Germanium (Ge) is expected to be an alternative material for high performance MOSFET due to its higher carrier mobility than silicon (Si). However, the deposition of HfO2 film on Ge degrades the electrical properties of MOSFET. In this study, we investigated the HfO2/GeO2 interfacial reaction and thermal diffusion of the atoms to obtain the guideline for electrical improvement.

**Motivation: Realization of high performance High-k/Ge based MOSFET**

- High quality Ge-MOS stacks
- Ge channel: High carrier mobility
- High-k dielectric: Under 1nm-thick EOT
  - EOT: Equivalent Oxide Thickness
  - Realization of Metal/High-k/Ge stacks for high performance MOSFET

**Evaluation of gate stacks by STEM-EELS (Study on HfO2/GeO2x interfacial reaction)**

- Relationship between leakage current (JL), EOT and annealing temperature after gate stack formation
- Increase in leakage current and EOT over 400°C annealing
- Investigation of stacked structures and elemental distribution by STEM-EELS

**Evaluation of oxygen diffusion behavior by dynamic SIMS with isotope tracer (18O)**

- we made the stacked structures using ordinary 16O and heavy oxygen (18O), to investigate the oxygen diffusion in HfO2 film by SIMS.

**Comparison of Ge-MOS properties**

<table>
<thead>
<tr>
<th>GeO2/Ge stack</th>
<th>Interface property</th>
<th>EOT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 10^11 cm^2/V-s</td>
<td>(Low-k)</td>
</tr>
<tr>
<td>HfO2/Ge stack</td>
<td>Interface defects</td>
<td>(High-k)</td>
</tr>
</tbody>
</table>


**Need both good interface property and EOT scaling**

- Interfacial GeOx layer: High-k/GeOx/Ge stacks
- AlOx insertion into HfO2/GeOx interface [3, 4]
- HfO2/GeO2 interfacial reaction
- Verification of effect of ultrathin AlOx layer insertion

**Study on HfO2/GeO2 interfacial reaction /Ge based MOSFET**

- HfO2 film after 500°C annealing
- Good interface properties
- Slight increase in roughness on HfO2 film after 500°C annealing
- Further improvement is needed

**Oxygen inter-diffused at HfO2/GeO2 interface.**
- Low Eo of oxygen
- Independent diffusion of Ge and oxygen
- No relationship between oxygen diffusion and electrical properties
- Independent diffusion of Ge and oxygen in HfO2
- Ge diffusion is attributable to electrical degradation.
- Suppression of HfO2/GeOx interfacial reaction and atomic diffusion by ultrathin AlOx layer insertion.
- Control of interfacial reaction is key for improvement.

**Guideline for high performance high-k/Ge MOSFET**

- Understanding the characteristics of individual atoms
- Precise control of Interface properties

**STEM images and EELS profiles of Pt/HfO2/GeO2/Ge stacks**

- Increase in GeOx interlayer after annealing ⇒ Increase in EOT
- Ge diffusion into HfO2 surface after annealing ⇒ Increase in JL
- Enhancement of HfO2/GeOx interfacial reaction by high temperature annealing (thermal instability)

**Interface defects**

- EOT: Equivalent Oxide Thickness
- Interface property EOT
- Interface defects

**Guideline for high performance high-k/Ge MOSFET**

- Understanding the characteristics of individual atoms
- Precise control of Interface properties

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