

HIGH MOBILITY SiGe SHELL-Si CORE OMEGA GATE pFETs

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ABSTRACT

Omega gate type pFETs with SiGe shell-Si core are demonstrated that show 30% mobility enhancement for (110) oriented fins and 46% mobility enhancement for (100) oriented fins compared to Si omega gate devices. Performance improvement is demonstrated because of higher mobility and inherent epitaxial strain, while the external resistance in the two SiGe and Si omega FETs is comparable. Performance can further be improved by uniaxial compressive stress.

INTRODUCTION

Planar Si channel devices may not be able to provide for the high performance needed in future MOSFETs beyond 22nm node. [1] Two categories of advanced performance enhancements currently dominate the literature: alternate channel materials [2] and Multi-Gate FETs (MuGFETs) [3]. The simplest of these to introduce from a materials perspective is MuGFETs, while both methods have integration challenges. For these reasons, it may be speculated that MuGFETs will be introduced first, possibly as early as the 22nm node. This is because gate length scaling has severely saturated, as the composite data in Fig. 1 indicate. While the advent of High-k/metal gates for gate stack scaling [4] may increase the rate of scaling, future advances in MuGFET performance may require that addition of alternate channel materials. Ge based channels have been reported to demonstrate performance improvement over Si [2]. This work is the first demonstration of a SiGe shell-Si core omega gate type of pFET.

DEVICE FABRICATION

The SiGe/Si transistors were formed by standard gate-first CMOS flow. Thin (~15nm) epitaxial Si_{0.7}Ge_{0.3} is selectively grown by CVD on Si fins etched on SOI substrates. As Fig 2-4 show, uniform epitaxy on (110) and (100) oriented fins is observed. HfSiO_x dielectric and TiN metal gate was deposited using atomic layer deposition (ALD). Both (110) and (100) oriented fins show >90% gate coverage.

RESULTS AND DISCUSSION

Figure 5 shows the Id-Vg of SiGe shell-Si core (110) omega gate devices compared to Si omega gate devices for saturation and linear drain voltages. The higher drain current is expected because of higher mobility of SiGe channel and the biaxial stress in the fins along the channel direction. Figure 6 shows that a threshold shift of ~200mV is observed because of the SiGe channel. A 300mV Vt shift between SiGe and Si

devices is expected for similar Ge % [5], which suggests that the SiGe in these Omega FETs is partially relaxed. Figure 7 and 8 show 46% mobility enhancement for (100) oriented fins and 30% mobility enhancement for (110) oriented fins in SiGe based omega FETs compared to Si based FETs. These experimentally observed mobility trend matches that expected by simulations for relaxed Si and biaxially strained 30% SiGe FinFET, as shown in Fig 9 and 10. The difference in experimental and simulation observations for SiGe can be attributed to several reasons like partial relaxation of the SiGe layer or scattering in SiGe fins because of either alloy scattering or surface roughness scattering or the presence charge traps. The temperature dependence of peak mobility between SiGe and Si fins, Fig 11, shows similar slopes are observed, suggesting that alloy scattering is not a significant contributor to mobility degradation.

Fig 12 shows the Ion-Ioff plot for (110) oriented SiGe and Si channels. The Id-Vg plot for 140nm gate length (as drawn) device shows higher on current for the SiGe based devices compared to Si fin devices. Fig 13 shows that one of the contributing factors for the higher off-state current for SiGe/Si devices is the gate leakage which is approximately two orders of magnitude larger in SiGe based devices compared to Si based devices. Fig. 14 and 15 show the drain current variation with drain bias for various gate overdrives and the Capacitance voltage curves for (110) oriented fins. A performance improvement of ~19% at Vd=0.9V and (Vg-Vt)=0.6V. Figure 16 shows that a comparable external resistance of 357 ohm-um and 253 ohm-um is extracted for SiGe and Si fins respectively.

A flexure based 4-point bending setup [6] was used for applying uniaxial compressive stress (up to 300 MPa) on p-finFETs of varying channel lengths to understand the performance additivity of external stress. The linear drive-current enhancement plotted as a function of stress is shown in Fig 17 and 18. As shown in Figure 17, SiGe/Si devices have the same enhancement as observed in Si FinFETs. Hence the enhancement shown by SiGe based devices because of enhanced mobility and stress in channel is additive to the external stress applied.

CONCLUSION

SiGe shell-Si core pFETs with an omega gate are demonstrated. A mobility enhancement of up to 46% and current improvements of ~19 % are observed compared to Si devices. We have presented a first study and demonstration of advanced devices beyond the introduction of FinFETs.

References: [1] R. Chau, Proc. *IEEE. Nanotechnology*, 2004; [2] T. Yamamoto, IEDM 2007; [3] J. Kavalieros, VLSI 2006; [4] K. Mistry IEDM 2007; [5] Harris, VLSI 2007 ; [6] S. Suthram, IEDM 2007;

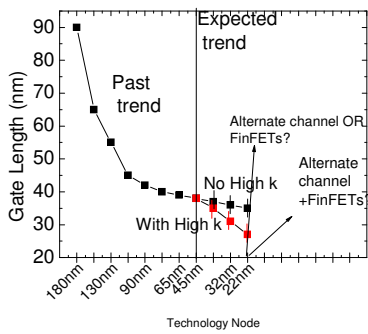


Figure 1. Past gate length scaling and possible future technology solutions for various nodes.

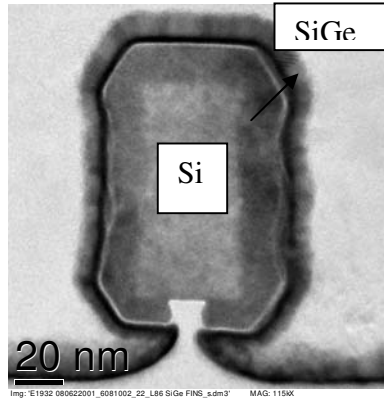


Figure 2. (110) oriented fins showing good epi. Angled Epi on fin sidewalls.

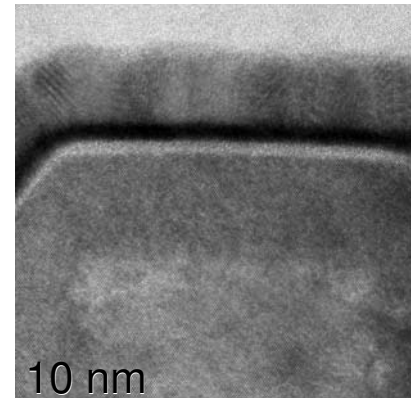


Figure 2. (100) oriented fins showing continuation of lattice between Si and SiGe. ~3.6nm of dielectric layer.

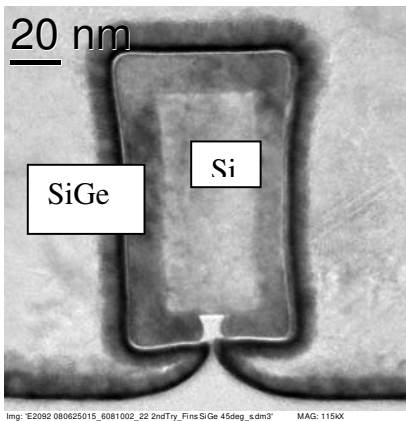


Figure 3. (100) oriented fins showing uniform growth of epitaxy in all directions

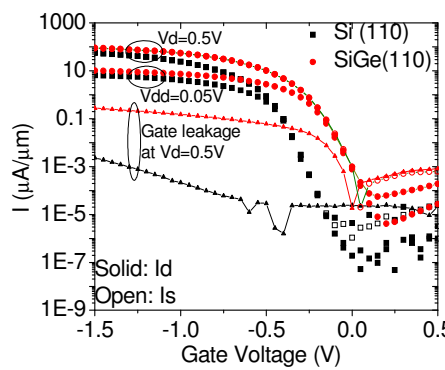


Figure 5. Id-Vg plot for SiGe and Si channel fins for long channel (2μm) device.

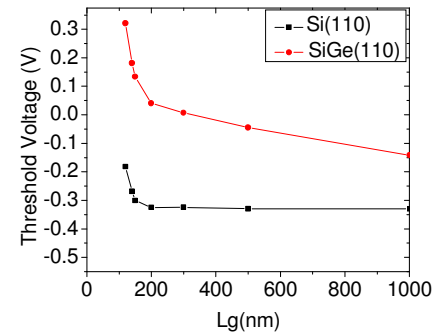


Figure 6. Threshold voltage shift because of SiGe

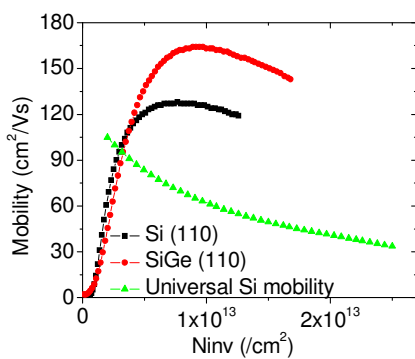


Figure 7. Mobility comparison between (110) oriented SiGe and Si fins. (100) universal Si mobility is shown for comparison.

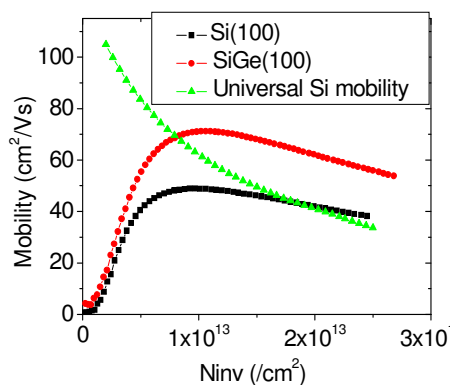


Figure 8. Mobility comparison between (100) oriented SiGe and Si fins. (100) universal Si mobility is shown for comparison.

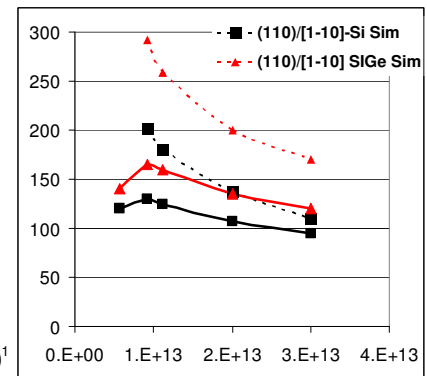


Figure 9. Experimental (solids lines) and simulation (dashed lines) mobility comparison for (110) oriented fins.

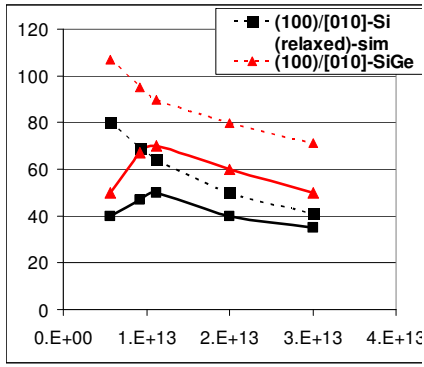


Figure 10. Experimental (solid lines) and simulation (dashed lines) mobility comparison for (100) oriented fins.

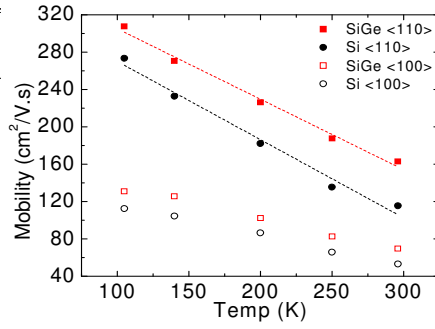


Figure 11. Temperature dependence of mobility curves show similar slopes for peak mobility between SiGe and Si.

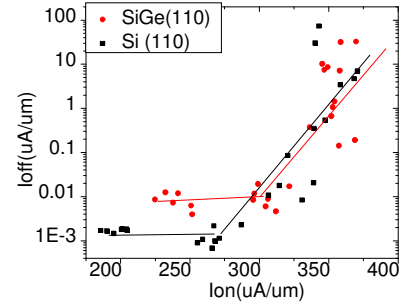


Figure 12. Ion-Ioff comparison between SiGe and Si for (110) oriented fins.

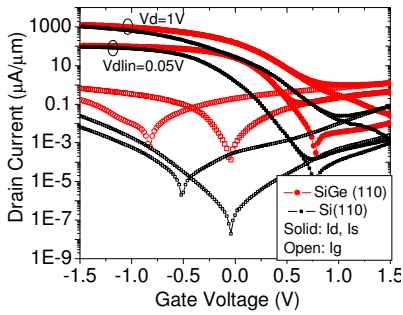


Figure 13. Id-Vg comparison between SiGe and Si based devices with $L_g=140\text{nm}$ (as drawn).

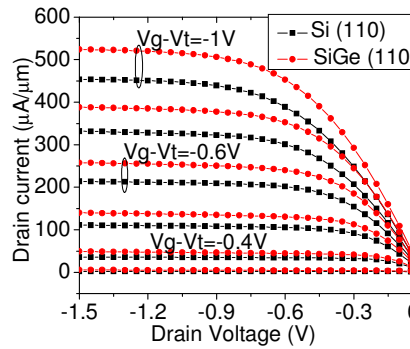


Figure 14. Id-Vd comparison between SiGe and Si based devices with (110) orientation and $L_g=250\text{nm}$ (as drawn) for V_g-V_t from 0 to -1V (in steps of -0.2V).

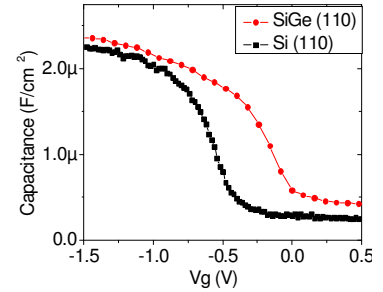


Figure 15. Capacitance Voltage curves for (110) oriented fins.

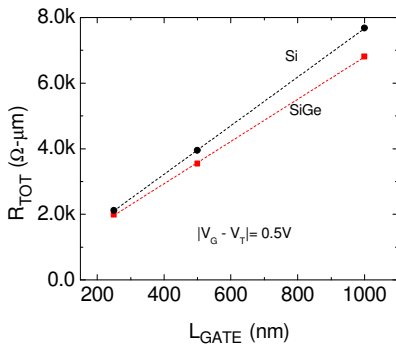


Figure 16. The external resistance comparison between SiGe and Si shell shows comparable external resistance.

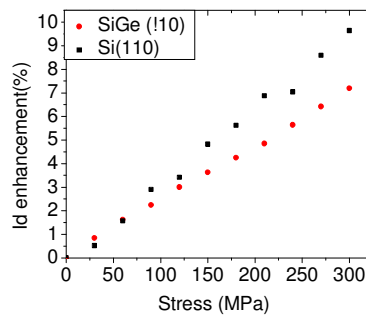


Figure 17. SiGe shell-Si core omega gate FET and Si omega gate FET show similar performance enhancement with uniaxial bending stress.

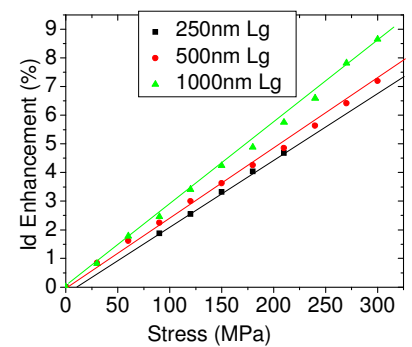


Figure 18. Id enhancement for (110) oriented fins with applied uniaxial stress for various gate lengths.