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# Research for Hot Carrier Degradation in N-Type Bulk FinFETs

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**Abstract**: In this paper, the effect of hot carrier injection on an n-bulk fin field-effect transistor (FinFET) is analyzed. The hot carrier injection method is applied to determine the performance change after injection in two ways, channel hot electron (CHE) and drain avalanche hot carrier (DAHC), which have the greatest effect at room temperature. The optimum condition for CHE injection is $V_G=V_D$, and the optimal condition for DAHC injection can be indirectly confirmed by measuring the peak value of the substrate current. Deterioration by DAHC injection affects not only hot electrons formed by impact ionization, but also hot holes, which has a greater impact on reliability than CHE. Further, we test the amount of drain voltage that can be withstood, and extracted the lifetime of the device. Under CHE injection conditions, the drain voltage was able to maintain a lifetime of more than 10 years at a maximum of 1.25 V, while DAHC was able to achieve a lifetime exceeding 10 years at a 1.05-V drain voltage, which is 0.2 V lower than that of CHE injection conditions.

**Keywords**: Bulk FinFET, Hot carrier effect, Impact ionization, Drain avalanche hot carrier, Channel hot electron

## 1. INTRODUCTION

MOSFETs have been continuously reduced in size to improve the productivity and performance of integrated circuits. However, as the size is reduced to nano meters, the gate control is lowered and the leakage current increases [1,2]. A 3D FinFET has been developed to solve this problem [3,4]. Unlike conventional MOSFETs, FinFETs have higher gate controllability for the channel portion because the gate covers the channel region on three sides [5]. Therefore, short channel effects (SCE) such as drain induced barrier lowering (DIBL) and gate induced drain (GIDL) lowering is possible, and leakage below the threshold voltage can be reduced. For this reason, FinFET is being used for low power CPU/SOC mobile.

However, the VDDs are saturating at around level 1 V due to the non scalable subthreshold slopes of the MOSFETs and the electric field increases with device scaling [6]. Therefore, finding a voltage that affects reliability by hot carrier has been studied as a very important research topic in recent years. In this paper, the substrate current is measured according to channel length and total change to investigate the characteristics of bulk FinFET and analyze and report the operating voltage affecting element reliability.

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## 2. RESEARCH METHOD

### 2.1 Hot-carrier injection mechanism

Figure 1 shows the hot-carrier injection mechanism of

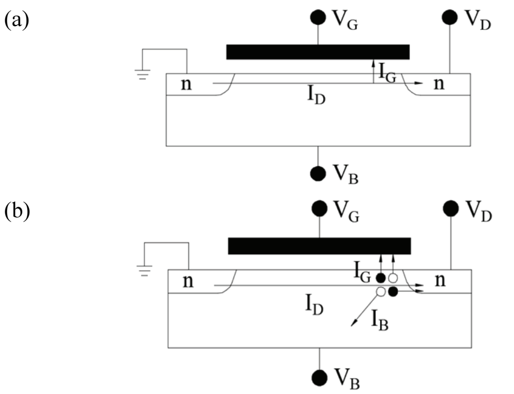


**Fig. 1.** (a) Channel hot electron injection and (b) drain avalanche hot carrier injection.

MOS transistors. Channel hot electron (CHE) is a phenomenon in which lucky electrons with high energy are injected into the oxide film near the drain. It can also be formed at room temperature, causing significant degradation of the oxide and Si-$SiO_2$ interface and a significant gate current flow. Lucky electrons are electrons flowing from the source to the drain, as shown in Fig. 1(a) because they have enough energy to cross the barrier between Si-$SiO_2$ without losing energy by collision in the channel. Ig max due to CHE injection appears when $V_G$=$V_D$. Degradation of the device is caused by carrier trapping and can be confirmed through gate current. Therefore, it can be seen that the most optimal condition for CHE injection due to lucky electrons is $V_G$=$V_D$.

Drain avalanche hot carrier (DAHC) injection is the gate currents of electrons and holes formed by impact ionization and affects not only hot electrons but also hot holes, causing the most severe degradation at room temperature [7]. When Vg is sufficiently smaller than $V_D$, the electric field near the drain becomes large enough to effect of avalanche multiplication by impact ionization. This phenomenon is called DAHC injection and can be expressed as shown in Fig. 1(b) [8].

### 2.2 Experimental conditions

Figure 2 shows the structure of the n-type bulk FinFET used in the experiment. These devices feature a high-k gate dielectric (2.3 nm HfSiON on 1 nm interfacial oxide) and 100 nm of polycrystalline silicon on top of a 5 nm

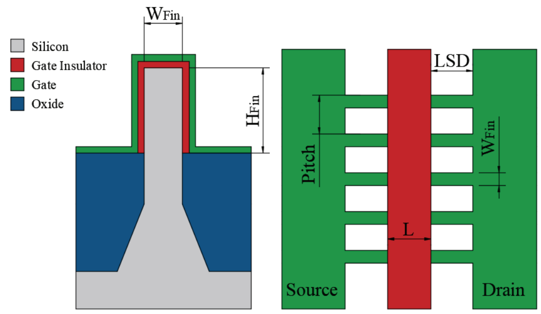


**Fig. 2.** Definition of fin height, fin width, channel length, and pitch in the FinFETs.

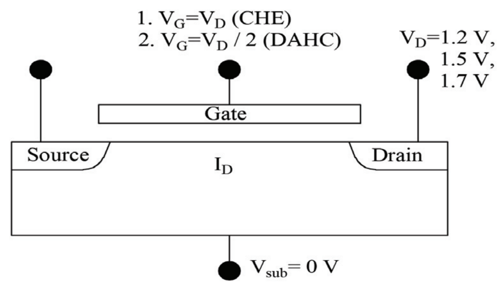


**Fig. 3.** Hot carrier stress condition in n-type bulk FinFETs.

TiN metal gate. The source/drain access region is formed by selective epitaxial growth of Si on the source and drain areas, followed by NiPt silicidation.

Figure 3 shows the bias conditions for measuring transconductance against voltage stress in a Bulk FinFET. The drain voltage was changed to 1.2 V, 1.5 V, and 1.7 V to measure the transconductance according to the stress time.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Substrate current measurement

As mentioned above, DAHC injection is caused by impact ionization. Therefore, substrate current ($I_{SUB}$) is used as a measure for hot carrier generation [9]. Due to the electron-hole pair generated by the impact ionization, the generated electrons move to the drain, generates a drain current, and holes move to the substrate. At this time, the current caused by the hole increases the substrate voltage as it passes through the substrate, causing secondary impact ionization in the drain-substrate depletion region

(a)
(b)

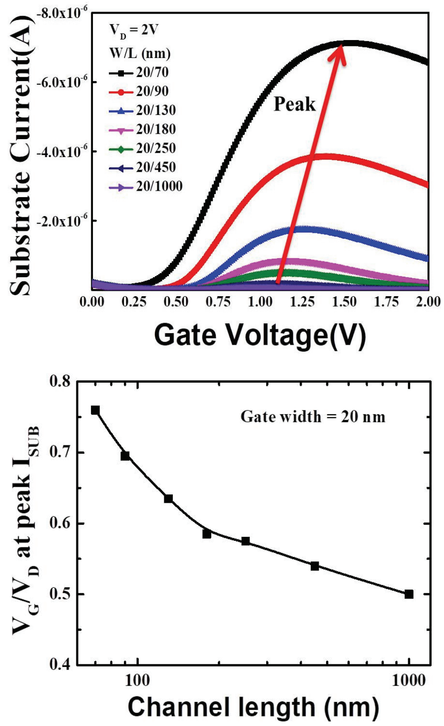


**Fig. 4.** (a) The shift of the $I_{SUB}$ peak when the channel length and (b) voltage position of the $I_{SUB}$ peak as a function.

(a)
(b)

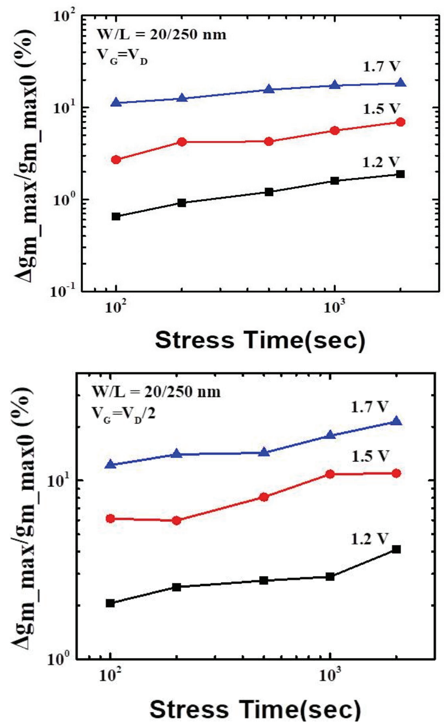


**Fig. 5.** Gm_max degradation with different baises at the stress condition of (a) $V_G=V_D$ and (b) $V_G=V_D/2$.

[10]. Figure 4 shows the dependence of the substrate current on the channel length of the n-bulk FinFETs. At low gate voltages, the substrate current increases with the number of carriers inside the channel. As the gate voltage increases further beyond a certain range, the electric field at the channel and drain interface decreases, resulting in a decrease in substrate current.

Additionally as shown in Fig. 4(b), for long channel transistors, the $I_{SUB}$ peak is obtained around $V_G=V_D/2$, whereas for short channel transistors the $I_{SUB}$ peak is shifted towards $V_G=V_D$ due to the short channel effect [11].

### 3.2 Hot carrier degradation measurement

Figure 5(a) shows the transconductance change under the CHE ($V_G=V_D$) injection condition and Fig. 5(b) shows the transconductance change under the DAHC ($V_G=V_D/2$) injection condition. As shown in the figure, it was confirmed that the bulk FinFET was damaged more in DAHC injection condition. Figure 6 shows the operating voltages available under CHE and DAHC injection conditions by specifying lifetime as the point where gm_max drops by 10%. To maintain

(a)
(b)

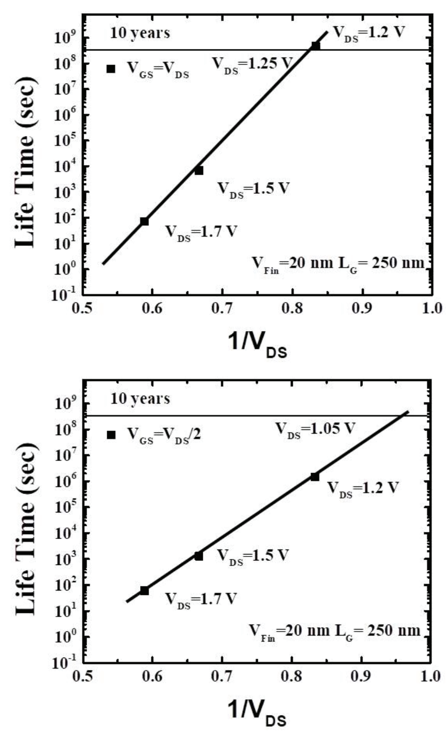


**Fig. 6.** The device lifetime with different stress bias conditions (a) $V_G=V_D$ and (b) $V_G=V_D/2$.

a life time of at least 10 years, around 1.25 V drain voltage can be used under CHE injection conditions, and around 1.05 V drain voltage can be used under DAHC injection conditions. As a result, DAHC injection can cause significant damage to the device even with a small drain voltage.

## 4. CONCLUSION

In this paper, hot carrier deterioration was analyzed in n-bulk FinFET. In the case of DAHC injection, not only hot electrons formed by impact ionization but also hot holes are affected. We also tested how much drain voltage it was able to with stand and extracted the lifetime of the device. Under CHE injection conditions, the drain voltage could maintain a lifetime of more than 10 years at a maximum of 1.25 V. However, DAHC could achieve a lifetime of more than 10 years at a 1.05 V drain voltage, which is 0.2 V lower than that of CHE injection conditions.

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