Photoelectron Study of HfO_2/Ge(100) Stacked Structures

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OUTLINE

1. Motivation & Background
2. Sample Preparation & Experimental Procedure
3. Characterization
   - Chemical Bonding Features of HfO_2/Ge(100)
   - Blocking Properties of Pregrown SiONx on the Interfacial Reaction
4. Determination of Energy Band Alignment for HfO_2/Ge(100) System
   - O1s Energy Loss Spectra
   - XPS Valence Band Spectra
5. Summary

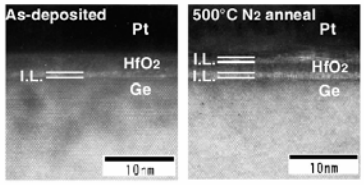
Motivation

☆ Improvement of device performance for MOSFETs ⇨ Enhancement of the channel mobility
- Ge, SiGe, Strained Si, etc

- Major technological challenges for implementation of the surface channel devices

GeOx ↑ > 450°C
K. Prabhakaran et al., Surf. Sci. 325, 263 (1995)

- The use of alternative gate dielectrics
- The control of interfacial reactions between gate dielectrics and Ge



Y. Kamata et al., Jpn. J. Appl. Phys. 44 (2005) 2323

☆ The combination of Ge channel and high-k dielectric is increasingly attractive
⇨ The thermal stability of the interface between high-k gate dielectric and Ge(100)

This Work

HfO_2/Ge(100) ⇨ Characterization of chemical bonding features near the interface and the energy band alignment between HfO_2 and Ge(100)

SAMPLE PREPARATION & EXPERIMENTAL PROCEDURE

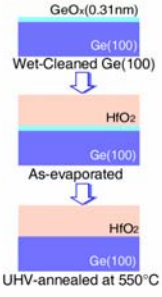
Substrates: p-Ge(100)
Precleaning
20% HCl (5min)
10% H_2O_2 (5min)
0.5% HF (1min)
Pure Water Rinse

ultrathin SiON
- Si Evaporation (~0.9nm)
- NH_3-annealed at 600°C

HfO_2 Evaporation (2.1~5.4nm)
in O_2 ~1.0x10^{-4} Pa, Room Temperature

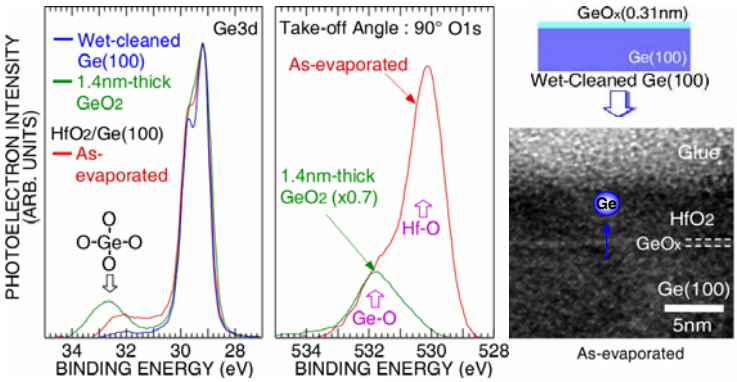
Ultra-high Vacuum (UHV) Anneal
~550°C, ~10^{-6}Pa, 1min

Wet-chemical etching (dilute HF etching)
for depth profiling of chemical bonding features

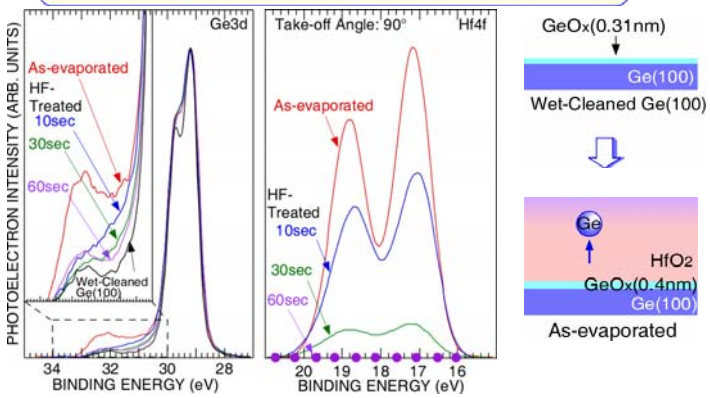


- X-ray Photoelectron Spectroscopy (XPS)
  - Core-Line Spectra: Hf4f, Ge3d, Si2p, N1s, O1s
    ⇨ Chemical Bonding Features
  - Photoelectron Energy Loss Spectra, Valence Band Spectra ⇨ Energy Band Profile of the annealed sample
- Transmission Electron Microscope (TEM) ⇨ Cross-check the Thickness of the Interfacial Layer

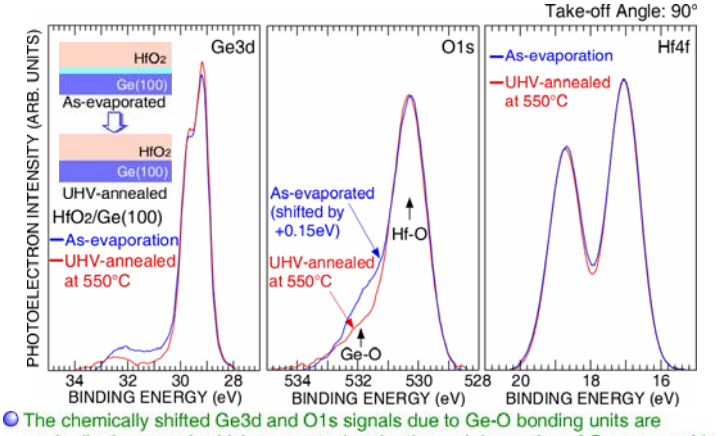
Ge3d & O1s Spectra Before & After HfO_2 Evaporated on Ge(100) Surfaces



Ge3d & Hf4f Spectra for the As-evaporated Sample with Progressive Etching in 0.1% HF Solution

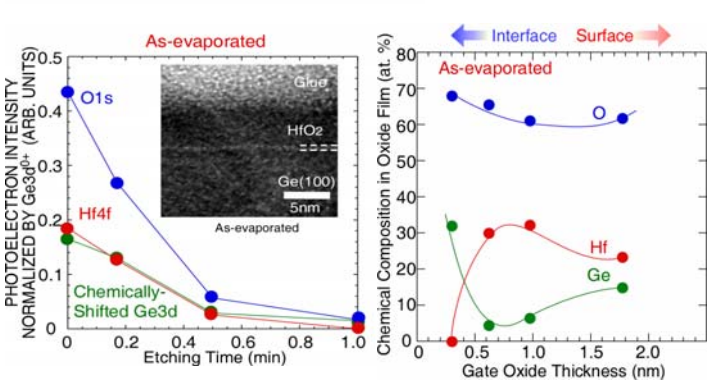


Ge3d, O1s & Hf4f Spectra Before & After UHV-annealed at 550°C

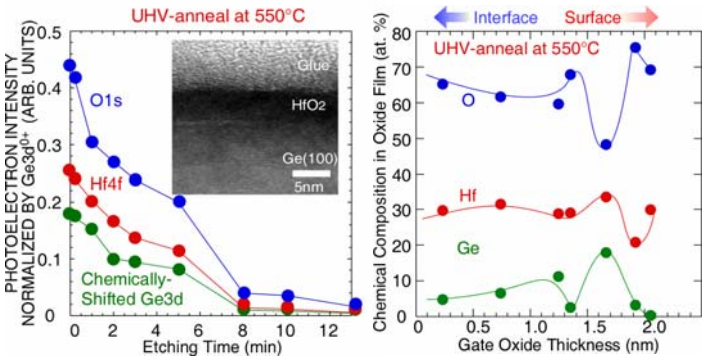


- The chemically shifted Ge3d and O1s signals due to Ge-O bonding units are markedly decreased, which suggests that the thermal desorption of Ge mono oxide occurs by UHV anneal.

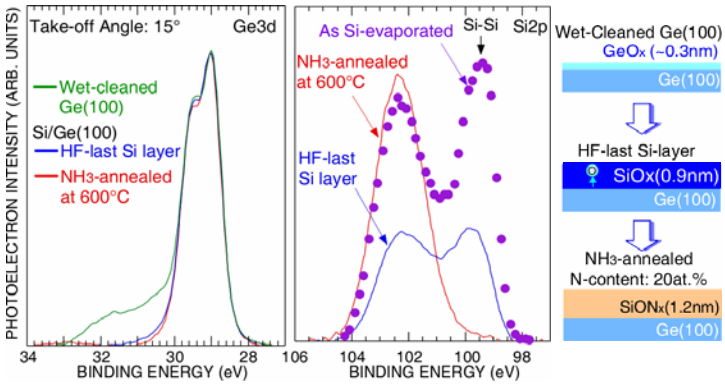
Changes in Integrated Intensities of Chemically-shifted Ge3d, O1s & Hf4f Spectra and The Compositional Profile for As-evaporated Samples



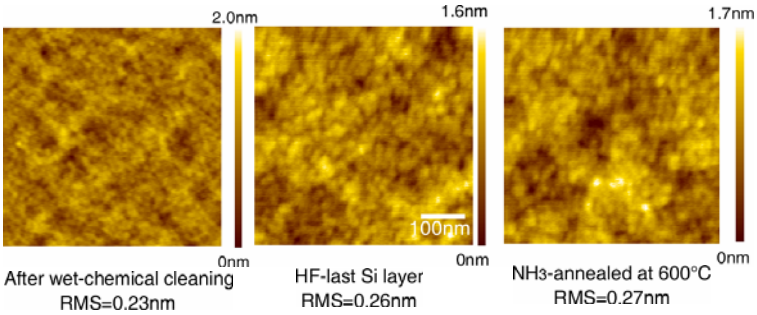
Changes in Integrated Intensities of Chemically-shifted Ge3d, O1s & Hf4f Spectra and The Compositional Profile for Annealed Samples



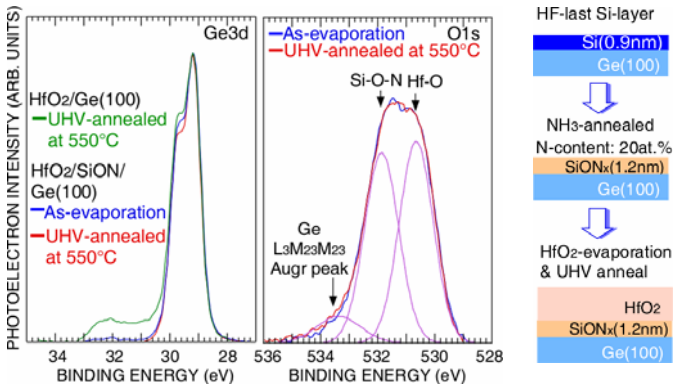
Ge3d & Si2p Spectra Before & After NH3-anneal at 600°C for the HF-last Si Layer



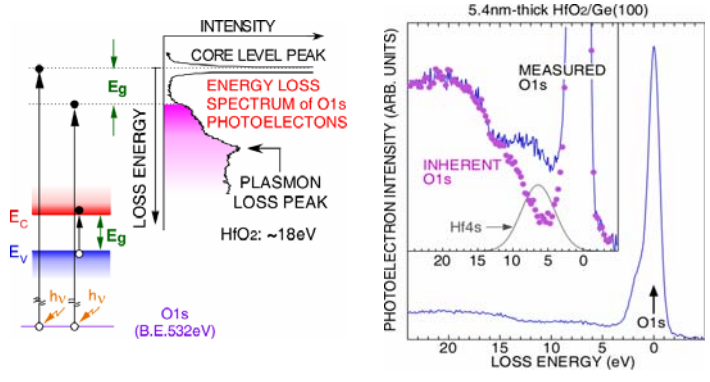
AFM Topographic Images for the HF-last Si Layer & SiON Film



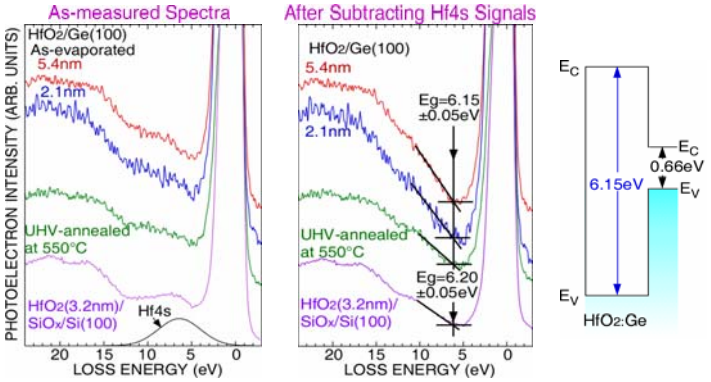
Ge3d & O1s Spectra Before & After UHV-anneal for HfO2/SiON/Ge(100) Stacked Structures



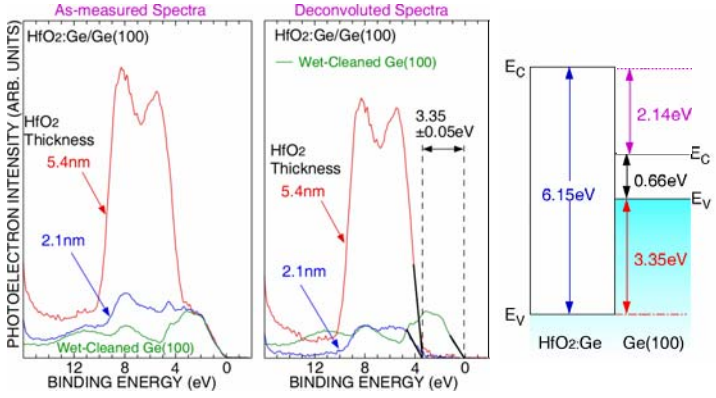
Determination of Bandgap Energies for HfO2 Films from O1s Photoelectron Energy Loss Spectra



Determination of Bandgap Energies for HfO_2 Films from O1s Photoelectron Energy Loss Spectra



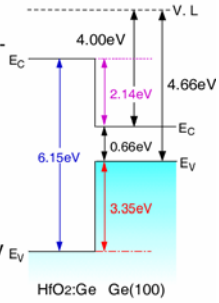
Valence Band Spectra for HfO_2:Ge/Ge(100) Structures & Deconvoluted Spectra



Summary

The chemical bonding features and the energy band alignment between HfO_2 and Ge(100) were evaluated by X-ray photoelectron spctroscopy

- During HfO_2 evaporation, it is found that Ge atoms are diffused and incorporated into 2.1nm-thick HfO_2 films by ~10at.% in average.
- In UHV-anneal at 550°C, the Ge content was increased up to ~20at.% in the near-surface region, but no Ge atom was detected at the top surface.
- The energy band offsets between HfO_2:Ge and Ge(100) after UHV anneal at 550°C are ~3.35eV in the valence band edge and ~2.14eV in the conduction band edge, respectively.



Acknowledgements

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