Drive Current Performance of Inversion Mode Ge CMOS Transistors
Xiao Gong* and Yee-Chia Yeo.
Department of Electrical and Computer Engineering, National University of Singapore (NUS), Singapore 117576.
*Phone: +65-6516-1589, Fax: +65-6779-1103, Email: elegong@nus.edu.sg

I. Introduction

Germanium (Ge) is a promising alternative channel material for future complementary metal-oxide-semiconductor (CMOS) technology due to its high electron and hole mobilities. In the past decade, significant effort has been made in the research community to bring this material as a possible high-mobility replacement for silicon which has been the dominant channel material in CMOS technology for almost 50 years [1]-[25]. To exploit the full potential of the high mobility property of Ge, one of the key issues is the formation of thermodynamically stable Ge/gate dielectrics interface with low interface trap density ($D_{it}$), small equivalent oxide thickness (EOT), and low gate leakage current.

In this paper, drive current performance benchmarking for inversion mode Ge CMOS is performed. This is done with a specific focus on a recently reported passivation technique using an ultra-thin InAlP layer for both n-channel field-effect transistors (nFETs) and p-channel FETs (pFETs). We will also discuss the recent progress in the gate stack formation on Ge using various surface passivation techniques, and the benchmarking of electrical characteristics for Ge nFETs and pFETs.

II. InAlP as a Common Passivation Technique for Ge nFETs and pFETs

Fig. 1 shows a recently reported concept of forming a high-quality, epitaxial, single crystalline, and potentially defect-free interfacial layer on the Ge channel and beneath the gate dielectric. An excellent material candidate is In$_{0.52}$Al$_{0.48}$P, which is lattice-matched to Ge and has a relatively large bandgap of 2.36 eV. InAlP can be epitaxially grown on Ge by MOCVD prior to high-$k$ dielectric deposition. Using X-ray Photoelectron Spectroscopy, it was found that InAlP has a conduction band offset ($\Delta E_C$) and valence band offset ($\Delta E_V$) of 0.84 and 0.86 eV, respectively, with respect to Ge [Fig. 2 (a)] [2]. These band offsets between InAlP and Ge are large enough to confine the electrons in Ge channel in nFETs and holes in the Ge channel in pFETs, as illustrated in the energy band diagrams of pFETs and nFETs at strong inversion regime in Fig. 2 (b). The InAlP layer separates the carriers from the interface traps at the high-$k$/InAlP interface, leading to reduced carrier scattering and enhanced carrier mobility.

III. Benchmarking of Germanium nFETs

Fig. 3 (a) and (b) plot the $I_{off}$-$V_{GS}$ curves at $V_{DS}$ of 0.05 and 1 V, respectively, of InAlP-capped Ge (100) nFETs and other planar Ge (100) nFETs by various passivation techniques reported in literature. For both high and low $V_{DS}$, the InAlP-capped Ge nFETs exhibit subthreshold swing $S$ of less than 110 mV/decade and On-state current to Off-state current
Effective Electron Mobility \( \mu_{\text{eff}} \ (\text{cm}^2/\text{V}\cdot\text{s}) \)

Peak Mobility

- Fig. 4. Record high drive current of 12 \( \mu \text{A}/\mu\text{m} \) was achieved for enhancement mode Ge nFETs at \( V_{GS}-V_{TH} \) of 1 V and \( V_{DS} \) of 1 V though the \( L_G \) is not the shortest.

- Fig. 5. \( S \) values as a function of EOT for long channel planar Ge nFETs with different surface passivation techniques. InAlP passivation leads to the realization of Ge nFETs with \( S \) comparable to the best reported values.

- Fig. 7. Benchmarking of \( I_{ON} \) at \( V_{GS}-V_{TH} = 1 \) V and \( V_{DS} = 1 \) V of the Ge nFETs with the InAlP cap with other \( I_{ON} \) extracted at the similar bias conditions from the literature. Very high \( I_{ON} \) was achieved for the InAlP-capped Ge pFETs.

IV. Benchmarking of Germanium pFETs

From cost-effective point of view, a common passivation technique is preferred for both Ge nFETs and pFETs. As discussed in Section II, in addition to a large \( \Delta E_C \) of 0.84 eV between InAlP and Ge, there is also a \( \Delta E_V \) of 0.86 eV between the two. This indicates that InAlP can also be a good passivation layer for Ge pFETs. \( I_{OFF} \) of the InAlP-capped Ge pFETs are compared with those of other Ge pFETs using different passivation techniques in literature (Fig. 7). \( I_{ON} \) was extracted at \( V_{GS}-V_{TH} \) of 1 V and \( V_{DS} \) of 1 V. The InAlP-capped Ge pFETs show high \( I_{ON} \) at relatively large \( L_G \).

V. Conclusion

We compared the electrical characteristics of InAlP-capped Ge nFETs and pFETs with various surface passivation techniques. The benchmarking shows that InAlP is a promising passivation technique for the gate stack formation for both nFETs and pFETs in future high performance and low power logic applications.

References

[1] B. Liu et al., IEDM 2013, p. 756
[3] Y. C. Fu et al., IEDM 2010, p. 432
[16] G. Thareja et al., IEDM 2010, p. 245
[18] N. Wu et al., EDL 25, p. 631, 2004
[20] A. Ritenour et al., IEDM 2003, p. 18.2.1
[21] B. Liu et al., EDL 33, p. 655