Reduction in Al Acceptor Density by Electron Irradiation in Al-Doped 4H-SiC

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Abstract
The influence of electron irradiation on the hole concentration in Al-doped 4H-SiC epilayers is investigated using the temperature dependence of the hole concentration $p(T)$.

By 4.6-MeV electron irradiation, the $p(T)$ is reduced in the whole temperature range.

In the unirradiated and irradiated samples, $\sim200$ meV Al acceptors and $\sim370$ meV unknown defects are detected.

By irradiation, only the density of Al acceptors is reduced from $6.2\times10^{15}$ cm$^{-3}$ to $8.2\times10^{14}$ cm$^{-3}$.

The main reduction in $p(T)$ by electron irradiation results from the decrease of the Al acceptor density, not from the creation of defects.
Motivation

Electron Irradiation

In the case of Si
The creation of vacancy-related defects.

The controlled generation of intrinsic defects in Si for using high power devices.

The decrease of the acceptor density in p-type Si.

The degradation of the conversion efficiency of Si solar cells used in space.

What happens in Al-doped p-type SiC?
Experimental

Al-doped 4H-SiC epilayer

<table>
<thead>
<tr>
<th>Al-doped 4H-SiC epilayer</th>
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<tbody>
<tr>
<td>(thickness: 10 μm, Al-doping density: ~5x10^{15} cm^{-3})</td>
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<tr>
<th>n-type 4H-SiC wafer</th>
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<td>(thickness: 375.9 μm, resistivity: 0.02 Ω cm)</td>
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Irradiation

- 4.6 MeV electrons with 2.6x10^{14} cm^{-2} at room temperature

Hall-effect measurement

- Temperatures: 135 K to 580 K
- Magnetic field: 1.4 T
**Change of temperature dependence of hole concentration**

- **p(T) is reduced by electron irradiation**

**The possible reason**

1. The creation of defects (hole traps or donor-like defects)

2. The decrease in acceptor density
Verification of obtained values

Comparison between experimental and simulated p(T)

The p(T) simulations are in good agreement with the experimental p(T).

<table>
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<tr>
<td>$\Delta E_{A1}$ [meV]</td>
<td>203</td>
<td>206</td>
</tr>
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<td>$N_{A1}$ [cm$^{-3}$]</td>
<td>$6.2 \times 10^{15}$</td>
<td>$8.2 \times 10^{14}$</td>
</tr>
<tr>
<td>$\Delta E_{A2}$ [meV]</td>
<td>365</td>
<td>383</td>
</tr>
<tr>
<td>$N_{A2}$ [cm$^{-3}$]</td>
<td>$4.2 \times 10^{15}$</td>
<td>$3.4 \times 10^{15}$</td>
</tr>
<tr>
<td>$N_{comp}$ [cm$^{-3}$]</td>
<td>$3.4 \times 10^{13}$</td>
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Origins of these energy levels

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- Al acceptors
- Unknown defect
The main reason for the reduction in $p(T)$ by electron irradiation

The Al acceptor density (~200 meV level) is decreased from $6.2 \times 10^{15}$ cm$^{-3}$ to $8.2 \times 10^{14}$ cm$^{-3}$.

The unknown defect density (~370 meV level) appears unchanged.

Therefore, the decrease in the Al acceptor density results in the reduction in $p(T)$. 
The cause of the decrease in Al acceptor density by electron irradiation

1) The movement of the substitutional Al atoms into the interstitial sites
2) The bond-breaking between the substitutional Al atom and the nearest neighbor atom

Further research in this area is in progress.
Summary

1) The effect of electron irradiation on Al-doped 4H-SiC was investigated with Hall-effect measurements.
2) $p(T)$ was reduced by 4.6-MeV electron irradiation.
3) ~200 meV Al-acceptor density was decreased.
4) ~370 meV unknown defects appeared unchanged.
5) The main reduction in $p(T)$ by irradiation resulted from the decrease in Al acceptors, not from the creation of hole traps or donor-like defects.