Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 140–141

A-3-3

Reduction of Gate-Induced Drain Leakage (GIDL) Current in Single-Gate Ultra-Thin Body and Double-Gate FinFET Devices

Yang-Kyu Choi, Daewon Ha, Tsu-Jae King, and Jeffrey Bokor
Department of Electrical Engineering and Computer Sciences
University of California, Berkeley, CA 94720, USA

Abstract

Gate-induced drain leakage (GIDL) current is investigated in single-gate (SG) ultra-thin-body FET and double-gate (DG) FinFET devices. The GIDL current is significantly lower in the thin-body devices as compared with bulk MOSFETs, and it decreases with decreasing body thickness, because of reductions in the vertical electric field at the surface of the drain. Measured reductions in GIDL current for SG and DG thin body devices are reported for the first time.

Introduction

Thin-body SOI transistor structures such as the single-gate (SG) ultra-thin-body (UTB) FET [1] and the double-gate (DG) FinFET [2] are attractive for scaling CMOS into the nanoscale regime. These advanced transistors rely on a thin silicon channel to control short-channel effects by eliminating any leakage paths far from the gate electrode. A thinner body allows for more aggressive scaling, so that such structures may be easier to scale to sub-30nm gate lengths as compared to the standard bulk MOSFET structure.

Minimization of transistor off-state leakage current is an important issue for low-power applications. A large component of off-state leakage current is gate-induced drain leakage (GIDL) current, caused by band-to-band tunneling [3]. GIDL is a crucial constraint for scaling down the effective gate-oxide thickness in MOSFETs. Although GIDL current becomes less significant as the power-supply voltage is reduced below 1 Volt (which corresponds to the energy band gap potential) for logic applications, it is still an important consideration for applications such as DRAM for which data retention time is significantly degraded by GIDL current. This problem will be even worse in a negative word-line scheme [4]. In this work, GIDL currents for the SG-UTBFET and symmetrical DG-FinFET are investigated and compared against that of standard bulk MOSFETs. It is shown that thin-body transistor structures can provide significant reductions in GIDL current.

GIDL Current and Discussion

Band-to-band tunneling can be estimated using the WKB approximation and assumption of direct band-gap [5], so that GIDL current density can be analytically modeled for the bulk MOSFET [3][6][7] by the equation

$$J = A \cdot E_s \cdot \exp(-B / E_s) \qquad (1)$$

where A and B (typically 23~70 MV/cm [6][7]) are physical constants and the vertical electric field E_s at the surface is given by

$$E_s \approx (V_{dg} - 1.2) / 3T_{ox} \,. \qquad (2)$$

The equation (2) for E_s is not applicable to thin-body SOI devices. Fig. 1 and Fig. 2(a) show that the vertical electric field is lower for thin-body MOSFETs compared to the bulk MOSFET. This reduction is greater for the DG structure than for the SG structure, and the impact of reduced vertical field becomes more dominant as the body thickness decreases [8].

There is no analytical equation available to describe the electric field strength dependence on the body thickness, so we investigated the electric field distribution with a 2-D device simulator (MEDICI) for the bulk-, SG-, and DG-MOSFETs, for various body thicknesses. Fig. 2 shows that the electric field at the surface is significantly lower in the thin-body devices (SG and DG) than in the bulk-MOSFET. To first-order approximation, the on-state performance of a SG-MOSFET is comparable to a DG-MOSFET of twice the body thickness. Fig. 3 shows how the electric field decreases with body thickness. From Figs. 2 and 3 it is clear that the electric field in a DG-MOSFET with body thickness $2T_{Si}$ is lower than that of a SG-MOSFET with body thickness T_{Si}.

Figs. 4 and 5 are measured *I-V* characteristics of SG UTB FETs, showing that GIDL current is reduced as the body thickness is decreased, for both n-channel and p-channel devices. Measured *I-V* characteristics of symmetrically doped DG FinFETs are shown in Fig. 6, indicating no GIDL current when $|-V_g| < 2V$. Thus, another significant benefit of the symmetrical DG MOSFET structure is the essential elimination of GIDL.

Conclusion

GIDL current is significantly lower for thin-body SOI MOSFETs as compared to bulk MOSFETs, and it decreases with body thickness due to the impact of reduced vertical electric field in the surface of the drain.

Acknowledgement

This research is supported under MARCO contract 2001-MT-887 and SRC contract 2000-NJ-850.

References

[1] Y.-K. Choi *et al.*, *IEEE Electron Device Lett.*, p. 447, 2001.
[2] Y.-K. Choi *et al.*, *IEDM*, p. 421, 2001.
[3] J. Chen *et al.*, *IEEE Electron Device Lett*, p. 515, 1987.
[4] H. Tanaka *et al.*, *VLSI Symp. Circuits Dig.*, p. 94, 1998.
[5] E. Kane, *Journal of Applied Physics*, p. 83, 1961.
[6] S. Parke *et al.*, *IEEE Trans. Electron Devices*, p. 1694, 1992.
[7] J.G. Fossum, *IEEE Trans. Electron Devices*, p. 2195, 1999.
[8] L. Chang *et al.*, *IEDM*, p. 99, 2001.

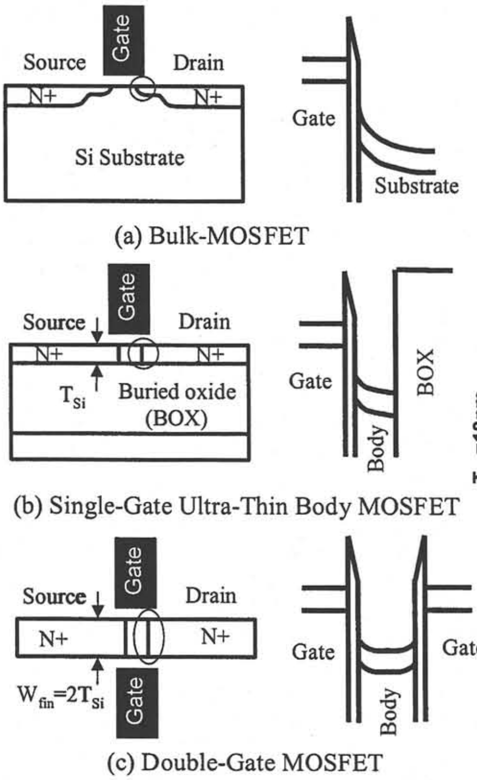

Fig. 1 Structure and GIDL energy-band diagrams for bulk-MOSFET, SG-UTBFET, and DG-FinFET.

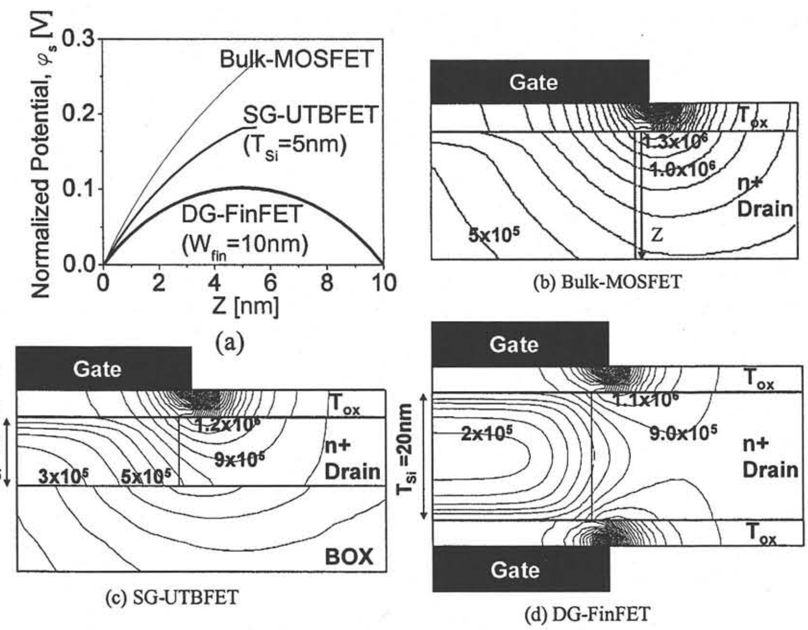

Fig. 2 Potential profile (a) and 2-D electric field profile (b)-(d) for bulk-MOSFET, SG-UTBFET, and DG-FinFET (V_g=-1V, V_d=1V, T_{ox}=2.0nm, N+=$1.0x10^{18}cm^{-3}$).

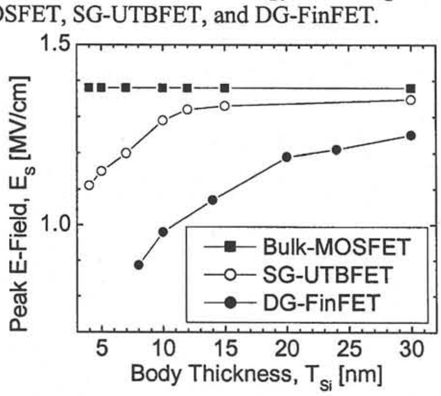

Fig. 3 Drain surface electric field in the bulk-MOSFET, the SG-UTBFET, the DG-FinFET (T_{ox}=2nm, V_{dg}=2V).

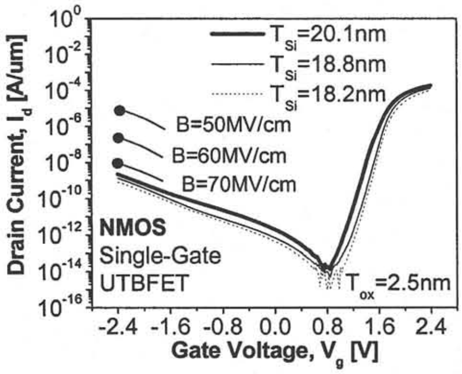

Fig. 4 Measured I_d-V_g characteristics of SG-UTB NMOSFET. A thinner body gives lower GIDL current. For reference, the GIDL current is plotted using Eq. (1) and Eq. (2) with empirical parameter B for bulk-MOSFETs (V_d=1V).

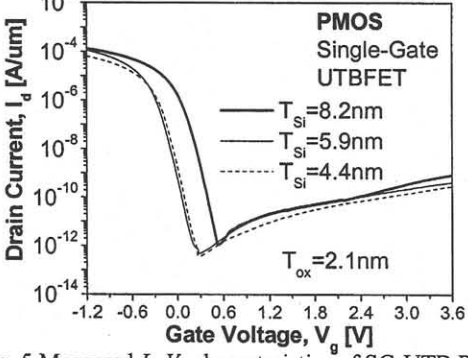

Fig. 5 Measured I_d-V_g characteristics of SG-UTB PMOSFET. A thinner body gives lower GIDL current (V_d=-1V).

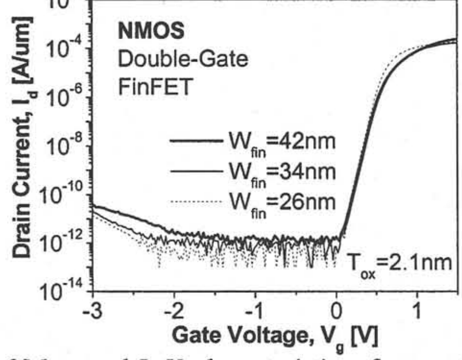

Fig. 6 Measured I_d-V_g characteristics of symmetrical DG-FinFET. A thinner body gives lower GIDL current (V_d=1V).