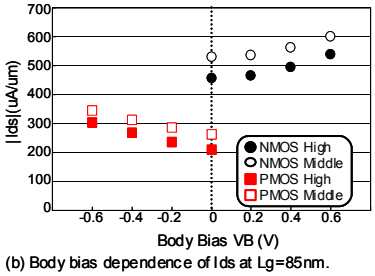


Fig.2 Vg-Id characteristics.(@VB=0V)



(a) Body bias dependence of Vth at Lg=85nm.



(b) Body bias dependence of Ids at Lg=85nm.

Fig.3 Body bias dependence of Vth and Ids.

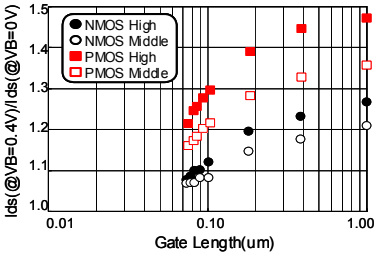


Fig.4 Gate length dependence of Ids increase.

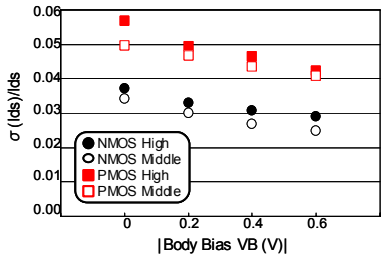


Fig.5 Body bias dependence of Ids variation.

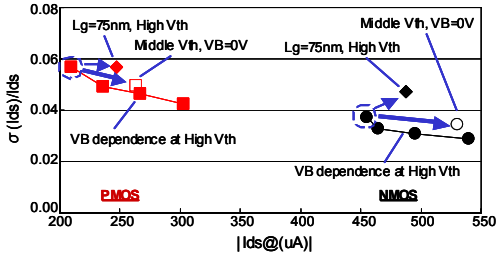


Fig.6 Process condition dependence of Ids variation.

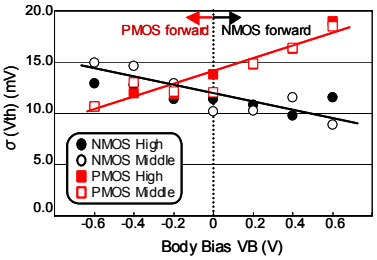
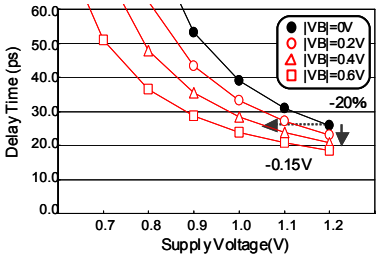
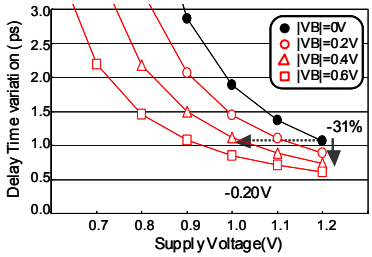


Fig.7 Body bias dependence of Vth variation.

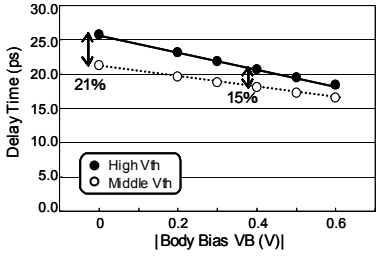


(a) Delaytime of the ring oscillators at High Vth.

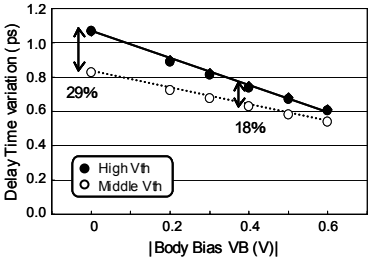


(b) Delaytime variation of the ring oscillators at High Vth.

Fig.8 Measured delay time of the ring oscillators and its variation. (Wn=0.54μm,Wp=0.82μm,@RT)



(a) Delaytime of the ring oscillators.



(b) Delaytime variation of the ring oscillators.

Fig.9 Body bias dependence of delay time and its variation.

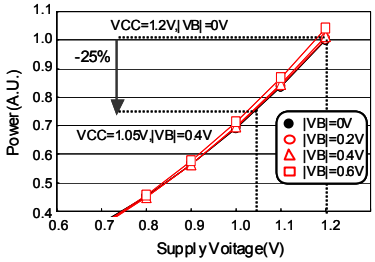


Fig.10 Normalized power of the ring oscillators.