Evaluation of 4H-SiC epitaxial layers by synchrotron x-ray topography

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Summary
**Background in electric power field**

Ratio of electric power in total energy consumed in Japan in each year [1].

Low-loss SiC devices

Electric power transmission and distribution systems in near future.
# Materials for power electronic devices

## CRIEPI

<table>
<thead>
<tr>
<th>Material</th>
<th>4H-SiC</th>
<th>Si</th>
<th>GaAs</th>
<th>GaN</th>
<th>diamond</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Bandgap</td>
<td>[eV]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.26</td>
<td>1.12</td>
<td>1.42</td>
<td>3.42</td>
<td>5.47</td>
</tr>
<tr>
<td>Electron Mobility</td>
<td>[cm²/Vs]</td>
<td>1000</td>
<td>1350</td>
<td>8500</td>
<td>1200</td>
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<tr>
<td>Breakdown Field</td>
<td>[MV/cm]</td>
<td>2.8</td>
<td>0.3</td>
<td>0.4</td>
<td>3</td>
</tr>
<tr>
<td>Saturation Drift Velocity</td>
<td>[cm/s]</td>
<td>2.2x10⁷</td>
<td>1.0x10⁷</td>
<td>1.0x10⁷</td>
<td>2.4x10⁷</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>[W/cmK]</td>
<td>4.9</td>
<td>1.5</td>
<td>0.46</td>
<td>1.3</td>
</tr>
<tr>
<td>p-type control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n-type control</td>
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<tr>
<td>Thermal oxidation</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Conductive Wafer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(SiC)</td>
</tr>
<tr>
<td>insulating Wafer</td>
<td></td>
<td>(SOI)</td>
<td></td>
<td></td>
<td>(Sapphire)</td>
</tr>
</tbody>
</table>

Table 1. Material property and present situation of 4H-SiC, Si, GaAs, GaN and diamond [2].

[2] H. Matsunami:

Present status of SiC

Excellent properties of SiC

High quality SiC layer

High performance SiC power devices
(High temperature resistant and low-loss devices)

Defects
Impurity
Uniformity

Micropipe
Propagation of micropipe

Micropipe is a large screw dislocation having a large Burgers vector and it has a hollow core. ($|b| > 3c$)

Hollow core of micropipe is continued into the epilayer

Step of screw dislocation on a substrate surface.
Influence of micropipe
-for electrical property-

I-V characteristics of SBD

SBD (Schottky Barrier Diode) with micropipe

Breakdown in low reverse voltage

Reference: good SBD without micropipe
Study on SiC

Substrates Evaluation → KOH etching, X-ray topography, Microscopy, SIMS

Epitaxial growth Evaluation → KOH etching, PL, X-ray topography, Microscopy, SEM, TEM, SIMS, AFM

Device fabrication Process Evaluation → I-V, C-V, DLTS, EL,
Evaluation of defect -KOH etching-

|b| = 1c or 2c

*KOH etching* ~ 500 °C

Etch Pits
Dislocations are easily investigated by KOH etching as etch pits. However, the KOH etching is destructive evaluation.
**X-ray topography measurements**

- **Topography image**
- **Film**
- **Incident beam**
- **Sample**
- **Goniometer**

### Table

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</thead>
<tbody>
<tr>
<td>~8 [keV]</td>
<td>~1.54 [keV]</td>
<td>(1108)</td>
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<tr>
<td></td>
<td></td>
<td>(1128)</td>
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</tbody>
</table>
Dislocations are observed by X-ray topography. Moreover, the X-ray topography is non-destructive evaluation.
To investigate dislocations and defects in SiC epilayers, proper methods to evaluate the dislocations and defects are needed.

KOH etching can be used for evaluation of the dislocations in SiC, however, the KOH etching is destructive evaluation.

Dislocations (screw dislocations, edge dislocation and micropipes) are observed by the Synchrotron X-ray topography as a non-destructive evaluation.