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Impact Ionization in Uniaxially Strained-Si MOSFET

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1. Introduction

Strained-Si channel MOSFET [1] is effective to obtain higher current drive due to increased carrier mobility. The strained Si devices will facilitate further increase in circuit performance. Particularly, strained-Si on Insulator MOSFET (strained-SOI) [2] has great potential to realize very high speed and low power device.

In MOSFETs, the impact ionization is important issue from the view of hot-carrier induced degradation of reliability and, in the case of strained SOI, the floating body effect. Besides the strained Si devices, strain in MOSFET tends to become large as the device size shrinks and the structure becomes complex. Therefore, effect of strain on impact ionization must be clarified for developing future devices including strained Si MOSFET.

In this paper, the influence of uniaxial strain on impact ionization is investigated by applying external mechanical strain to conventional SOI MOSFET. It is found that impact ionization is reduced by applying uniaxial strain on MOSFET. On the other hand, the drain breakdown voltage is found to be reduced with increasing strain. While physics involved is not clear at the present, the aim of this report is to present experimental data for further understanding of the device operation under the presence of strain.

2. Experimental

Figure 1 shows an optical micrograph of SOI MOSFET array fabricated on Separation by IMplanted OXygen (SIMOX) wafer. The SOI layer is 200 nm in thickness, which is thick enough to operate at the partially-depleted (PD) mode. Each MOSFET has 4 electrodes (source, drain, gate and body). The gate length and gate width were 2 μm and 10 μm, respectively. The thickness of gate oxide was 30 nm. The channel directions of MOSFETs were aligned with either [110] or [$\bar{1}$10] direction on (001) substrates to investigate effects of strain direction.

Figure 2 shows the cantilever prepared for measurement. The uniaxial strain was applied by mechanically inducing bending deformation to a MOSFET chip which was cut to a size of $13 \times 3 \times 0.5$ [mm^3]. Dependence on strain of transconductance g_m, body current and drain breakdown voltage was measured.

3. Results and Discussion

In order to investigate effect of uniaxial strain on carrier mobility, we measured the strain dependence of g_m. Figure 3 shows the strain dependence of $\Delta g_m/g_{m0}$ when the body terminal is open. g_{m0} is defined as the value without the external strain. We can observe that $\Delta g_m/g_{m0}$ is proportional to the tensile strain. The apparent strain coefficients of $\Delta g_m/g_{m0}$ are evaluated to be 3.8%/0.1%-strain for longitudinal direction ($J//\varepsilon$) and 1.8%/0.1%-strain for transverse direction ($J \perp \varepsilon$) in n-channel MOSFET and 4.0%/0.1%-strain for longitudinal direction ($J//\varepsilon$) and −3.5%/0.1%-strain for transverse direction ($J \perp \varepsilon$) in p-channel MOSFET. The threshold voltage of MOSFET stayed constant under the application of strain. The observed g_m changes can be qualitatively correlated with piezoresistance coefficients [3] of Si aligned in the [110] direction on (001) shown in Table 1. This results indicate that the g_m change is due to piezoresistive effect [3].

Next, the strain dependence of body current was measured to investigate effects on impact ionization. Figures 4(a) and 4(b) show the strain dependence of body current. The body current was measured under the body terminal grounded. We can find that body current decreases with tensile strain for both n-channel and p-channel MOSFET. This indicates that impact ionization is reduced by applying uniaxial strain on MOSFET. These results do not correspond to the g_m change shown in Fig. 3 where g_m increases in n-channel and decreases in p-channel under the same direction of strain.

We also investigated how the uniaxial strain affected the drain breakdown voltage of SOI MOSFET. Figure 5 shows the strain dependence of drain breakdown voltage observed for n-channel SOI MOSFET when the body terminal is open. Drain breakdown voltage is defined as the voltage at which the second kink appeared (V_{GS}=2 [V] and I_D=0.5 [mA]). The breakdown voltage was 7 [V] when no strain applied. From Fig. 5, we can find that drain breakdown voltage decreases with tensile strain, nevertheless the fact that impact ionization is reduced by applying uniaxial strain (Fig. 4(a)). The results suggest that potential barrier for the injection of holes from the body to the source increases with increasing uniaxial strain. It is noteworthy that, when the strain was applied in the direction perpendicular to the current flow, reduction of breakdown voltage was also observed while the change was smaller than the result shown in Fig. 5. In case of p-channel SOI MOSFET, investigation of the floating body effect was hard because of significant hot carrier effect. Further investigation is in progress to clarify the floating body effect under the presence of strain.

4. Conclusion

The influence of uniaxial strain on impact ionization and floating-body effect of SOI MOSFET has been investigated by applying external mechanical strain. We found that impact ionization is reduced by applying uniaxial strain on MOSFET. Nevertheless the reduction of drain breakdown voltage was found for n-channel SOI MOSFET.

Acknowledgment

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References

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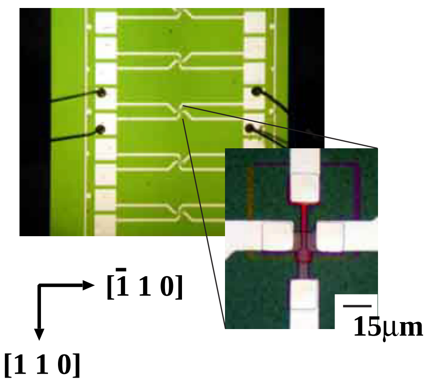

Fig. 1: An optical micrograph of partially-depleted (PD) SOI MOSFET array fabricated. (L/W = 2μm/10μm, t_{ox} = 30nm) Each MOSFET has 4 electrodes. The channel directions of MOSFETs were aligned either [110] or [$\bar{1}$10] direction on (001) substrates.

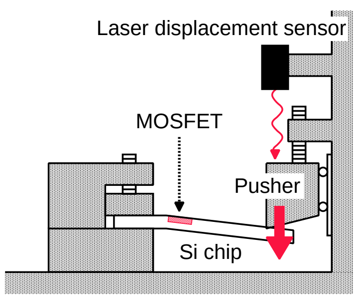

Fig. 2: The cantilever prepared for measurement. The uniaxial strain was induced by applying bending deformation to a MOSFET chip which was cut to a size of 13 × 3 × 0.5 [mm^3].

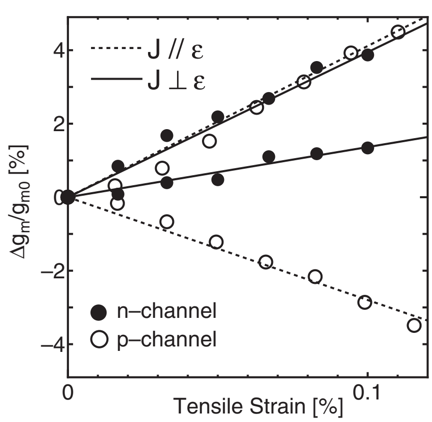

Fig. 3: The strain dependence of transconductance change $\Delta g_m/g_{m0}$ when the body terminal is open. g_{m0} is defined as the value without the external strain.

Table 1: Piezoresistance coefficients of Si aligned in the [110] direction on (001). These coefficients are calculated from three tensors (π_{11}, π_{12} and π_{44}) determined by Smith [3].

[$\times 10^{-11} Pa^{-1}$]

Direction	p-type	n-type
Longitudinal: [110]	+71.8	−31.2
Transverse: [$\bar{1}$10]	−66.3	−17.6

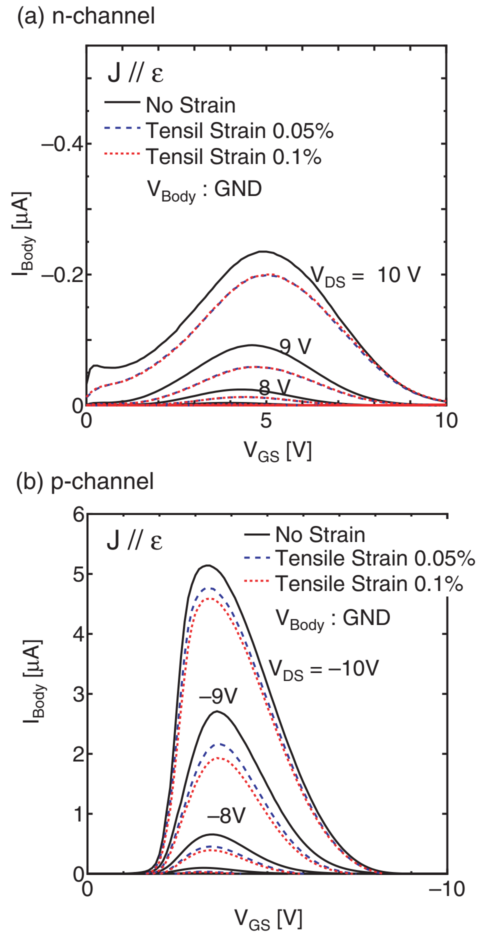

Fig. 4: The strain dependence of body current when the body terminate grounded. (a) n-channel and (b) p-channel.

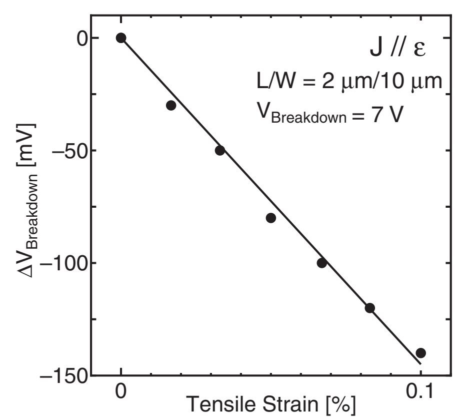

Fig. 5: The strain dependence of drain breakdown voltage observed for n-channel SOI MOSFET when the body terminal is open. Drain breakdown voltage is defined as the voltage at which the second kink appeared (V_{GS}=2 [V] and I_D=0.5 [mA]). The breakdown voltage was 7 [V] when no strain applied.