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Clarification of Floating-Body Effects on Current Drivability in Deep Sub-Quarter Micron Partially-Depleted SOI MOSFET's

T. Matsumoto, S. Maeda, Y. Hirano, K. Eikyu, Y. Yamaguchi, S. Maegawa, M. Inuishi and T. Nishimura
ULSI Development Center, Mitsubishi Electric Corporation
4-1 Mizuhara, Itami, Hyogo 664-8641, Japan
Phone: +81-727-84-7324, Fax: +81-727-80-2693, e-mail: tmatsumo@lsi.melco.co.jp

1. Introduction

Partially-depleted (PD) SOI MOSFET's have an advantage of better threshold voltage control than fully-depleted (FD) SOI MOSFET's. However, PD SOI MOSFET's have serious floating-body problems that the device characteristics are significantly influenced by the parasitic bipolar action which is caused by holes generated due to impact ionization. In particular, the reduction of the drain breakdown voltage in the higher drain voltage region becomes a crucial problem. Regarding the circuit performance, it was reported that the circuit speed was limited by the higher linear threshold voltage in order to suppress the floating-body effect [1]. On the other hand, it was also reported that a proper optimization solved the problem and gave the PD SOI MOSFET's around 20% superior performances to the bulk MOSFET's[2]. However, in terms of the current drivability itself, PD SOI and bulk MOSFET's have never been compared in detail.

In this paper, we point out for the first time that the higher channel concentration for suppressing the Vth lowering limits the saturation drive current of PD SOI MOSFET's. We analyze detailed mechanism of the limited drive current in PD SOI MOSFET's. Then, we propose shallow source-drain junction (SSD) structure which improves the drive current of PD SOI MOSFET's.

2. Experiments

SOI MOSFET's were fabricated on SIMOX wafers according to 0.18 μm technologies using shallow trench isolation. The gate oxide, SOI and buried oxide thicknesses are 3.5nm, 100nm and 370nm, respectively. The source-drain extension and the cobalt salicide structure was used to reduce the parasitic resistance.

The floating and body-fix PD SOI n-MOSFET's were measured without and with body terminal, respectively.

3. Results and Discussion

The threshold voltage dependence of the drain current for floating and body-fix PD SOI MOSFET's is plotted in Fig.1 where the channel impurity doping is changed from 6×10^{12} cm^{-2} to 2×10^{13}cm^{-2}. As is obvious in this figure, the drive current of the floating PD SOI MOSFET is 15% lower than that of the body-fix one at Vth=0.2V. This can be understood by the difference of the drain saturation voltage (Vdsat) between the floating and body-fix PD SOI MOSFET as follows. Figure 2 shows the results of the variations of Vdsat for a given (Vg-Vth) value in the floating and body-fix PD SOI MOSFET with the same gate length and saturation threshold voltage. It is clear that Vdsat for the floating SOI MOSFET becomes smaller. This reduction of Vdsat for the floating SOI MOSFET is attributed to larger body effect. Under the same threshold voltage, while the depletion charges near the source region become the same between both the SOI MOSFET's, the depletion charges of the floating PD SOI MOSFET become larger than those of the body-fix one near the drain region because of higher channel impurity doping. Therefore, the larger depletion charges near the drain region cause the smaller Vdsat, which limits the saturation current in floating PD SOI MOSFET's. This can be also interpreted as follows. Figure 3 compares the lateral electric field for the floating and body-fix PD SOI MOSFET. It is clear that the lateral electric field near the drain region in the floating PD SOI MOSFET is higher because of small Vdsat. On the other hand, the lateral electric field near the source region in the floating PD SOI MOSFET decreases compared with body-fix one. The mobility near the source region in the floating and body-fix PD SOI MOSFET is almost the same as shown in Fig.4, because the longitudinal electric field is approximately the same under the same threshold voltage condition although the impurity scattering increases because of higher channel impurity doping. Therefore, the lower lateral electric field near the source region for the floating PD SOI MOSFET causes the lower drive current.

From these results, we found that the problem of low current drivability can be solved by suppressing the parasitic bipolar action because it becomes the cause which the threshold voltage is reduced and then the channel impurity concentration must be set higher. As the structure suppressing the parasitic bipolar action, we propose the floating PD SOI MOSFET with shallow source-drain junction (SSD). The cross sectional view of SSD SOI MOSFET is illustrated in Fig.5 (b). The depth of the source and drain junction for SSD structure was optimized by taking account of the junction capacitance and the junction leakage current. Figure 6 shows the parasitic bipolar gain in the conventional and SSD SOI MOSFET's. As is obvious in this figure, the SSD SOI MOSFET has around 2 decade lower bipolar gain than the conventional one. We have verified that this is due to the reduction of emitter efficiency. As a result, for the SSD SOI MOSFET, the reduction of the threshold voltage due to the floating body effect can be suppressed as shown in Fig.7. As a model of the lower bipolar gain, we have considered that the micro-defects related to cobalt silicide would act as the life time killer when the source-drain junction is shallow. The threshold voltage dependence of the drain current for the conventional floating PD SOI MOSFET, the conventional body-fix one and the SSD floating one is plotted in Fig.8. It is obvious that the drive current of the floating PD SOI MOSFET can be improved by using SSD structure. Thus, the floating PD SOI MOSFET with SSD structure is very useful as a high drive current device.

4. Conclusions

The drive current on floating and body-fix PD SOI MOSFET's was evaluated in detail. It was clarified for the first time that the limitation of the drive current for floating PD SOI MOSFET's is due to larger body effect because of higher channel impurity doping. In addition, the floating PD SOI MOSFET with shallow source-drain junction structure was proposed in order to improve the drive current.

References

[1] R. Chau et al., IEDM Tech. Dig., p591 (1997)
[2]E. Leobandung et al., IEDM Tech. Dig., p403 (1998)

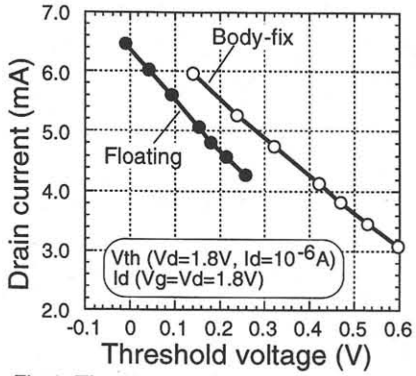


Fig.1 Threshold voltage dependence of drain current. (Lg=0.18 μm, W=10 μm)

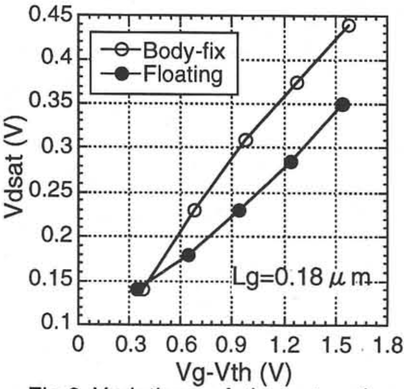


Fig.2 Variations of the saturation voltage versus (Vg-Vth). Vdsat was extracted from the measured Id-Vd characteristics.

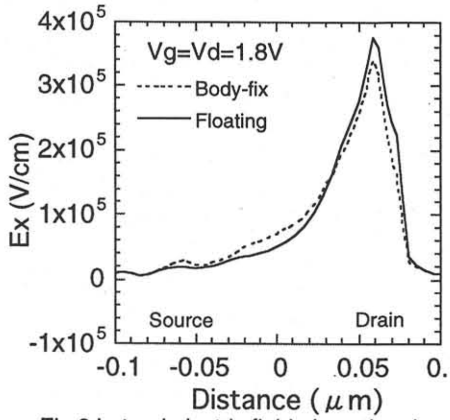
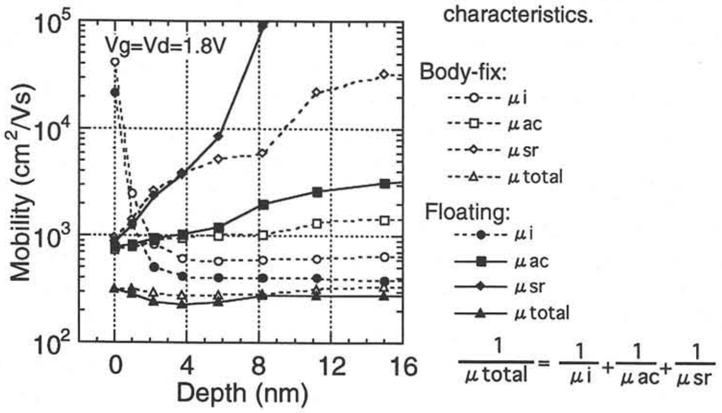


Fig.3 Lateral electric field along the channel. (simulation)



$$\frac{1}{\mu\text{total}} = \frac{1}{\mu i} + \frac{1}{\mu ac} + \frac{1}{\mu sr}$$

Fig.4 Electron mobility near the source region.(μi, μac and μsr stand for the mobility component of impurity scattering, acoustic phonon scattering and surface scattering, respectively.) (simulation)

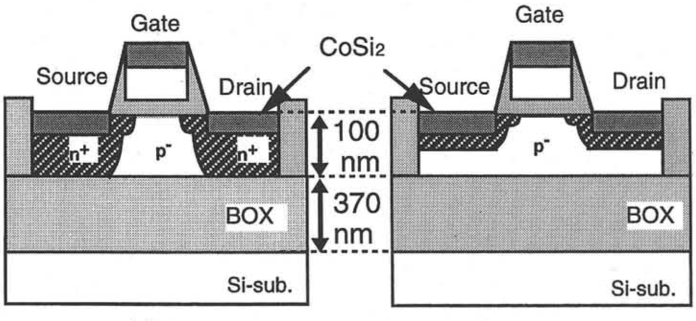


Fig 5. The cross section of conventional PD SOI MOSFET(a) and shallow source-drain junction (SSD) PD SOI MOSFET (b).

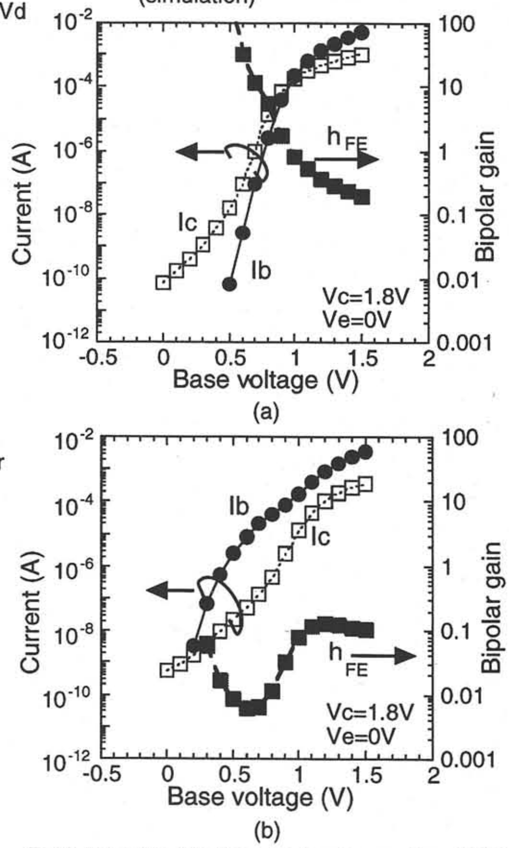


Fig.6 Parasitic bipolar gain for conventional PD SOI MOSFET (a) and SSD PD SOI MOSFET (b). (Vg=0V)

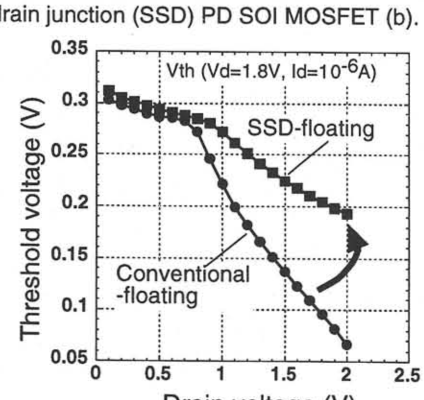


Fig.7 Drain voltage dependence of threshold voltage.

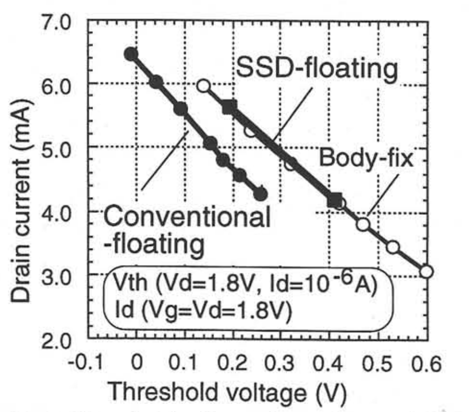


Fig.8 Threshold voltage dependence of drain current.