# The Channel Material Study of Double Gate Ultra-thin Body MOSFET for On-current Improvement

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## ABSTRACT

In this paper, quantum mechanical simulations of the double-gate ultra-thin body (DG-UTB) MOSFETs are performed according to the International Technology Roadmap of Semiconductors (ITRS) specifications planned for 2020, to devise the way for on-current ($I_{on}$) improvement. We have employed non-equilibrium Green’s function (NEGF) approach and solved the self-consistent equations based on the parabolic effective mass theory [1]. Our study shows that the [100]/<001> Ge and GaSb channel devices have higher $I_{on}$ than Si channel devices under the body thickness ($T_{bd}$) $<$5nm condition.

## INTRODUCTION

Among emerging devices, DG-UTB MOSFETs are considered as one of the most promising candidate over next decades. The device performance strongly related to $I_{on}$ has become important issue. While best channel material for MOSFETs is Si at present, it does not guarantee the best performance for downscaled devices. Thus it is needed to consider other materials.

## METHOD & DEVICE DESCRIPTION

The DG-UTB MOSFETs simulated in this work are shown in Fig. 1. The Γ-, Δ-, and Λ-effective valleys of Si, Ge and III-V materials (InAs, GaAs, InSb, GaSb) as channel materials were taken into account. For each material, the calculated crystal transport/confinement directions are [100]/<001>, [110]/<001>, [111]/<0$\bar{1}$1> and the $T_{bd}$ varied from 3 to 10 nm. The other parameters followed the prescriptions from the ITRS planned for the year 2020 (channel length, $L_{ch}$=10nm, body thickness, $T_{bd}$=5nm, oxide thickness, $T_{ox}$=0.6nm, drain voltage, $V_D$=0.7V, threshold voltage, $V_{th}$ = 242mV, on-current, $I_{on}$=1942μA/μm, and off-current, $I_{Off}$= 0.1μA/μm).

## RESULT & DISCUSSION

At first, the $I_D$ for $T_{bd}$=5nm was calculated using conventional [100]/<001> crystal orientation. The Fig. 2. shows the result of the simulation. From the result, it is found that Si and GaAs satisfy the $I_{off}$ criterion. The Table 1. represents the $V_{th}$ and $I_D$ comparison of these materials with ITRS value. Their $I_{on}$ exceeded the ITRS requirement.

To investigate directional dependence of $I_D$, the portion of each valley is considered. The calculated valley contribution is illustrated on the Fig. 3. (b). Inspecting valley contribution, it is found that each three-effective-valley material shows distinct valley contribution and has one dominant valley (portion$>$75%). We now call the dominant valley as a group such as Λ-group. The Fig. 3. (a). shows arrangement of the materials by effective valley and represents dominant valley in the parenthesis. Focusing on symmetry of valleys, it can be shown that Γ-valley is isotropic, Δ-valley is axial directional, and Λ-valley is <111> directional in the perspective of $I_D$.

The $I_D$-$V_G$ characteristics are drawn on the (a)-(f) of Fig. 4., for the case of fixed 5nm-$T_{bd}$. As expected, the Γ(-dominant)-group shows virtually no dependence on orientation while Δ- and Λ-group show little change (smaller than 5%) with different orientation. From this result, changing transport orientation turned out to be ineffective way to improve the $I_{on}$ in the case of 5nm-$T_{bd}$.

The Fig. 5. illustrates the calculated $I_{on}$ for various material, $T_{bd}$, and crystal orientation. Some points including $T_{bd}$=10nm are absence because they do not satisfy the $I_{off}$ requirement. The result can be analysed in two perspectives. In the $I_{off}$ perspective, Λ-group materials are not adjustable for 2020 ITRS specifications under $T_{bd} \geq 10$nm. In the $I_{on}$ perspective, Ge and GaSb can replace Si under $T_{bd}<5$nm, which is smaller $T_{bd}$ than the

ITRS specification for 2020. It is also found that $I_{on}$ of GaAs is inferior to Si under sub-10nm $T_{bd}$. For further works, it is possible to show the $I_{on}$ improvement of IV materials by applying strain effects [2].

## Conclusion

We have calculated $I_{on}$ for DG UTB MOSFETs with various channel materials. The result shows that [100]/<001> Si is the best material in current technology ($T_{bd}$>5nm), but [100]/<001> Ge or [100]/<001> GaSb would show better performance than Si if device is downscaled to very thin body thickness ($T_{bd}$<5nm).

## References


[1] Anisur Rahman *et al.*, Journal of Applied Physics. **97**, 053702 (2005).

[2] Kah-Wee Ang *et al.*, Electron Devices, IEEE Transactions on. **55**, 850 - 857 (2008).


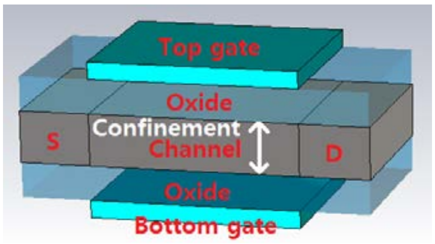


Fig. 1. The double-gate ultra-thin body MOSFET

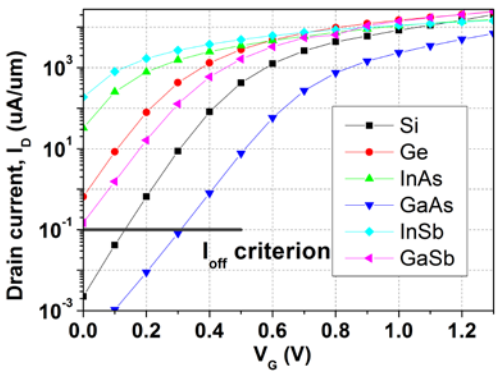


Fig. 2. $I_D$ vs $V_G$ ($T_{bd}$=5nm, [100]/<001> crystal orientation)

**Table I. Comparison of $V_{th}$ and $I_{on}$ among [100]/<001> Si, [100]/<001> GaAs, and ITRS value at $T_{bd}$=5nm**

| | Ion (μA/μm) | Vth (V) |
|---|---|---|
| Si | 4837 | 0.133 |
| GaAs | 2396 | 0.307 |
| ITRS value | 1942 | 0.242 |

**(a)**

| Effective Valley | Materials |
|---|---|
| Δ | Si |
| Γ | InAs, InSb |
| Γ, Δ, Λ | Ge(Λ), GaAs(Γ), GaSb(Λ), |

**(b)**

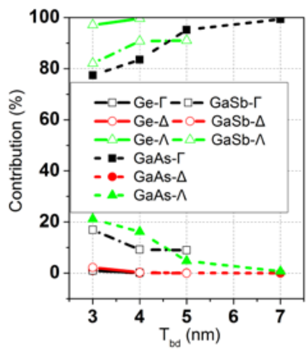


Fig. 3. (a) Effective valley and materials in each group. Dominant valleys are in the parenthesis. (b) Valley contribution vs $T_{bd}$ of three-valley materials

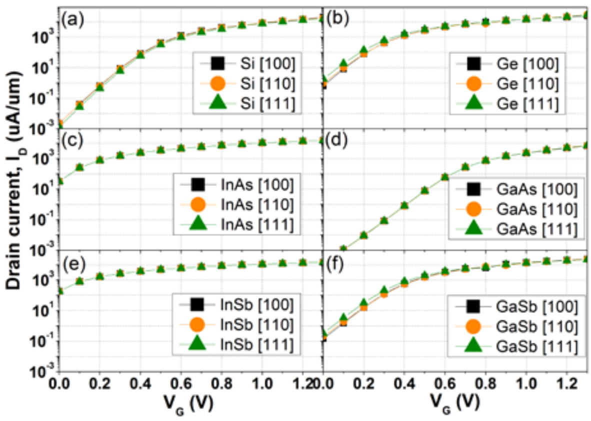


Fig. 4. $I_D$ variation with different crystal directions ($T_{bd}$=5nm)

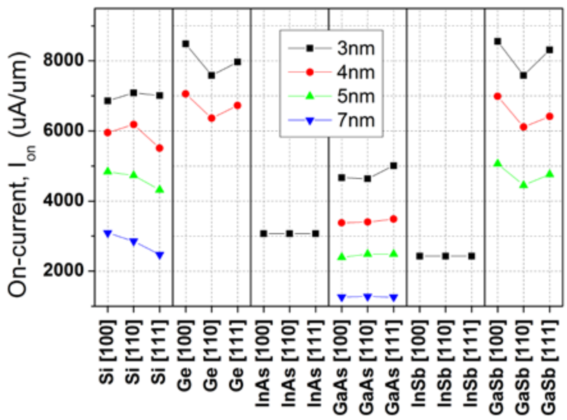


Fig. 5. Calculated $I_{on}$ vs $T_{bd}$, material, and direction