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High Performance Accumulated Back-Interface Dynamic Threshold SOI MOS-FET's (AB-DTMOS) with Large Body Effect at Low Supply Voltage

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1. Introduction

The dynamic threshold MOSFET's (DTMOS) are attractive for very low power applications due to the ideal subthreshold slope and the high current drive at very low supply voltage (V_{dd} < 0.5 V) [1-4]. To enhance the current drive of DTMOS, a large body effect is essential, because DTMOS operating at V_{dd} effectively operates at $V_{dd}+\Delta V_{th}$ [2]. The large body effect is usually achieved by high channel doping to reduce the depletion layer width. In this paper, we propose a novel Accumulated Back-Interface Dynamic Threshold SOI MOSFET's (AB-DTMOS), in which the very large body effect is achieved by thin SOI thickness.

2. AB-DTMOS

Fig. 1 shows a schematic view of the proposed AB-DTMOS. The back interface between the non-doped thin SOI and the buried oxide is accumulated by the large negative back bias. The gate electrode is connected to the body. The body effect factor (γ) of AB-DTMOS is expressed as

$$\gamma \equiv \left|\frac{\Delta V_{th}}{\Delta V_{bs}}\right| = \frac{C_{SOI}}{C_{fox}} \cong 3\frac{t_{fox}}{t_{SOI}} \qquad (1)$$

where t_{SOI} is the SOI thickness and t_{fox} is the gate oxide thickness. By thinning the SOI thickness, AB-DTMOS can realize larger γ and thus, higher current drive than conventional DTMOS.

The accumulated back-interface devices with suppressed short channel effect have already been proposed as electrically thinned intrinsic channel (ETIC)-SOI MOSFET [5], in which the gate is not connected to the body. They have: (1) poor subthreshold slope (> 100 mV/dec), (2) low current drive due to very high vertical electric field leading to low mobility, (3) severe floating body effect due to accumulated holes at back interface. By connecting the gate to the body, AB-DTMOS solves all the drawbacks. Therefore, the AB-DTMOS has the advantages of both the ETIC-SOI MOSFET and conventional DTMOS.

3. Experimental

The AB-DTMOS and ETIC-SOI MOSFET are compared in the experiment. The devices measured are fully depleted (FD) SOI devices fabricated on a SIMOX wafer [6]. The thicknesses of the gate oxide, SOI, and buried oxide are 100Å, 400Å, and 1000Å, respectively. N^+ poly Si gate is used and the channel doping concentration is in the order of 10^{16} cm^{-3}. The devices are characterized in the three modes shown in Table I. When V_{bs}=0V and V_{sub}=0V, the devices operate as the FD mode. When V_{bs}=0V and V_{sub}=-20V, they operate as the ETIC-SOI mode. When gate is tied to body ($V_{bs}=V_{gs}$) and V_{sub}=-20V, they operate as the AB-DTMOS mode. Fig. 2 shows the subthreshold characteristics in the three modes. V_{th} of ETIC-SOI is too high and that of FD SOI is too low, but V_{th} of AB-DTMOS is just between them. Fig. 3 shows the subthreshold characteristics of AB-DTMOS and ETIC-SOI where V_{bs} is varied. Body current is also shown. Derived γ from Fig. 3 is as high as 0.8. Figs. 4 and 5 show the V_{th} rolloff and the S degradation by the short channel effect. AB-DTMOS has the ideal subthreshold slope and suppresses the short channel effect very well. In Fig. 6, the on/off characteristics are compared. AB-DTMOS shows the high current drive and low off-current, but ETIC-SOI shows the poor current drive.

4. Comparison with Conventional DTMOS

The AB-DTMOS and conventional DTMOS are compared analytically. In the conventional DTMOS, uniformly doped channel profile is assumed. At a given V_{th}, the depletion layer width of AB-DTMOS is half of that of conventional DTMOS and V_{th} for both devices are expressed as a function of γ,

$$V_{th}(\text{Conv. DTMOS}) = 2\phi_{F1} + \frac{V_{FB1}}{1+2\gamma} \qquad (2)$$

$$V_{th}(\text{AB-DTMOS}) = 2\phi_{F2} + \frac{V_{FB2}}{1+\gamma} \qquad (3)$$

where ϕ_{F1} and ϕ_{F2} are Fermi potentials and V_{FB1} and V_{FB2} are work function differences. Note that V_{FB1} and V_{FB2} are negative. It is expected that γ of AB-DTMOS has two times as large as that of the uniform DTMOS at fixed V_{th}.

Fig. 7 shows the dependence of V_{th} on γ calculated by the simulation. To vary V_{th} and γ, the channel doping concentration is changed in the conventional DTMOS and the SOI thickness is changed in the AB-DTMOS. In both devices, the increase in γ leads to the increase in V_{th}. As is discussed above, AB-DTMOS has larger γ at a given V_{th}. It should be noted that the experimental result fits the simulation very well.

The retrograde channel profile is often used in the conventional DTMOS for low V_{th} and large γ [2]. However, the retrograde channel profile has always lower γ than AB-DTMOS at fixed V_{th}, because AB-DTMOS realizes the ideal low/ultrahigh step channel profile electrically and achieves the maximum γ. Although the counter doping in the conventional DTMOS also leads to larger γ and low V_{th} [2], the same effects apply to the AB-DTMOS.

DTMOS operates at the low vertical electric field because the body is tied to the gate [1]. At the low vertical electric field, the impurity scattering is dominant. AB-DTMOS also shows higher mobility than the conventional DTMOS, because AB-DTMOS with non-doped channel shows the less impurity scattering than the conventional DTMOS. Both large γ and high mobility in AB-DTMOS result in the high current drive.

5. Conclusions

We have proposed the high performance AB-DTMOS with large body effect at low supply voltage. AB-DTMOS has thin depletion layer width corresponding to the SOI thickness and an ideal low/ultrahigh channel profile, resulting in the maximum body effect. Experimental results show steep subthreshold slope, high current drive due to the large V_{th} shift, and suppressed short channel effect.

References

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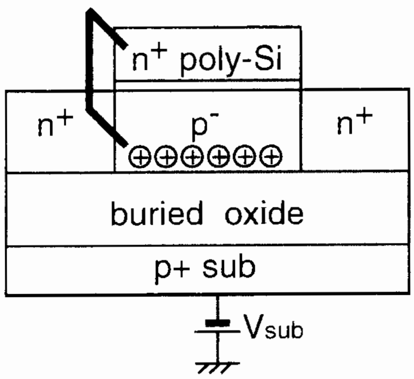

Fig. 1 A schematic view of AB-DTMOS. The back interface between the non-doped thin SOI and the buried oxide is accumulated by the large negative back bias.

Table I Three operation mode of the devices.

operation mode	V_{bs}	V_{sub}
FD SOI MOSFET	-	0V
ETIC-SOI MOSFET	0V	-20V
AB-DTMOS	$=V_{gs}$	-20V

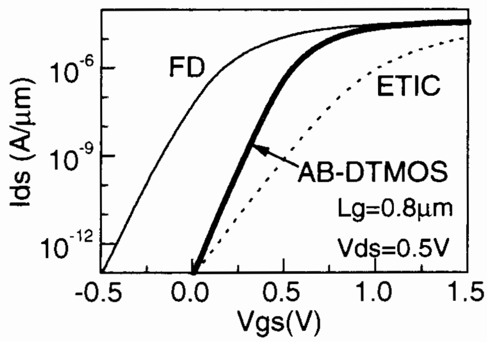

Fig. 2 The subthreshold characteristics of the FD, ETIC, and AB-DTMOS shown in Table I . L_g=0.8μm.

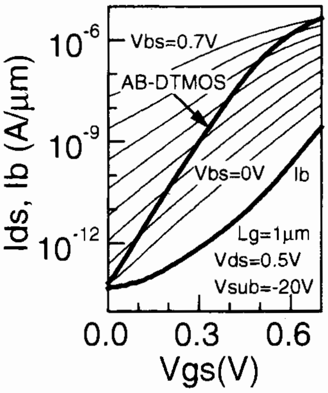

Fig. 3 The subthreshold characteristics of AB-DTMOS and ETIC-SOI MOSFET where V_{bs} is varied. Body current (I_b) of AB-DTMOS is also shown. V_{bs} =0-0.7V (0.1V step). Derived γ is 0.8.

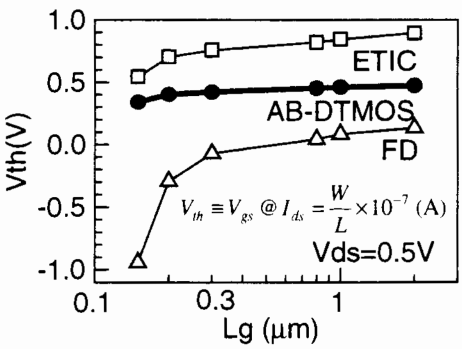

Fig. 4 The dependence of V_{th} on L_g. AB-DTMOS has appropriate V_{th} and suppresses the short channel effect well.

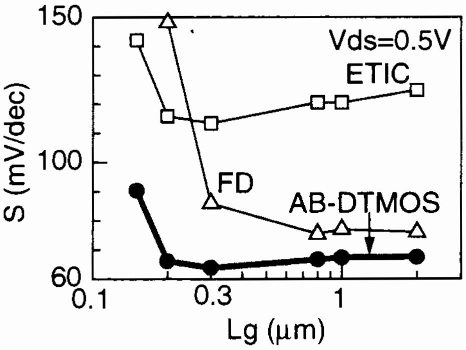

Fig. 5 The dependence of S on L_g. AB-DTMOS has the ideal subthreshold slope and suppresses the short channel effect well.

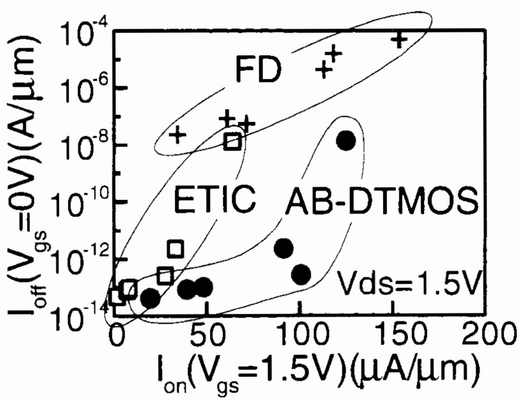

Fig. 6 The on/off characteristics of the FD, ETIC, and AB-DTMOS. L_g is varied. AB-DTMOS shows the high current drive and low off-current, but ETIC shows the poor current drive.

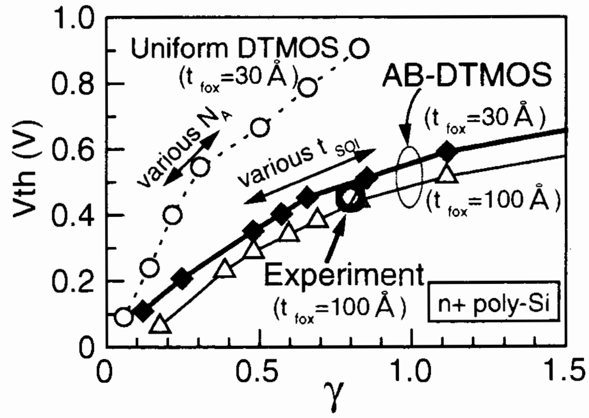

Fig. 7 The dependence of V_{th} on γ by the simulations for uniform DTMOS (t_{fox}=30 Å), and AB-DTMOS (t_{fox} =30,100 Å). Experimental data is also plotted. γ of AB-DTMOS has two times as large as that of the uniform DTMOS at fixed V_{th}.