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The Investigation of Effective Thermal Oxidation to SiC MOSFET Gate Oxide Quality Improvement

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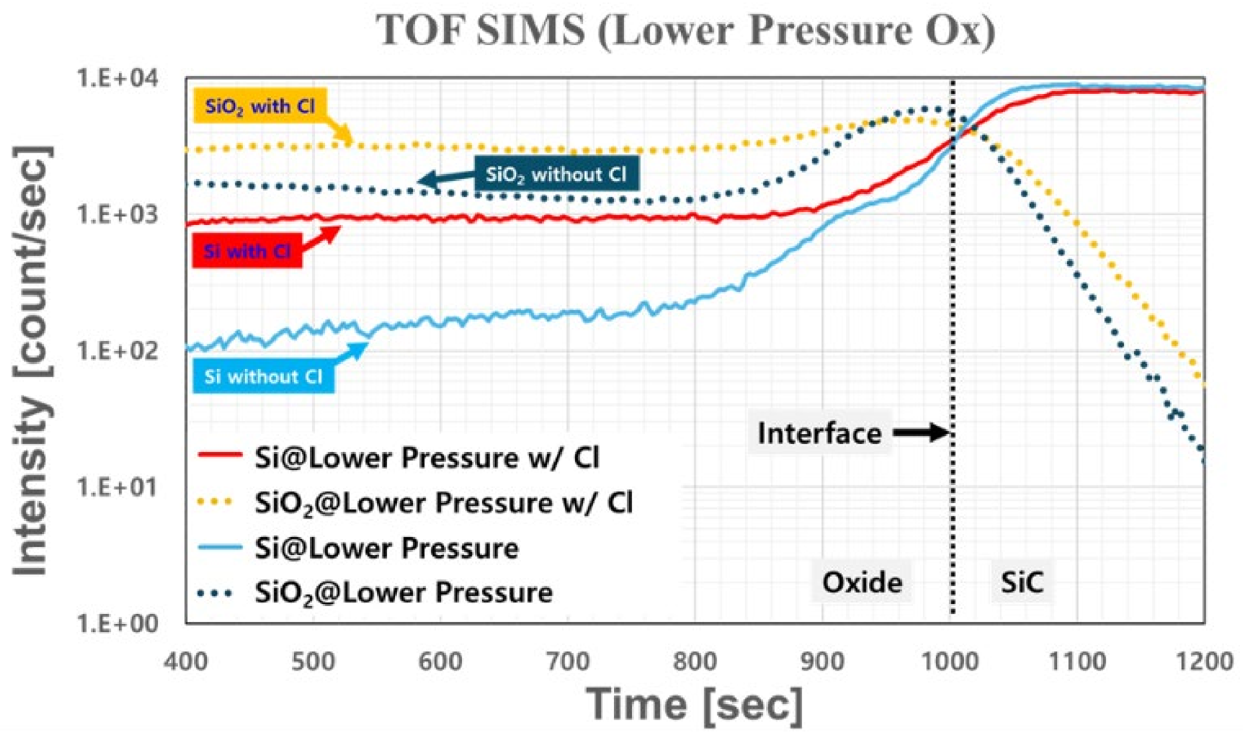
Abstract. This study investigates the effects of lower pressure and chlorine gas added oxidation on the Gate Oxide Integrity (GOI) during the SiC MOSFET Gate Oxide (GOX) process. For structural comparison, analyses were conducted using Dynamic SIMS and TOF-SIMS. Notable differences in the uniformity of silicon concentration within the oxide layer were observed under various GOX conditions. To evaluate the impact of these differences on the characteristics of SiC MOSFETs, Q_{BD} results were compared. To enhance the reliability of the findings, evaluations of GOX were performed across multiple products. The experimental results indicated that the SiC MOSFET wafers subjected to chlorine oxidation exhibited improved Q_{BD} performance compared to other conditions.

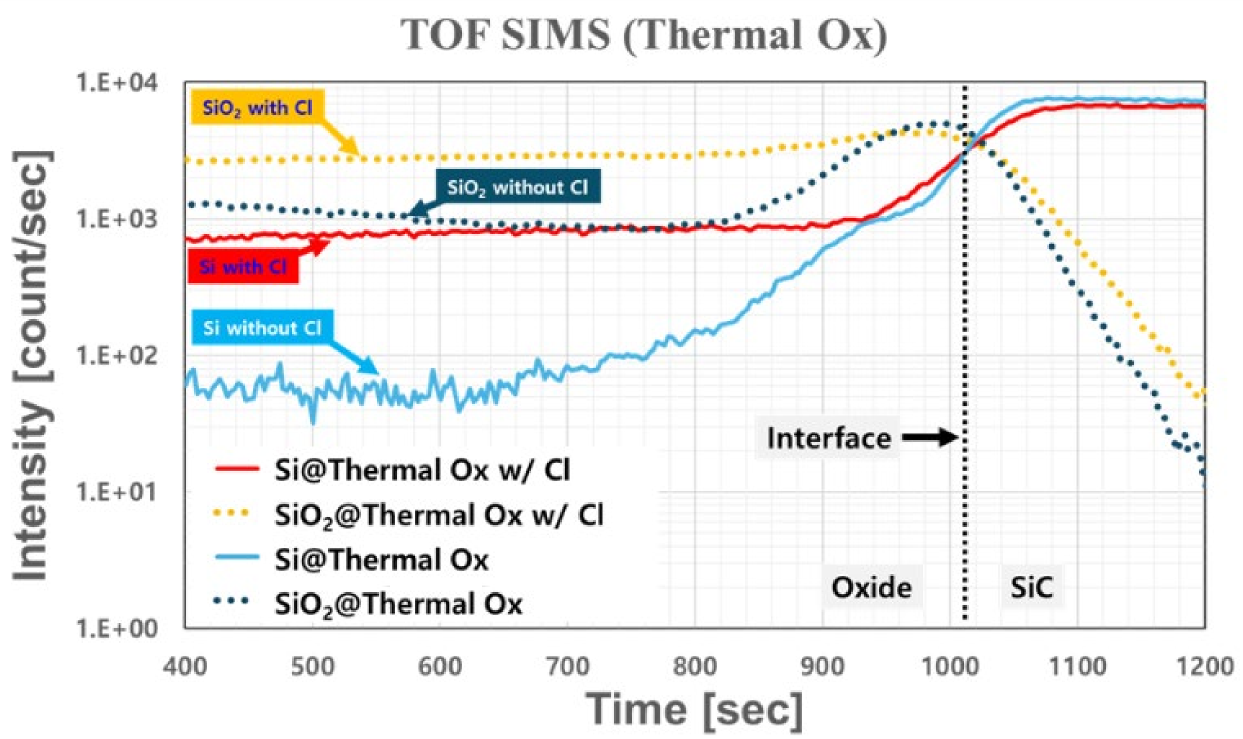
Introduction

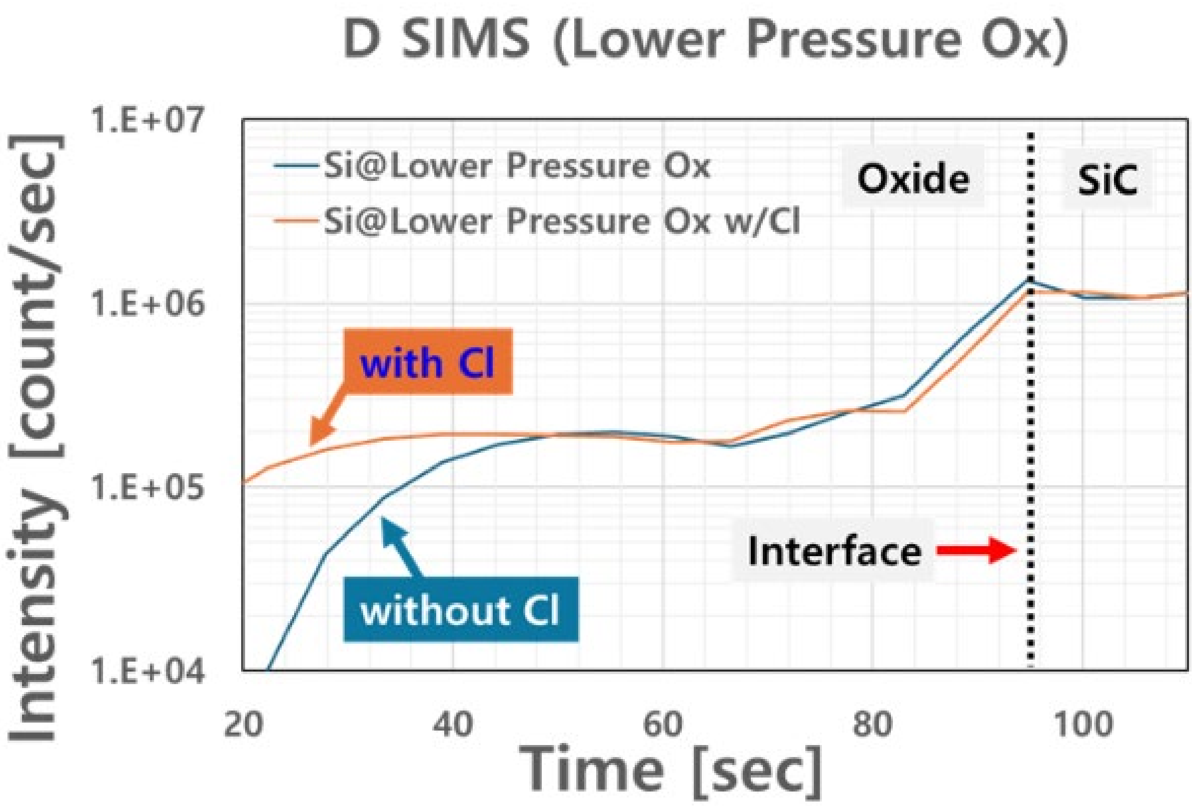
In the semiconductor oxidation process of Si, chlorine plays a crucial role in removing metallic impurities within the GOX [1-3]. However, in SiC processes, various other techniques are being introduced concerning the quality of GOX [4]. SiC devices primarily utilize implant sources like Al, which certainly introduces metallic impurities into the gate oxide during thermal oxidation process. And some of study shown effective results to SiC GOX process. [5-7] This paper aims to investigate the effects of chlorine oxidation on SiC MOSFET devices. Additionally, considering the influence of lower pressure oxidation on oxide quality, as discussed at ICSCRM2023 [8], we aim to examine its impact on SiC MOSFET devices.

Results and Discussion

This study evaluated the Q_{BD} characteristics representing the Gate Oxide Integrity (GOI) of SiC MOSFETs under various Gate Oxide (GOX) conditions to determine which conditions produce the most effective thermal oxidation process. Furnace thermal oxidation was performed to achieve the same target GOX thickness at a constant temperature. Additionally, SIMS analysis of the oxidized SiC wafers was conducted to compare the effects of lower pressure oxidation and chlorine gas-added oxidation during the GOX process.


TOF SIMS (Lower Pressure Ox)
Intensity [count/sec]
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
SiO2 with Cl
SiO2 without Cl
Si with Cl
Si without Cl
Interface
Si@Lower Pressure w/ Cl
SiO2@Lower Pressure w/ Cl
Si@Lower Pressure
SiO2@Lower Pressure
Oxide
SiC
400 500 600 700 800 900 1000 1100 1200
Time [sec]


TOF SIMS (Thermal Ox)
Intensity [count/sec]
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
SiO2 with Cl
SiO2 without Cl
Si with Cl
Si without Cl
Interface
Si@Thermal Ox w/ Cl
SiO2@Thermal Ox w/ Cl
Si@Thermal Ox
SiO2@Thermal Ox
Oxide
SiC
400 500 600 700 800 900 1000 1100 1200
Time [sec]



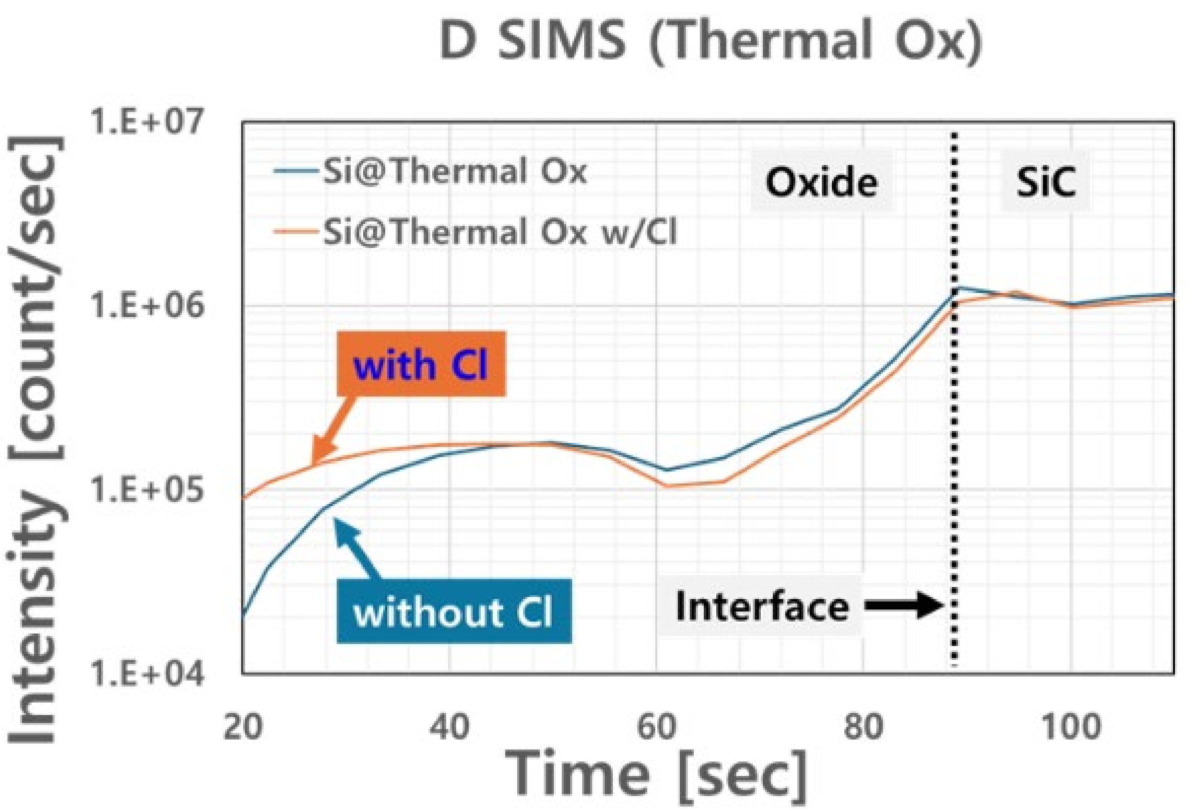


Fig. 1. SIMS comparison.

To compare the effects of pressure and chlorine in the gate oxidation process, TOF-SIMS and Dynamic SIMS(D SIMS) analysis (Fig. 1) were conducted. D SIMS analysis revealed the behavior of chlorine within the oxide layer, showing uniform Si distribution in the presence of chlorine. Similarly, TOF-SIMS analysis confirmed that in the presence of chlorine, both Si and SiO_2 exhibited uniformity within the layer.

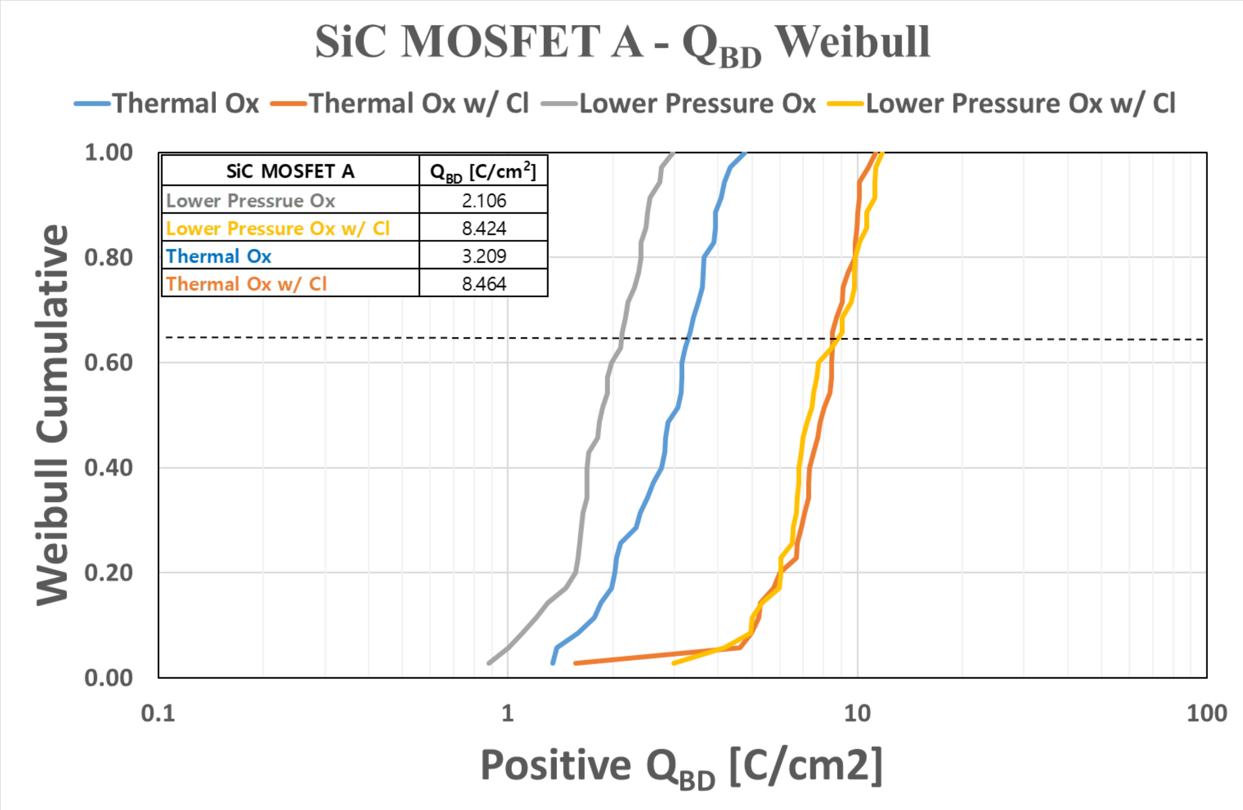


Fig. 2. Q_{BD} comparison – SiC MOSFET A, Istress=20mA/cm^2, Tstress=25°C.

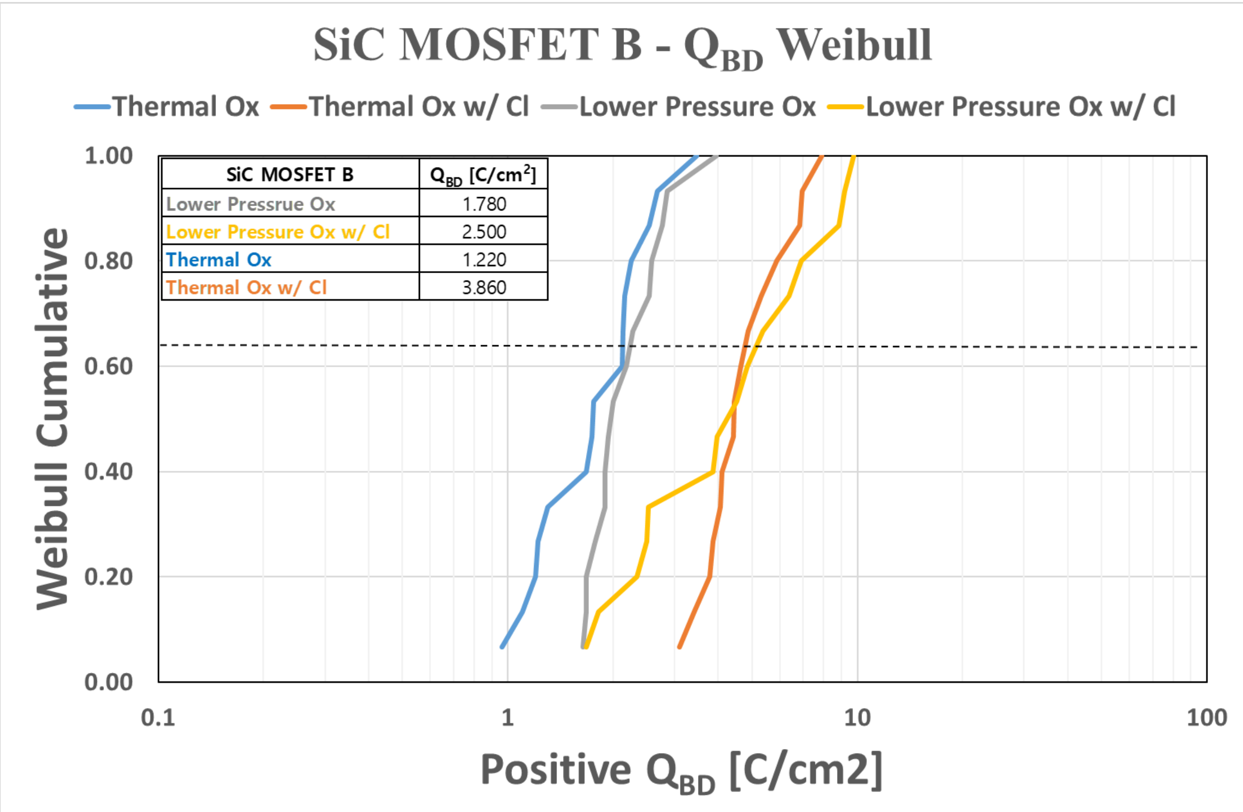


Fig. 3. Q_{BD} comparison – SiC MOSFET B, Istress=20mA/cm^2, Tstress=25°C.

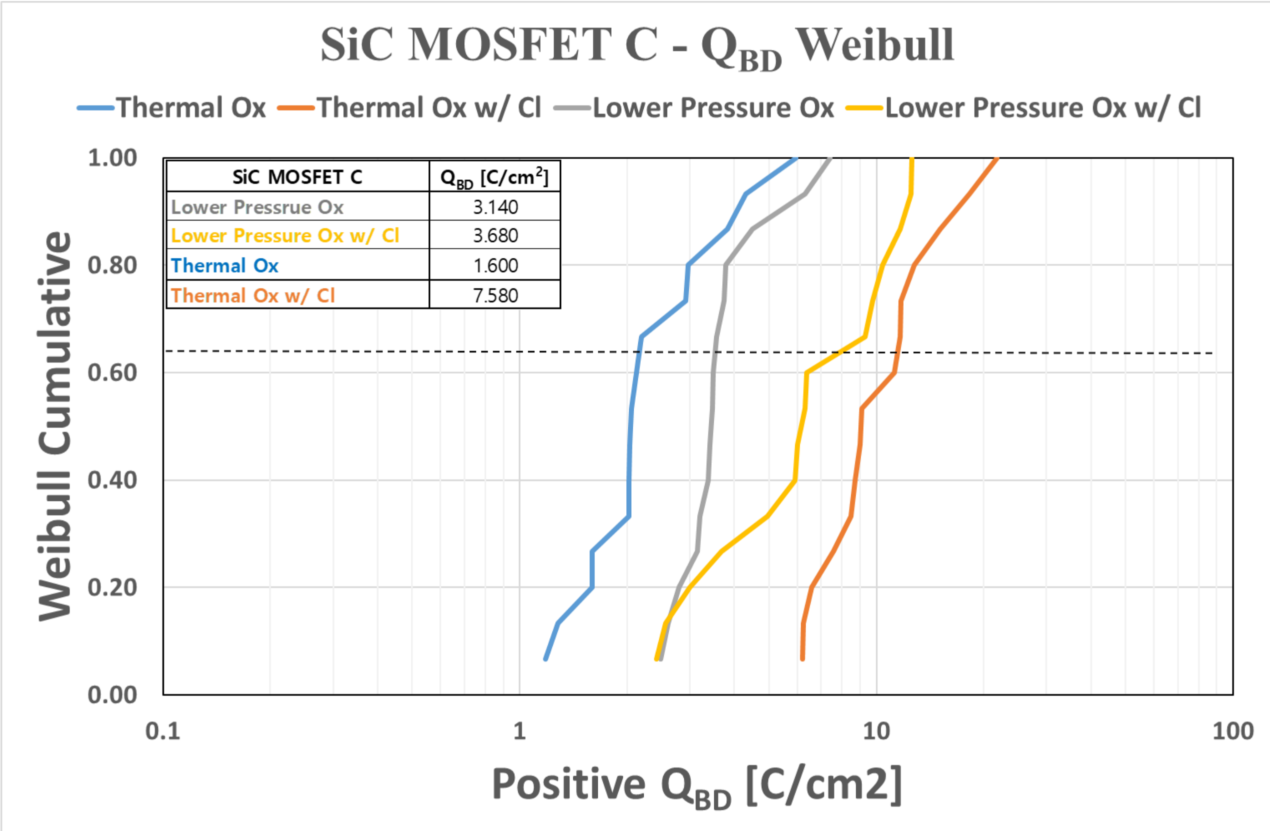


Fig. 4. Q_{BD} comparison – SiC MOSFET C, Istress=20mA/cm^2, Tstress=25°C.

The Q_{BD} is a standard destructive test method to verify the gate oxide quality in MOSFET devices. To evaluate the effect of pressure control and added chlorine gas during thermal oxidation, Q_{BD} characteristic is evaluated. As shown in Q_{BD} (Fig. 2-4) we obtained the results that improved at added chlorine gas (8.464 C/cm^2) better than thermal oxidation (3.209 C/cm^2).

The SIMS analysis and Q_{BD} evaluation results demonstrate the effect of added chlorine during the GOX thermal oxidation process. [5-7] Experimental results confirmed that the passivation or gettering effect reduces the defects within the GOX layer formed on the SiC wafer, leading to the formation of stable SiO_2.

Summary

The analysis results of this study demonstrated that, regardless of the pressure conditions in the GOX process, the gate oxide treated without chlorine exhibited a significant decrease in silicon concentration from the SiC/SiO_2 interface to the SiO_2 surface. In contrast, the gate oxide formed through chlorine oxidation maintained a consistent silicon concentration throughout the entire GOX layer. This signifies the maintenance of uniformity in SiO_2 across the entire gate oxide area and serves as evidence for improved Q_{BD} compared to gate oxides under different conditions showing Si concentration degradation comparatively due to carbon defects. Therefore, thermal oxidation with chlorine can form a stable SiO_2, and this effect is an improvement in gate oxide quality, as seen in Q_{BD} improvement results of SiC MOSFET devices.

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