Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 232-233

J-1-4

Investigation on the Body Bias Dependency of Gate Induced Drain Leakage Current in the Body-Tied finFET

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1. Introduction

A small cell size and low voltage with high-speed operations are necessary for the future DRAM cell transistor. A finFET is one of the candidates [1-4], since it has strong immunity to the short channel effect, the high drain current and the small body bias dependency of threshold voltage (Vth) (Fig. 1). However, Vth of the finFET is hard to control, since Vth is almost decided by a work-function of the gate material. To control Vth or an off-leakage current, new gate materials or negative word line (NWL) scheme were adopted, but unfortunately, these methods increase the gate induced drain leakage (GIDL) current and degrades the data retention time of the finFET DRAM [5]. It is well known that optimization of the gate oxide thickness and drain doping profile are necessary to reduce the vertical electric field and GIDL current. Besides, the GIDL depends not only on the vertical electric field but also the lateral electric field [6,7]. Generally, body bias is applied to DRAM cell transistors to reduce the off-leakage current from source to drain by increasing the Vth and decreasing the sub-threshold swing (SS). The body-tied finFET has better SS and negligible body bias dependence of Vth. Therefore, body bias is unnecessary in the body-tied finFET.

In this paper, we have investigated the body bias dependence of GIDL current in the body-tied finFET, since the body bias affects the lateral electric field. We have found that by reducing the body bias, GIDL current can be reduced, and the lateral electric field can be affected by gate bias in the body-tied finFET.

2. Experiment

Based on the 80nm design-rule, the local damascene (LD) finFET was integrated to avoid passing gate effects [8]. Fig. 2 shows simulation results of passing gate effects, when the passing gate is faced with a storage node through the gate oxide. If a negative bias is applied to the passing gate, GIDL current increases. If the operation bias is applied to the passing gate, Vth decreases. Therefore, in both perturbation cases, the off state leakage current is increased.

The field oxide under the word line at the both sides of the fin active is locally etched in the LD finFET structure, as shown in Fig. 3(a). After surface treatment of the fin, a radical oxidation for the gate oxide was followed by the gate poly silicon deposition on the LD patterns. Boron in-situ doped p+ type poly silicon was used as the bottom electrode of the gate. W was, then, deposited and followed by gate stack patterning and ILD deposition. Fig. 3(b) shows the fabricated LD finFET after gate stack formation.

3. Result and Discussion

Unlike SOI finFET, body bias can be applied to the body-tied finFET. The body bias dependence of GIDL current was measured in both drain and gate bias sweep cases. Insets of the Figs. 4 & 5 show that as the drain to body bias (Vdb) increases, GIDL current increases, even at the same Vdg. This phenomenon is understood that the lateral electric field (Vdb) lowers the tunneling barrier height of the vertical electric field (Vdg) [6, 7]. The activation energies of GIDL current as a function of Vdg were measured. The increased lateral electric field decreases the activation energies of GIDL current in the high Vdg (Fig. 6).

A different slope of GIDL current was observed as a function of Vdb and Vgb at the same Vdg. Figs. 7(a) and 7(b) show that the slope of GIDL current at the same Vdg are different in the channel accumulation and depletion case. This means that the lateral electric field between drain and body is changed by the gate bias. If the majority carriers in the fin channel are accumulated, the lateral electric field can be fully applied through a neural region within the fin. Then, the slope can be steeper than that of the depletion case. When the majority carriers in the fin channel are depleted, the lateral electric field is shielded by the depleted body. Therefore the slope of GIDL current is saturated in the depletion region (Fig. 8).

In order to confirm the above assumption, we compared the lateral electric filed dependency of GIDL current as a function of Vgb at the same Vdg. The band to band tunneling current can be expressed as equation (1) in the 3 terminal band to band tunneling current model [7].

$$J \sim \frac{A\psi_s E_{si}}{\eta + E_{si}\xi} exp\left(-\frac{B + \eta V_d}{E_{si}} + \xi V_d\right) \qquad (1)$$

Where $A = (q^3 m_e)/(2\pi^2\hbar^3)$, $B = (\pi m_e^{1/2} Eg^{3/2})/(2\sqrt{2}q\hbar)$, ξ is a fitting parameter, and $\eta = (3\pi(m_e\ Eg)^{1/2})/(2\sqrt{2}\hbar)$ with the effect mass $m_e = 0.2\ m_o$. We compared η and ξ (the lateral electric filed dependency of GIDL current). The values of η and ξ as a function of Vdg were extracted from the measured data with different bias condition. As Vdg increases, the band to band tunneling current dominates the drain leakage current. Therefore, η converges into the theoretical value. The value of ξ decreases as Vdb increases at the same Vdg (Fig. 9). As Vdb increases, Vgb increases at the same Vdg. This means that the lateral electric field dependency of GIDL current decreases as Vgb increases. It is clear that the lateral electric field dependency of GIDL current is affected by gate bias and the lateral electric filed dependency of GIDL current in the channel depletion condition is small compared to the channel accumulation condition.

4. Conclusion

In this paper, the body bias dependency of GIDL current in the body-tied finFET was investigated. GIDL current depends not only on the vertical electric field but also on the lateral electric field. We also found that the lateral electric filed dependency of GIDL current in the channel depletion condition is small compared to the channel accumulation condition.

References

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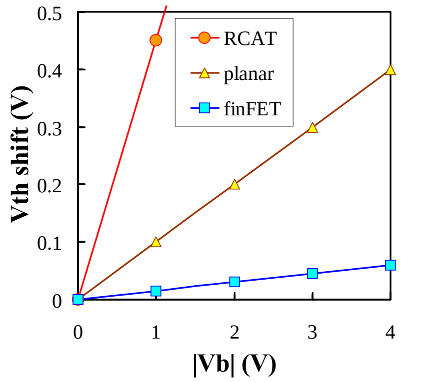
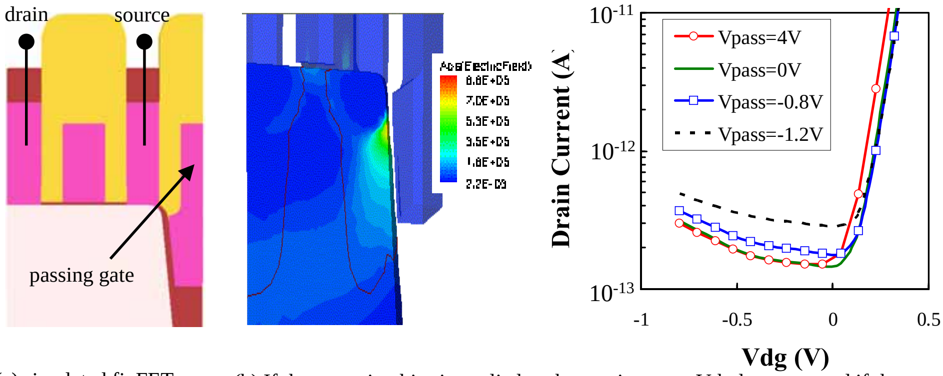


Fig. 1: The Vth shift as a function of the body bias with a different structure. A finFET shows negligible Vth shift compared to a planar transistor and a recess channel array transistor (RCAT).



(a) simulated finFET profile (pass gate butting)

(b) If the operation bias is applied to the passing gate, Vth decreases and if the NWL bias applied to the passing gate, GIDL current increases.

Fig. 2: The simulation result of the passing gate effect. The passing gate induced perturbation increases the off state leakage current.

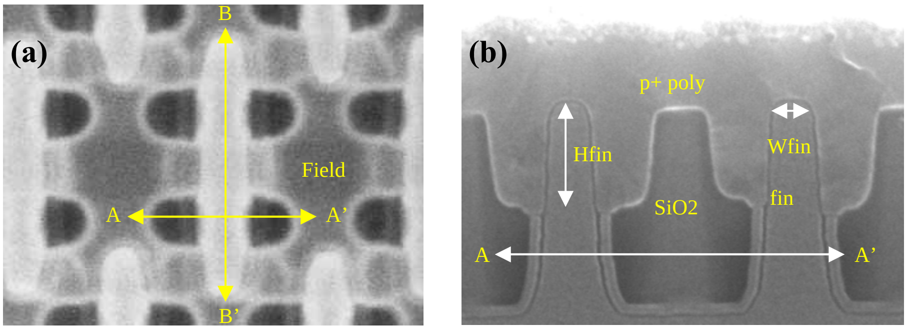


Fig. 3: SEM image of cell array LD finFET before gate oxidation (a) and after gate stack formation (b). The field oxide under the word line at the both side of fin was etched to remove the passing gate effect. The Hfin is about 150nm and the Wfin of a fin top is about 45nm.

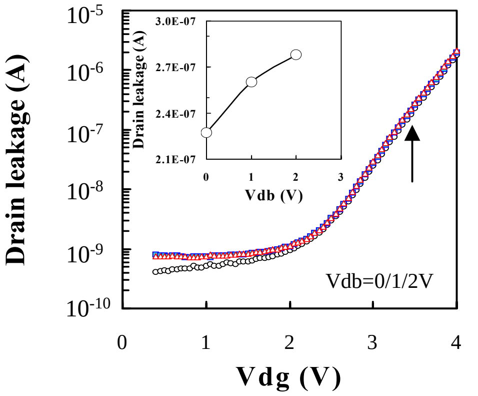


Fig. 4: Drain leakage current as a function of Vdg with **Vd** sweep. Inset shows drain leakage current at Vdg=3.5V as a function of Vdb.

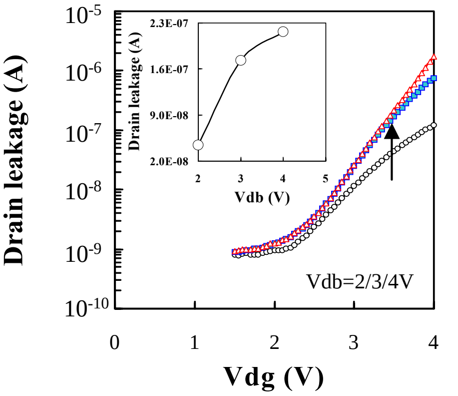


Fig. 5: Drain leakage current as a function of Vdg with **Vg** sweep. Inset shows drain leakage current at Vdg=3.5V as a function of Vdb.

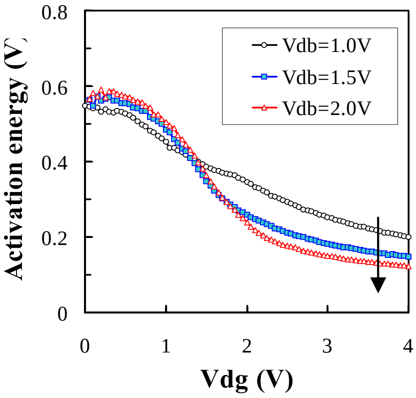


Fig. 6: The activation energy (Ea) of GIDL current as a function of Vdg. As Vdb increases, Ea decreases along the Vdg.

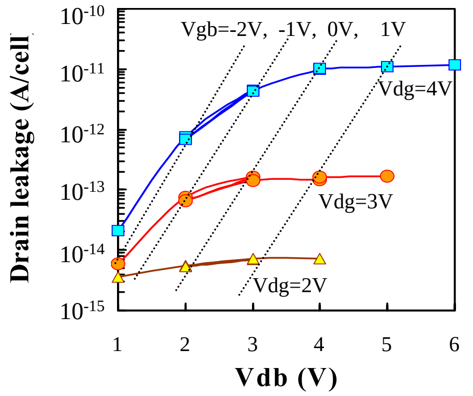


Fig. 7 (a): GIDL current as a function of Vdb which has different Vdg. The slope of GIDL current is steeper in the channel accumulation condition.

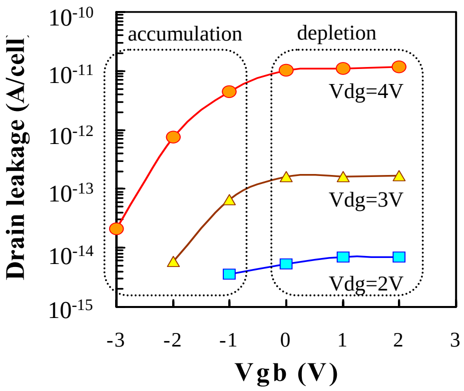


Fig. 7 (b): GIDL current as a function of Vgb for different Vdg. GIDL current dependency on Vgb is steep in the channel accumulation condition.

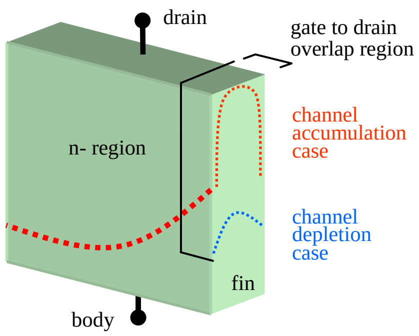


Fig.8: Schematic diagram of the Vg dependent GIDL current in the finFET. The electric field between drain and body varies with Vg. When majority carriers in the fin channel are accumulated, the electric field is fully applied because of the neutral region within the fin.

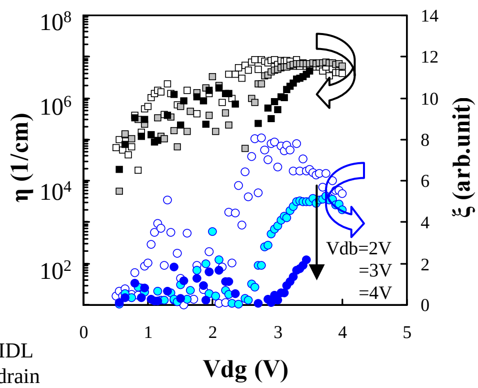


Fig. 9: The lateral electric field dependency of GIDL current (ξ) decreases as Vdb increases (= Vgb increases) at the same Vdg.