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Hot-Carrier Reliability of 0.1 μm Delta-Doped MOSFETs

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Hot-carrier reliability of delta-doped MOSFETs is investigated. Delta-doping technology can improve hot-carrier reliability as well as short-channel effects. This is because a delta-doping configuration takes the high electric field region away from the silicon surface. When comparing the devices having the same short-channel effects, delta-doped MOSFETs obviously have longer lifetime than conventioal devices. Evèn in 0.1 μm range, the delta-doped MOSFETs fabricated with selective epitaxy technology are estimated to have enough lifetime for the 1.5 V operation.

1. Introduction

Several technologies for scaling to 0.1 μm gate length were reported in this couple of years [1], [2]. In these studies, source-drain extension has been made shallower and more abrupt to suppress short-channel effects and reduce series resistance. Most of the 0.1 μm N-MOSFETs previously fabricated had As-LDD extension implanted at high dose and low energy. This approach caused the serious hot-carrier degradation by high electric field at the edge of LDD regions. Even with 1.5 V operation, some researchers reported significant degradation for 0.1 μm MOSFETs [3].

Delta-doped MOSFETs, also called Atomic Layer doped MOSFETs, were proposed to suppress short-channel effects without increasing the threshold voltages [4], [5]. This paper will present the advantage of the delta-doped MOSFETs in terms of hot-carrier reliability and discuss the defference of the hot electron injection rate between these devices and conventional MOSFETs by using device simulation.

2. Device Fabrication

We fabricated delta-doped MOSFETs using Post Low-energy Implantation Selective Epitaxy (PLISE) technology [5]. Figure 1 is the schematic cross-section of the delta-doped MOSFET. After forming P-type retrograde by implanting B at 300 KeV, BF_2 for the channel dopant was also implanted at 10 KeV through a 5 nm-thick silicon dioxide film. Undoped silicon was selectively grown on the active regions by ultra-high vacuum chemical vapor deposition (UHV-CVD) [6]. E-beam lithography was used to pattern the gate electrodes. LDD extensions were formed with implanting 5 x 13 cm^{-2} of As ions at 10 KeV and 100 nm side-wall spacers. RTA process at 1050 °C for 10 seconds provided steep channel doping profiles and shallow junctions. The gate thickness and the channel implant dose were 4 nm and 1.5 x 13 cm^{-2}, respectively. Conventional MOSFETs using BF_2 implantation at 120 KeV were also fabricated as references.

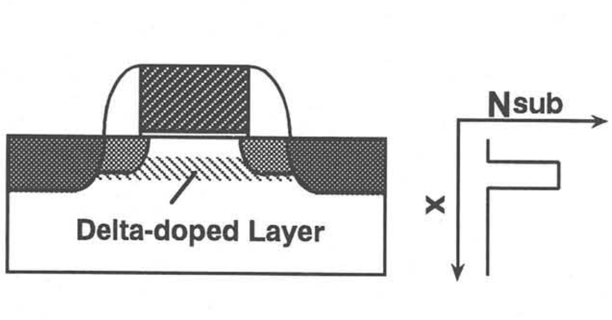

Fig. 1: Schematic cross-section of delta-doped MOSFET.

3. Results and Discussion

The delta-doped MOSFETs with different epi-layer thicknesses and conventional MOSFETs with different channel implant doses were compared in terms of hot-carrier lifetime. The lifetime was defined as the period of time when linear current degradation is 10 %. Figure. 2 shows the lifetime as the function of substrate current (Isub). The gate length (Lg) of these devices was 0.25 μm, and the drain was biased at 3 V, 3.5 V and 4 V during the measurement. The slope is approximately 2.8 for all devices. The relationship between the lifetime and Isub strongly depends on the epi-layer thickness. At the same drain bias, Isub is almost

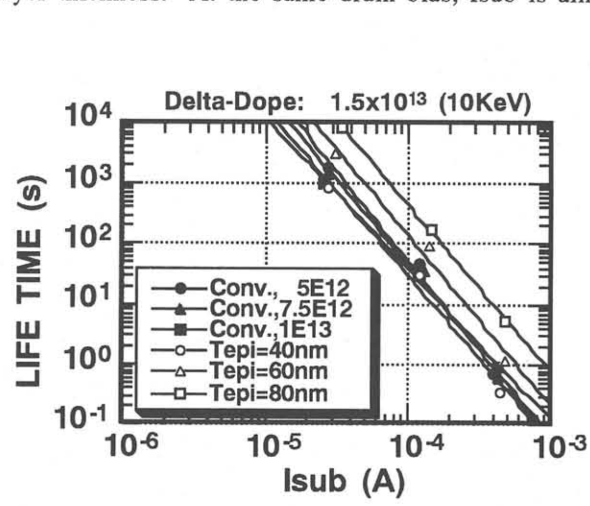

Fig. 2: Lifetime as function of Isub for delta-doped MOSFETs with different Tepi and for conventional MOSFETs at Lg=0.25μm.

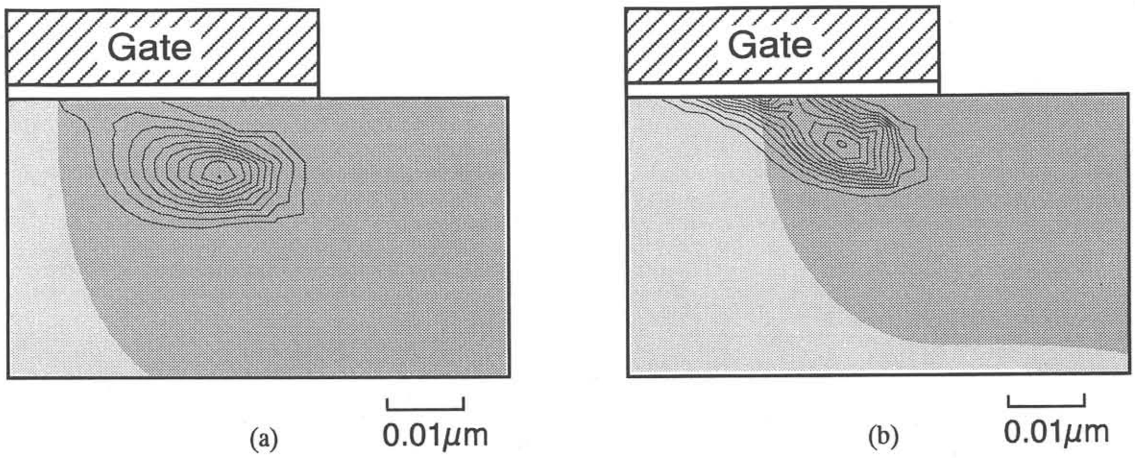

Fig. 3: Contours of generation rate due to impact ionization at drain edge for (a) delta-doped MOSFET with epi-layer 80 nm thick and (b) conventional MOSFET with 7.5×10^{12} cm^{-2} channel doping. Maximum generation rates are (a) 5.0×10^{30} $cm^{-3}s^{-1}$ and (b) 5.6×10^{30} $cm^{-3}s^{-1}$.

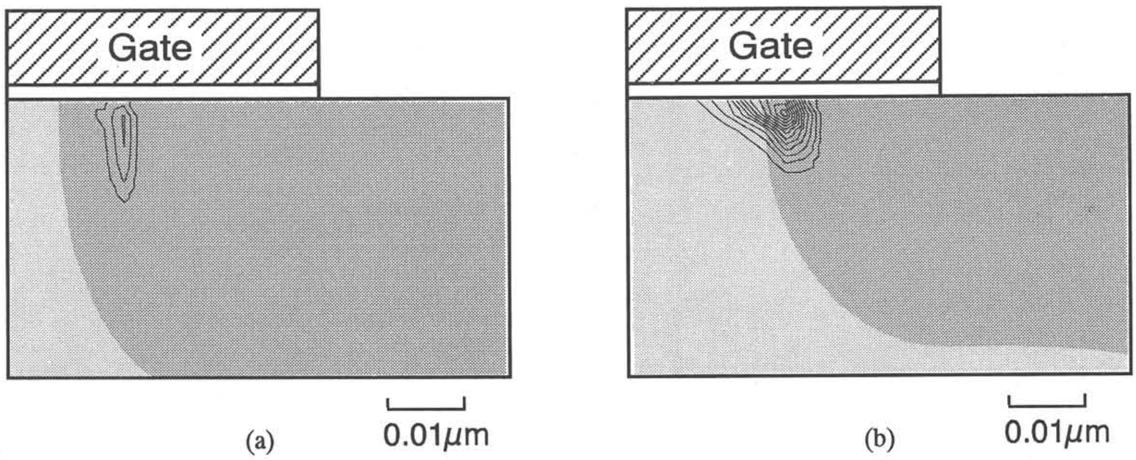

Fig. 4: Contours of hot electron injection current initiated from each point at drain edge for (a) delta-doped MOSFET with epi-layer 80 nm thick and (b) conventional MOSFET with 7.5×10^{12} cm^{-2} channel doping. Maximum injection current densities are (a) 6.0×10^{-7} A/cm^3 and (b) 1.2×10^{-5} A/cm^3.

constant for all samples, but the lifetime was improved with increasing epi-layer thickness. With an epi-layer 80 nm thick, the lifetime was approximately ten times larger than conventional devices at the same substrate current. The electron generation rate and the hot electron injection current initiated from each point are simulated with MEDICI for these devices. Figure 3 shows the hot electron generation rate at the drain edge for (a) delta-doped MOSFET with epi-layer 80 nm thick and (b) conventional MOSFET with 7.5×10^{12} cm^{-2} channel doping. Figure 4 shows hot electron injection current initiated from each point for these devices. The peak values of the impact ionization rate are almost the same in these MOSFETs but electron injection provability for the delta-doped MOSFET is significantly lower than for the conventional MOSFET. This is because the high electric field region in delta-doped MOSFETs is located farther away from the gate insulator as shown in Fig 3. Figure 5 shows the lifetime at Lg=0.25 μm as a function of the minimum gate length (Lmin) defined as the gate length where S factor shift is 10 mV/dec. The lifetimes of delta-doped MOSFETs are three to four times longer than conventional ones at the same Lmin. In addition, the lifetimes for delta-doped MOSFETs are more sensitive to the threshold voltages than conventional ones, as shown in Fig. 6, because epi-layer thickness determines the location of the hot-electron generation. Consequently, the delta-doped MOSFETs have an advantage of hot-carrier reliability in low threshold voltage range. Moreover, Fig. 7 shows that the 0.1 μm delta-doped MOSFET, of which effective channel length is 0.08 μm, has enough reliability at 1.5 V drain bias. The lifetime is shorter at smaller Leff even for a fixed Isub because the degraded channel region is a larger portion of Leff. The current degradation has been modeled as [7]

$$\frac{\Delta I}{Id} = K\left(l/Leff\right)\left(Tstress\left(\frac{Isub^3}{Id^2 \cdot Weff}\right)\right)^n \qquad (1)$$

where K and n are constants, l is the length of damaged portion of the channel, and Tstress is the stress time. According to this model, current degradation is proportional to 1/Leff for devices with identical amounts of hot-electron damage. Figure 8 shows the correlation between Isub3/Id2 and Leff·(ΔId/Id) for the delta-doped MOSFETs. A linear relationship is observed verifying equation (1) even for the 0.1 μm MOSFETs.

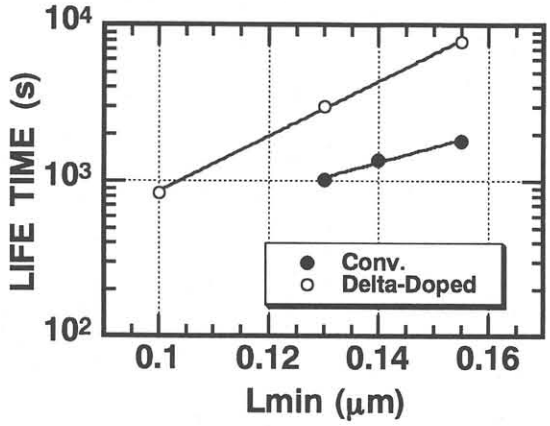

Fig. 5: Lifetime as function of Lmin for delta-doped and conventional MOSFET at Vd=3V and Lg=0.25μm.

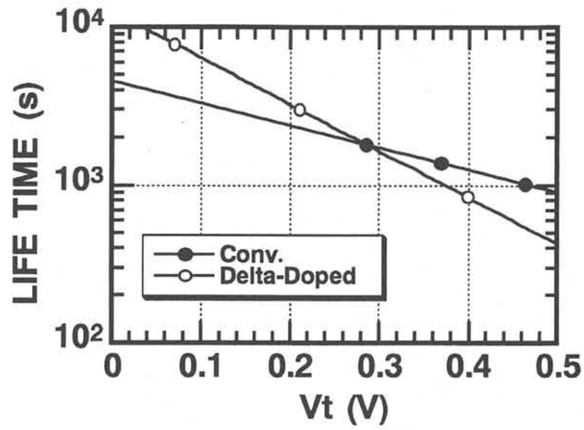

Fig. 6: Lifetime as functiona of Vt for delta-doped and conventional MOSFET at Vd=3V and Lg=0.25μm.

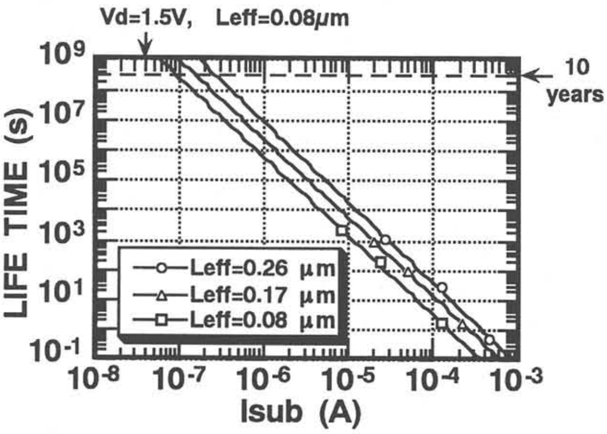

Fig. 7: Lifetime as function of Isub for different channel lengths.

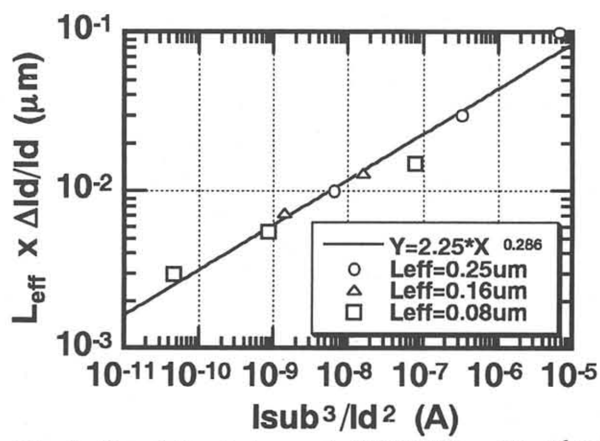

Fig. 8: Correlation between Leff (ΔId/Id) and $Isub^3/Id^2$ for different channel lengths.

4. Conclusion

Hot-carrier reliability of delta-doped MOSFETs and conventional MOSFETs has been investigated. Delta-doped MOSFETs have an advantage of the lifetime when comparing the devices having the same short-channel effects or the same substrate current. The simulation results indicated that a delta-doping configuration can reduce hot electron injection probability by taking the high electric field region away from the silicon surface. Even in 0.1 μm range, the delta-doped MOSFETs fabricated with selective epitaxy technology was estimated to have enough lifetime for the 1.5 V operation.

References

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