Abstract #2155, 224th ECS Meeting, © 2013 The Electrochemical Society

Integration of High-κ Dielectrics on Epitaxial (100), (110) and (111) Germanium for Multifunctional Devices

M. K. Hudait[1], Y. Zhu[1], D. Maurya[2], and S. Priya[2]
[1]Department of Electrical and Computer Engineering; [2]Center for Energy Harvesting Materials and Systems, Virginia Tech, Blacksburg, Virginia 24061

With continued transistor scaling, III-V and Ge channel materials and device architectures are needed for transistor miniaturization and to enhance transistor performance. According to ITRS, channel materials with superior transport properties, high-κ gate dielectric and multi-gate transistor configuration are required to achieve further increase in transistor drive current and resultant ULSI performance improvement. In recent years, low bandgap high electron mobility III-V compounds coupled with high-κ dielectrics have been demonstrated in n-channel device configuration operating at 0.5V;[1] however, the demonstration of a high hole mobility p-channel device configuration along with high-κ dielectric is mandatory to realize energy-efficient CMOS logic. The enhancement of carrier transport properties in the channel using high hole mobility Ge, different Ge surface orientations to improve the carrier mobility, and optimal channel direction have been proposed. The hole mobility of (110)Ge channel oriented along the <110> direction exhibited 2.3× higher hole mobility and 1.8× higher in electron mobility with (111)Ge compared with (100) and (110) orientations. These crystallographic oriented epitaxial Ge layers on GaAs and the detailed band offset properties of crystallographic oriented GaAs/Ge/GaAs heterostructure has been reported by Hudait *et al.* [2,3]. These advancements have intensified the research on Ge integration on Si with the possibility of exceeding Moore's law. Moreover, low bandgap Ge is compliant with the requirement of lower supply voltage operation of transistor and it is an excellent template for III-V heteroepitaxy and can be heterogeneously integrated on Si in conjunction with various optoelectronic components that could allow extending the Moore's law.

Although, excellent device performances were achieved using high-κ gate dielectrics on (100)Ge and oxide/(100)Ge band alignment properties; however, little attention has been devoted towards the integration of high-κ gate dielectrics on the epitaxial (100), (110) and (111)Ge and its associated energy band alignment at the interface. High-quality dielectric on these layers are essential to eliminate the formation of high density intrinsic defects, resulting in Fermi level unpinning at the oxide-semiconductor interface and the selected high-κ material should have valence and conduction band discontinuities (ΔE_v and ΔE_c) larger than 1eV relative to Ge to act as a barrier for both holes and electrons. *This paper will* presents a comprehensive study on the structural, morphological, and band alignment properties of epitaxial GaAs/Ge/GaAs heterostructures as well as energy band alignment of Al_2O_3, HfO_2, TiO_2 on (100)Ge, (110)Ge and (111)Ge substrates grown by MBE and x-ray photoelectron spectroscopy.

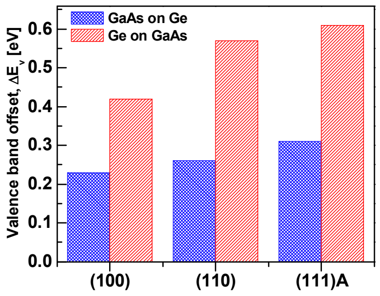

Fig. 1: Histogram of valence band offset distribution obtained from GaAs/Ge/GaAs heterostructures.

The undoped epitaxial (100), (110) and (111)Ge layers were grown using two separate MBE chambers for Ge and GaAs connected via ultra-high vacuum transfer chamber on crystallographic oriented (100)/6°, (110) and (111)A GaAs substrates. An initial 0.2μm GaAs buffer layer was grown on each GaAs substrate to generate a smooth surface prior to deposition of Ge epilayer. The growth temperature and growth rate of Ge were ~ 400°C and ~0.1A/s, respectively. The different thicknesses of high-κ layers (Al_2O_3, HfO_2, TiO_2) were deposited using atomic layer deposition and physical vapor deposition. Epitaxial Ge layers were cleaned using NH_4OH:H_2O_2:H_2O prior to high-κ deposition. The band alignment properties were investigated using a PHI Quantera SXM XPS system with a monochromated Al-Kα (energy of 1486.7eV) x-ray source, with a pass energy of 26eV and an exit angle of 45°. Fig.1 shows the band alignment of crystallographic oriented GaAs/Ge/GaAs double heterostructures, and both valence and conduction band offsets are higher on (111)A GaAs substrate and thus can have a potential advantage for electron confinement. Fig. 2 and Fig. 3 shows the cross-sectional TEM micrograph and band alignment properties of HfO_2 on (110)Ge and crystallographic oriented epitaxial Ge, respectively. Fig. 4 shows the band alignment properties of Al_2O_3 on Ge layers. *In both cases, band offsets were larger than 1eV, needed for carrier leakage.* These band alignment properties offer a potential advantage for designing p-and n-channel metal-oxide field effect transistors for low power logic.

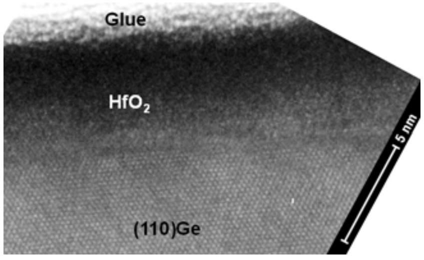

Fig. 2: Cross-sectional TEM micrograph of HfO_2/(110)Ge heterointerface.

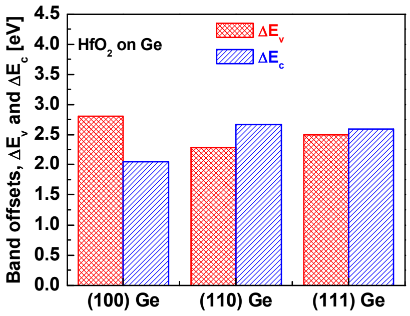

Fig. 3: Histogram of band offset distribution obtained from HfO_2/Ge heterointerface on crystallographically oriented epitaxial Ge layers

In conclusion, high quality GaAs/Ge/GaAs heterostructures as well as band alignment properties of high-κ dielectric on epitaxial crystallographic oriented Ge have been successfully demonstrated, resulting in possible high-performance short-channel Ge MOSFETs with good device characteristics for future high-speed, ultra-low power digital logic applications.

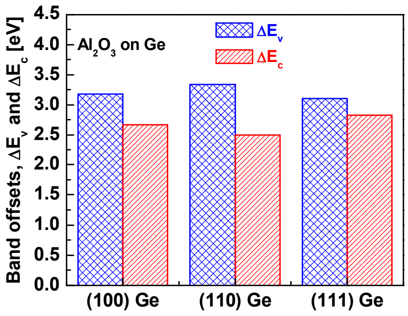

Fig. 4: Histogram of band offset distribution obtained from Al_2O_3/Ge heterointerface on crystallographic oriented Ge layers.

References

[1] M. K. Hudait et al, *ECS Transactions* 45, 581 (2012).
[2] M. K. Hudait et al, *J. Vac. Sc. Technol.* B31, 011206 (2013).
[3] M. K. Hudait et al, *Appl. Phys. Lett.* 102, 093109 (2013).