Wet Oxidation and Hydrogen Incorporation on 4H-SiC (c-face)

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Hydrogen reduces the interface defect density in Si MOS devices.

**Effect on SiC?**

Questions to answer:
- Is there hydrogen at the interface?
- Hydrogen vs. defect?
- Hydrogen vs. electrical properties?

**Water uptake during device processing**

Does hydrogen go into the oxide/interface during device processing?
Does this result in a electrical degradation?
Effect of pyrogenic oxidation ($H_2+O_2$) on $D_{it}$ & $\mu_{FE}$

Wet oxidation: temperature $\uparrow$ $D_{it}$ $\downarrow$

Effect of pyrogenic oxidation (H$_2$+O$_2$) on D$_{it}$ & $\mu_{FE}$

Wet oxidation: temperature $\uparrow$ D$_{it}$ $\downarrow$

Post oxidation H$_2$ anneal: D$_{it}$ $\downarrow$

Effect of pyrogenic oxidation ($H_2+O_2$) on $D_{it}$ & $\mu_{FE}$

![Graphs showing the effect of wet oxidation temperature on $D_{it}$ and channel mobility $\mu_{FE}$, and the effect of post oxidation $H_2$ anneal on $D_{it}$ and $\mu_{FE}$](image)

- Wet oxidation: temperature $\uparrow$ $D_{it}$ $\downarrow$
- Post oxidation $H_2$ anneal: $D_{it}$ $\downarrow$
- Post oxidation $H_2$ anneal: $\mu_{FE}$ $\uparrow$

Effect of hydrogen anneals on $D_{it}$

Effect of H$_2$ annealing at 500° C for Pt gated oxide

Final outcome:
- NO anneal reduced higher energy defects closer to $E_c$
- H$_2$ anneal reduce defects deeper into the gap
- NO + H$_2$ anneal reduced the defect density throughout the 0.2-1.6 eV range

S. Wang et al. PRL 98, 2007, 026101
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**Nuclear Reaction analysis (NRA)**

**Sensitivity to 2 x 10^{12} atoms/cm^2 (0.1% of a monolayer)**

\[
\frac{3}{2}\text{He} + \frac{2}{1}\text{D} \rightarrow \frac{4}{2}\text{He} + \frac{1}{1}\text{p}
\]

Roughly: \(\frac{4}{2}\text{He}: 3.6\text{MeV} \quad \frac{1}{1}\text{p}: 14.7\text{MeV}\)

Proton Yield \(\propto Q\Omega\sigma(E)N_t\)

\(N_t: \text{deuterium area density}\)
Summary of “D” uptake by 4H-SiC faces vs Si

Interface D content: after annealing dry oxide in D₂O at 400° C for 15 hrs

Summary of “D” uptake by 4H-SiC faces vs Si

Flat band voltage shift is proportional to the interface “D”

![Graph showing the relationship between flat band voltage shift ($\Delta V_{fb}$) and interface D content (cm$^{-2}$).](image-url)
Relationship between wet oxidation and interface “D” concentration
Wet oxidation

Oxidation at different temp. using D$_2$O

Stripping oxide followed by NRA
Wet oxidation

Oxidation at different temp. using D$_2$O

Stripping oxide followed by NRA

The less D retained at the interface during wet oxidation, the better $N_{it}$.
Post oxidation $D_2$ anneal

Wet oxidation at 1000° C

$D_2$ exposure at different temp.

C-V and NRA analysis
Post oxidation \( \text{D}_2 \) anneal

Post oxidation anneal improves the interface, and the defect density is inversely proportional to the D amount.

\[ N_{lt} \times 10^{12} \]

\[ \text{D}^2 \text{content} \times 10^{14} / \text{cm}^3 \]
Temperature dependent “D” uptake by exposure to D$_2$O from the SiO$_2$(dry)/SiC interface
Temperature dependent water uptake

Oxidation at 1150° C

D$_2$O exposure at different temp.

Stripping oxide followed by NRA
Temperature dependent water uptake

Oxidation at 1150° C

D$_2$O exposure at different temp.

Stripping oxide followed by NRA

D uptake is maximal at 700 °C
Temperature dependent water uptake

Oxidation at 1150° C

D₂O exposure at different temp.

Stripping oxide followed by NRA

4H-SiC (0001)

H passivation of Pb defect on Si(111)

D content (E13 atoms/cm²)

Normalized area Pb density

 Anneal Temperature (°C)

A. Stesmans, JAP 2002

H passivation of Pb defect on Si(111)
Effect of NO passivation on “D” uptake
Effect of NO passivation on “D” uptake

NO passivation significantly reduce the interface “D” at the SiO$_2$/SiC interface.
Conclusions

- Our quantification of D content with temperature, in combination with electrical measurements, suggest there is an optimum D content, hence the need to control temperature.

- D uptake is maximal at 700 °C

- At high temperatures: D incorporation during wet oxidation and post dry + D$_2$O annealing similarity suggest that “D” atoms bond to similar sites.

- D uptake as function of temperature is consistent with combined “up-take” and “loss” chemical processes, as previously identified for Si, but with characteristic temperatures substantially higher for SiC.
Questions and comments
Interfacial D content (c-f) vs $V_{fb}$

- NO
- $O_2$
- Ar

$V_{fb}$ (V)

Interface D ($x10^{13}$ cm$^{-2}$)

$D_2O$ exposure

- D passivate defects at the interface

N takes up defects site, D in the bulk does not affect $V_{fb}$