Total-Dose Radiation Response of Atomic Layer Deposition Al_2O_3 Films

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Abstract

The objective of this work targets the reliability of ALD high dielectric constant (high-k) oxide when exposed to space radiation.

Spacecraft rely on advanced microelectronic devices to perform actions in outer space such as power conversion, communication and computing. Integrated circuits (ICs) utilized in space applications require materials for reliable performance due to the constant bombardment of radiation.[1] The constant exposure to space radiation may cause storage failure, performance degradation, and even catastrophic failure in these devices. SiC is considered one of the most radiation and thermal stable semiconductor materials.[2] Also to meet the need of reduced leakage currents and feature scaling in advanced microelectronic devices, atomic layer deposited (ALD) high dielectric constant gate dielectric films (e.g. Al_2O_3, HfO_2, etc) have been investigated[3] in microelectronics. This work is to determine whether ALD gate oxides can be used to improve SiC device performance under space radiation conditions by studying the total-dose radiation response of the devices.

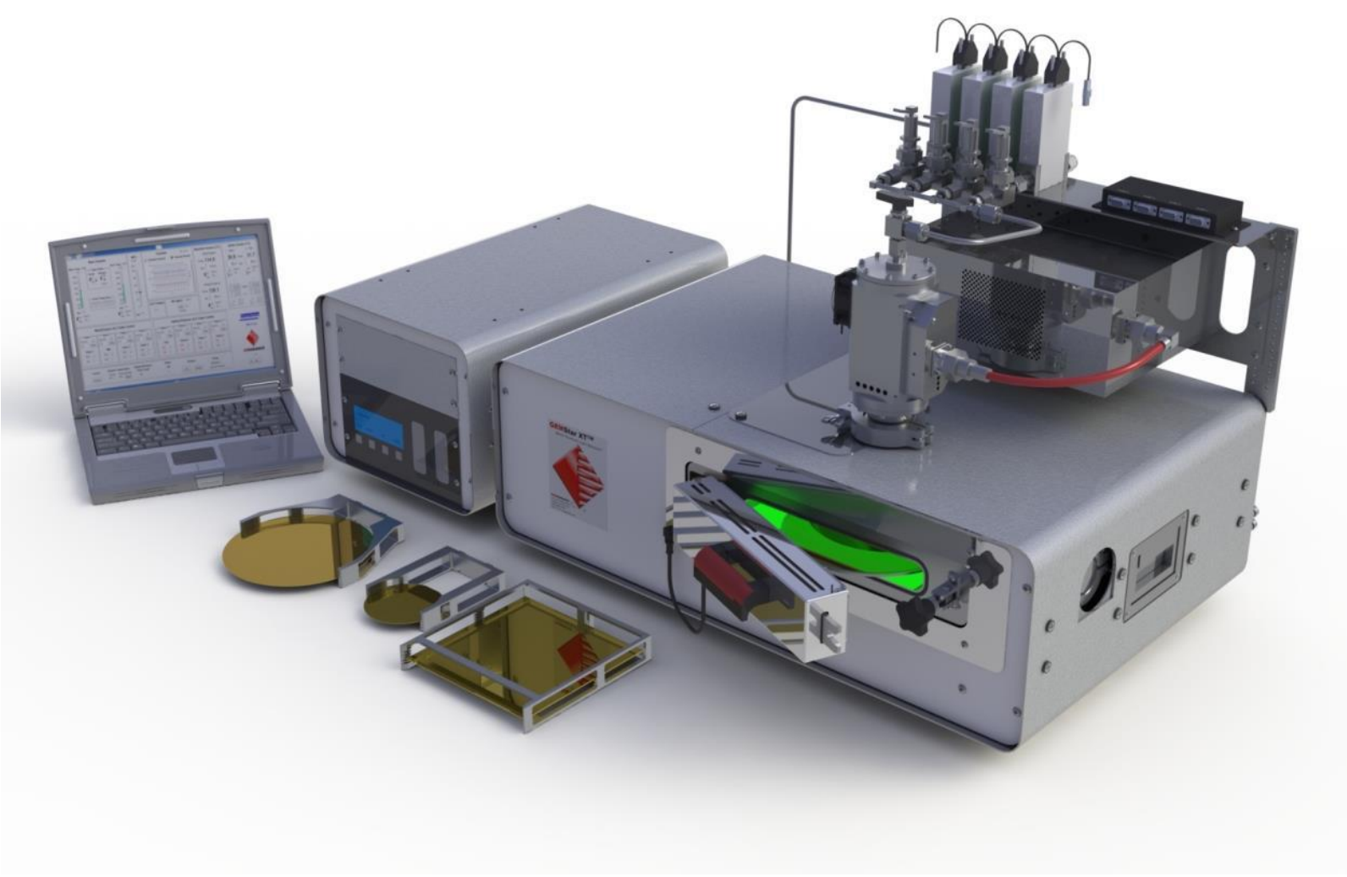
This study chose Alumina (Al_2O_3) because Al_2O_3 is the most stable, reliable and well studied dielectrics.[4-7] The favorable properties of Al_2O_3 include large band gap and band offset, thermodynamic and kinetic stability, low bulk defect density, and high radiation resistance. These properties satisfy most of the guidelines for an ideal gate oxide used in aerospace.

SiC technology, requires significant attention on the interface between a dielectric and the SiC, given SiC's particular challenge with channel mobility. This presentation highlights different surface preparations to the SiC substrates prior to ALD processing in an attempt to yield improved interface characteristics by mitigating surface states. Characterization of the pre and post total-dose radiation response measured by the C-V test method is provided as well.

Precursors and Instrumentation

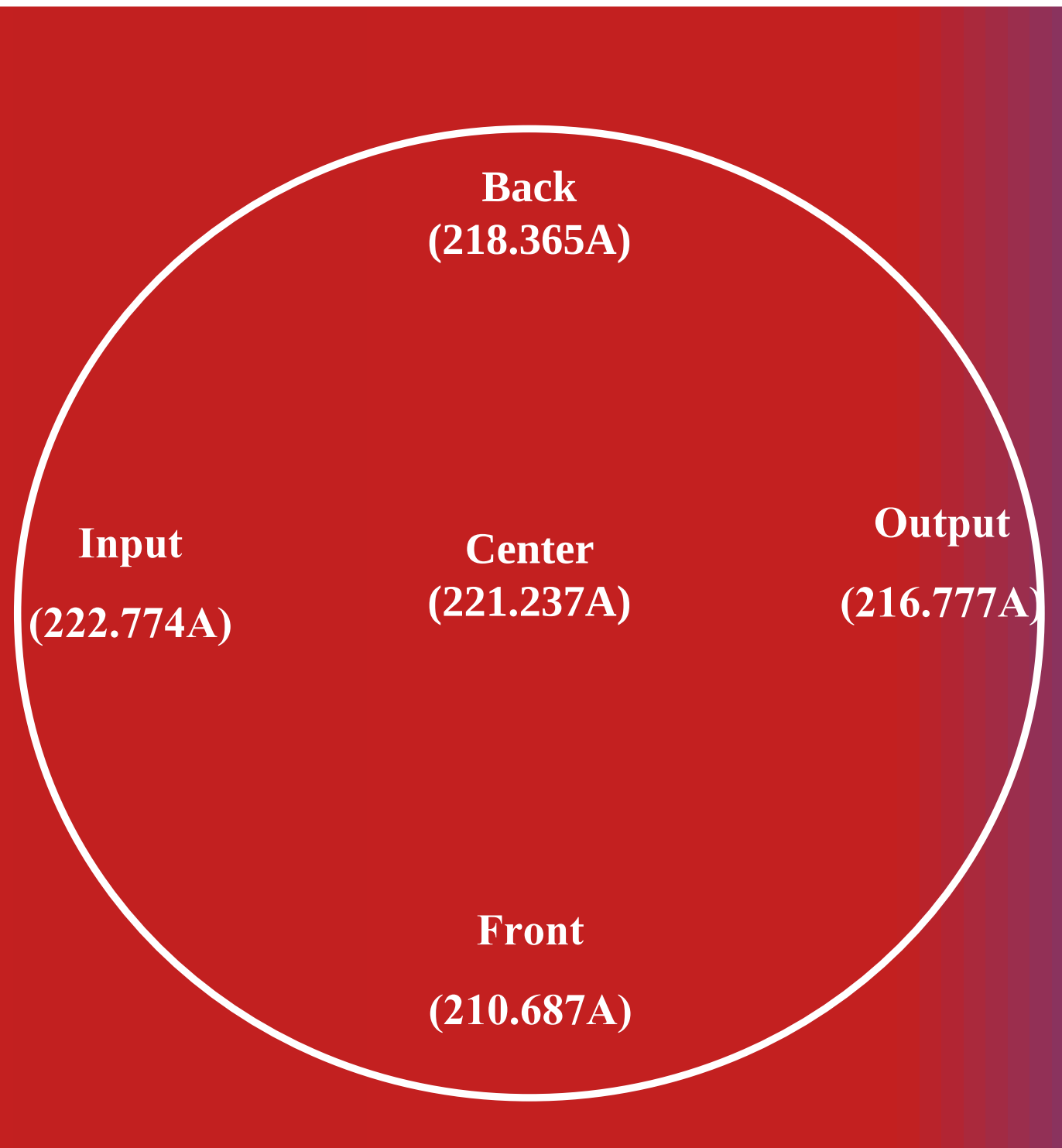
- **TMA provided the Al source and DI Water provided the O source.**
- **All films were deposited on a GEMStar XT™ ALD system with cassettes at 300 ℃.**
- **Commercial SiC substrates and one control Si substrate were pre-cleaned by *in-situ* O_3 cleaning and deposited with Al_2O_3.**
- **Following ALD processing each wafer was annealed.**
- **Total Dose radiation tests were performed using Cobalt 60 Radiation Source.**
- **C-V test were MDC Capacitance-Voltage Test System**

Cobalt 60 Radiation Source

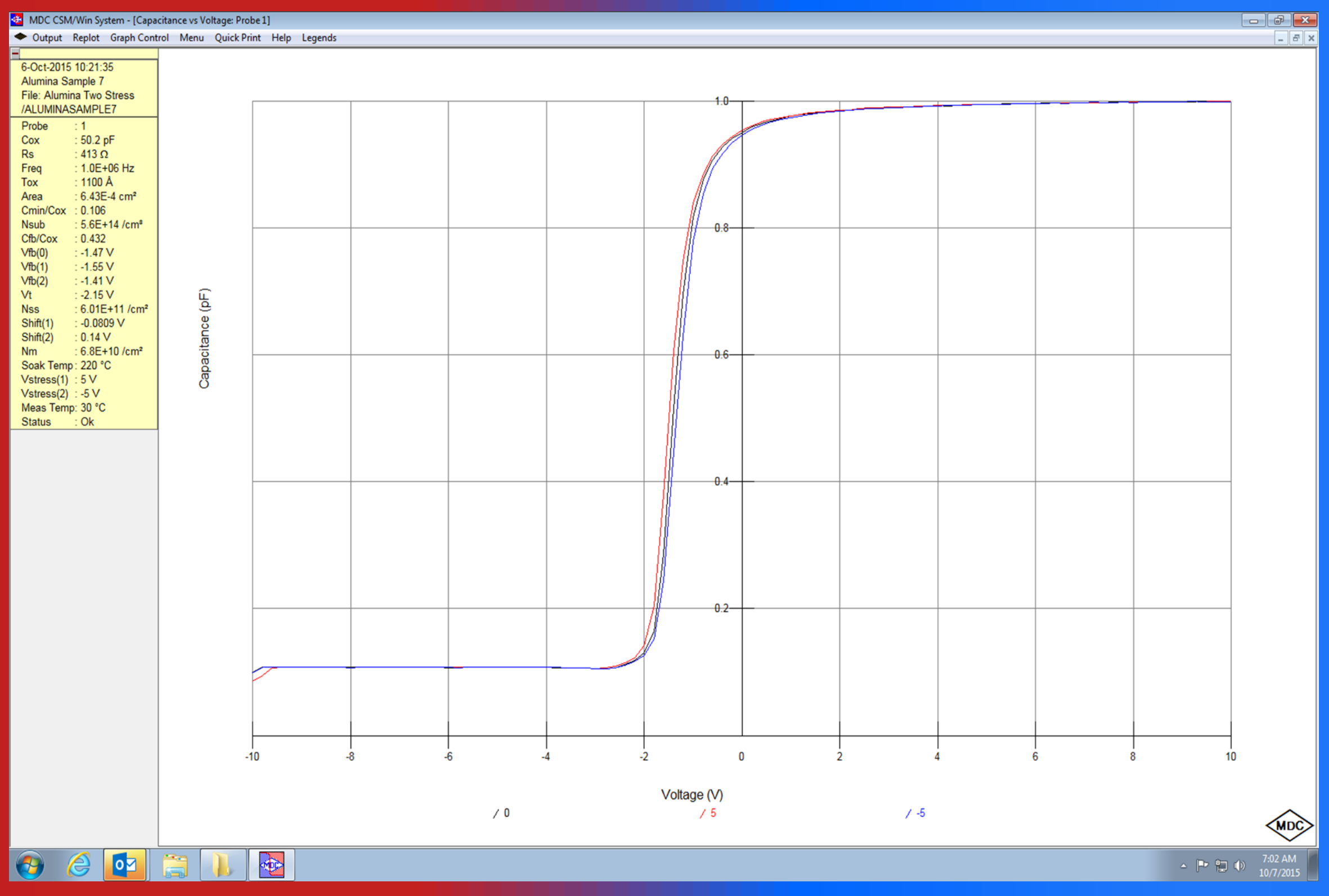


GEMStar XT™ ALD system

ALD Al2O3 Performance on Control Si wafers



The performance of typical ALD Al_2O_3 on 4" Si substrate using standard recipe at 300 °C with 8 s purging is shown at the left graph. The growth rate is 0.87 Å/cy. The stress for 100 nm of Al_2O_3 is < 150MPa and stable.



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MDC CSM/Win System - [Capacitance vs Voltage: Probe 1]
Output  Replot  Graph Control  Menu  Quick Print  Help  Legends

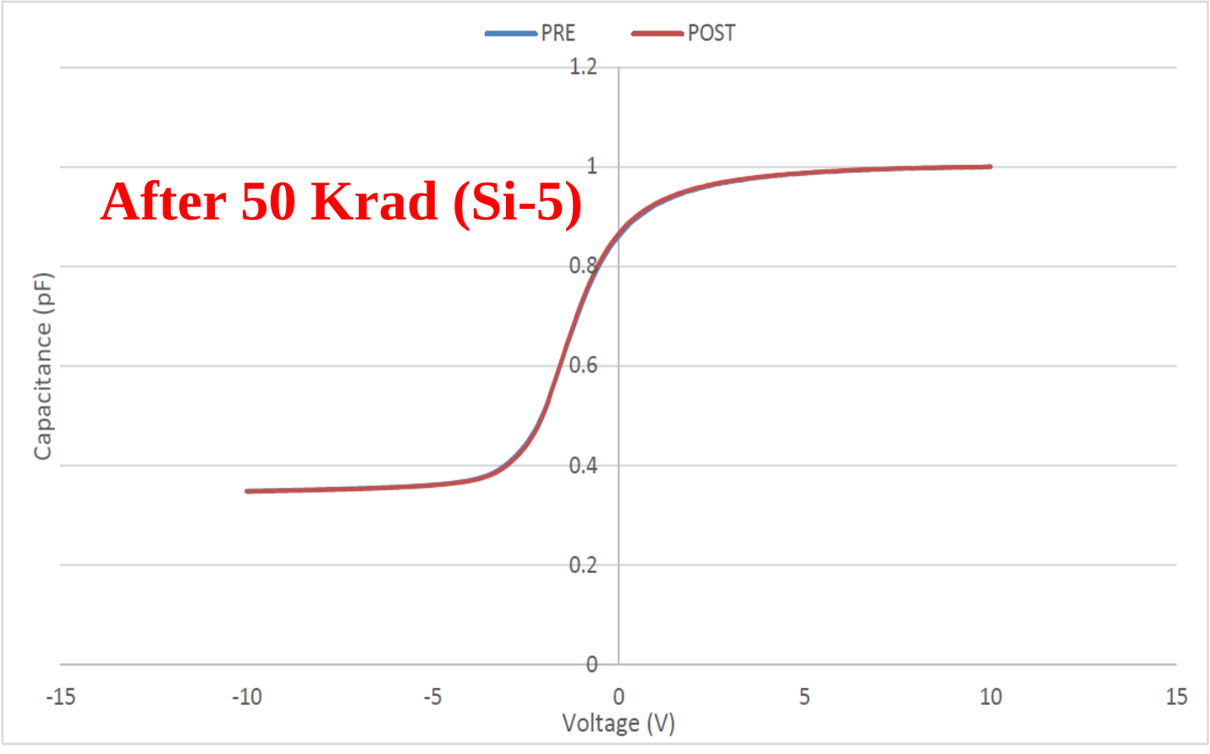
6-Oct-2015 10:21:35
Alumina Sample 7
File: Alumina Two Stress
/ALUMINASAMPLE7
Probe      : 1
Cox        : 50.2 pF
Rs         : 413 Ω
Freq       : 1.0E+06 Hz
Tox        : 1100 Å
Area       : 6.43E-4 cm²
Cmin/Cox   : 0.106
Nsub       : 5.6E+14 /cm³
Cfb/Cox    : 0.432
Vfb(0)     : -1.47 V
Vfb(1)     : -1.55 V
Vfb(2)     : -1.41 V
Vt         : -2.15 V
Nss        : 6.01E+11 /cm²
Shift(1)   : -0.0809 V
Shift(2)   : 0.14 V
Nm         : 6.8E+10 /cm²
Soak Temp: 220 °C
Vstress(1) : 5 V
Vstress(2) : -5 V
Meas Temp: 30 °C
Status     : Ok
```

The typical C-V curve of ALD Al_2O_3 films done by standard recipe at 300 °C shows a dielectric constant of 9.7.

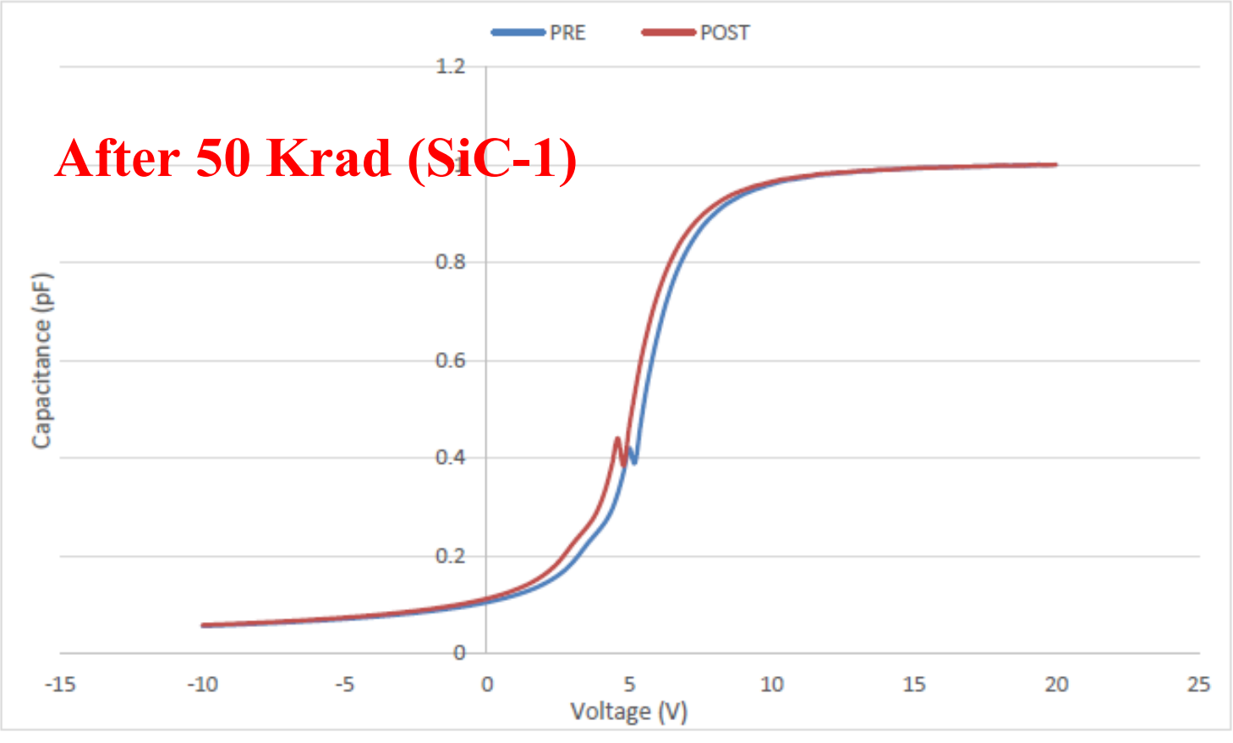
Total Dose Radiation Study on ALD Al2O3

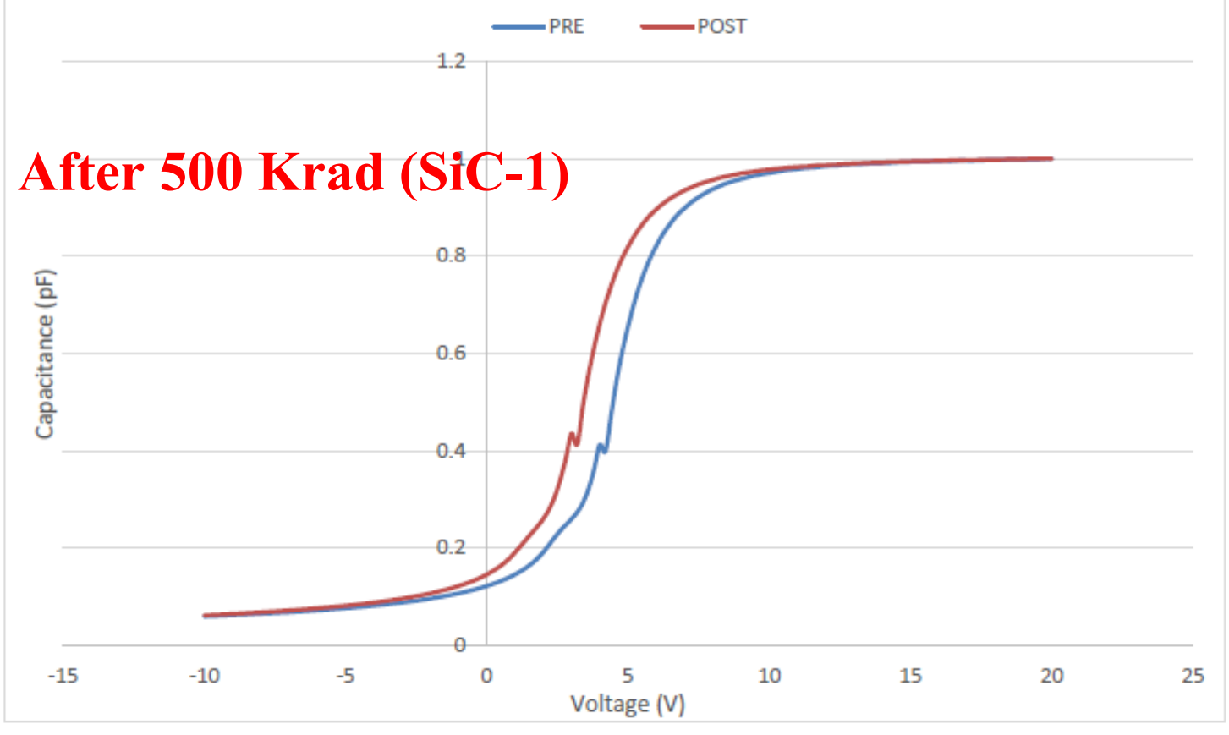
Wafer	Pre ALD treatment	Post ALD anneal
Si-5	5 mins of oxidation at 900°C to compensate for film stress	1100°C under N_2 for 30 mins then ramp to 1200°C under N_2 for 30 mins
SiC-1	Anneal at 1200°C under N_2 for 30 mins. It was attempted to passivate the surface by bonding nitrogen to any surface dangling bonds.	1100°C under N_2 for 30 mins then ramp to 1200°C under N_2 for 30 mins
SiC-2	5 mins under O_2 at 900°C then ramp to 1200°C under N_2 for 30 mins. It was attempted to further mitigate dangling bonds and surface states between the SiC/Al_2O_3.	950°C in a N_2 environment for 180 mins

All three wafers processed in one batch with 100 nm of Al_2O_3.

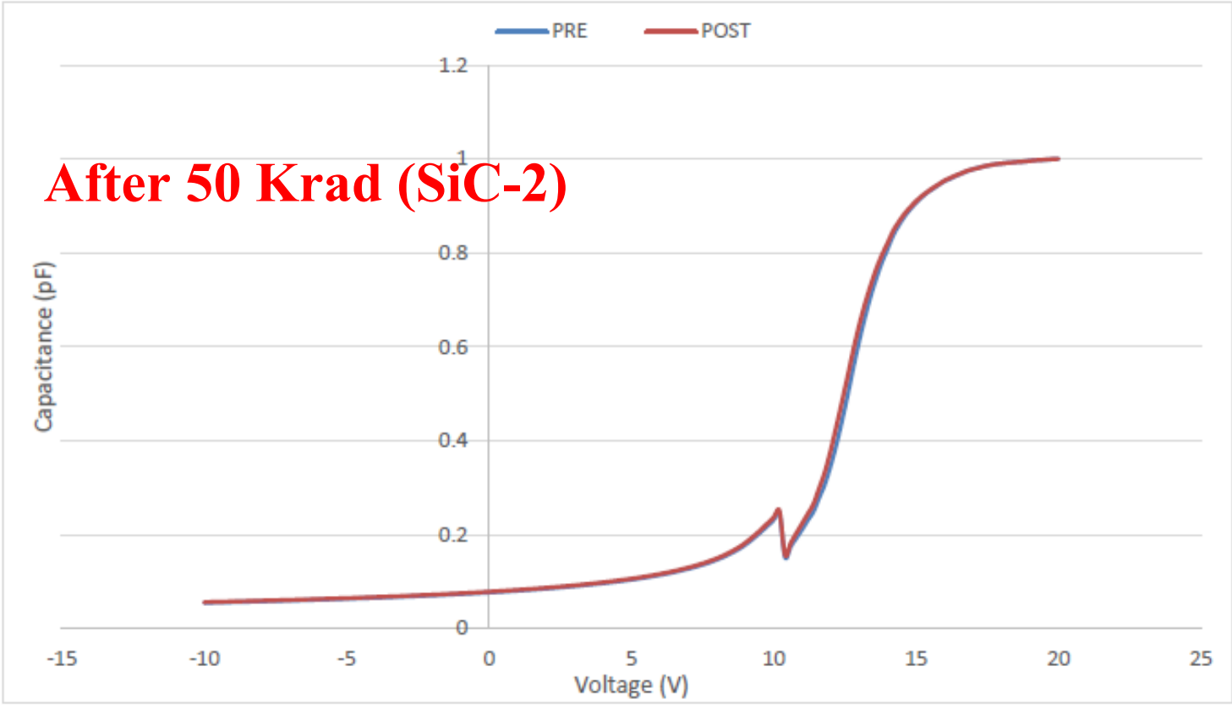


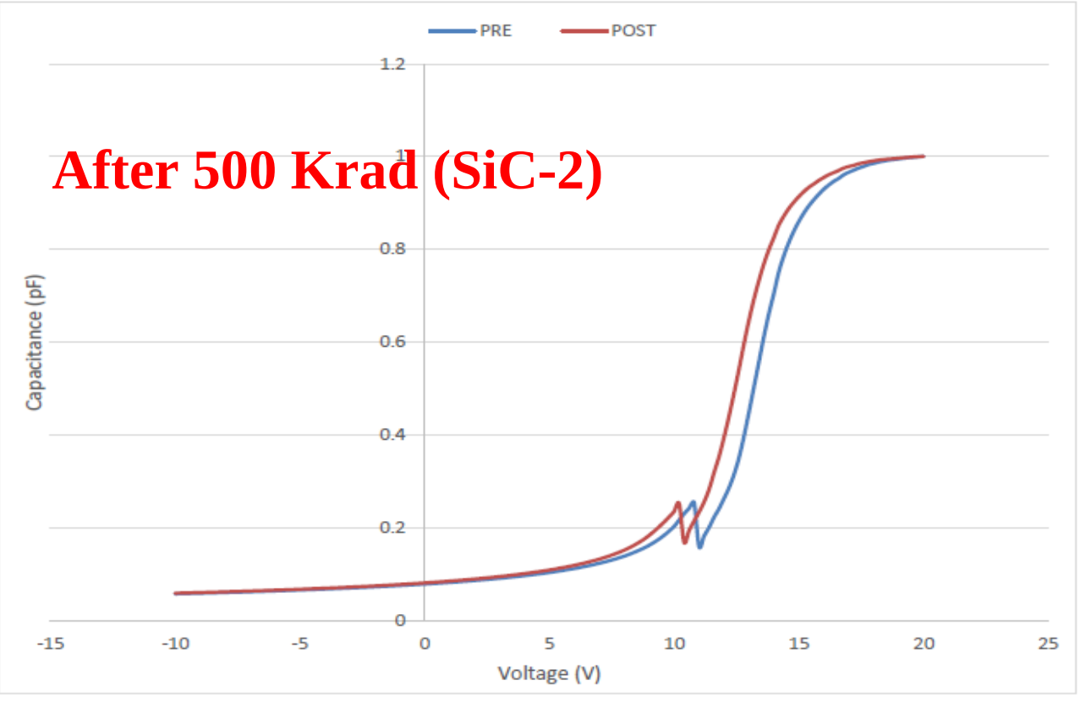
For control Si-5, flatband voltage shifts to negative very little indicating a positive fixed charge at a minimum. The pre-ox interface counteracts the negative fix charge in Al_2O_3. After 50 Krad exposure, flatband voltage changes little while after the 500 Krad exposure to same sample, flatband voltage shifts further left indicating a net positive charge accumulation within Al_2O_3.



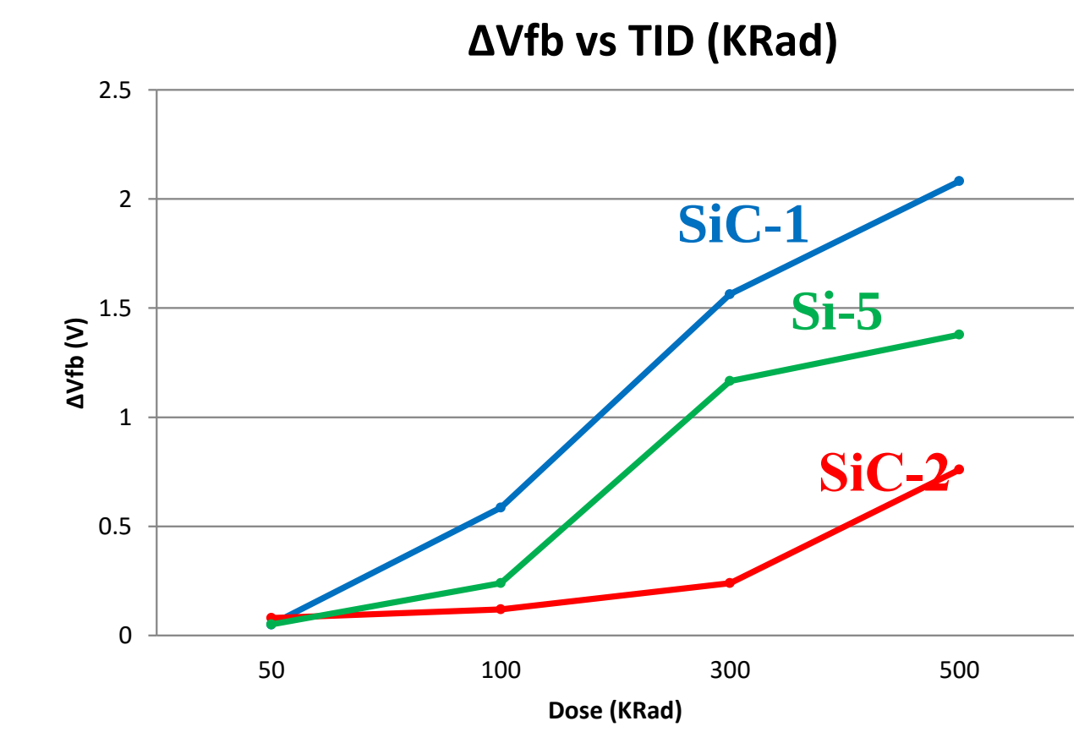


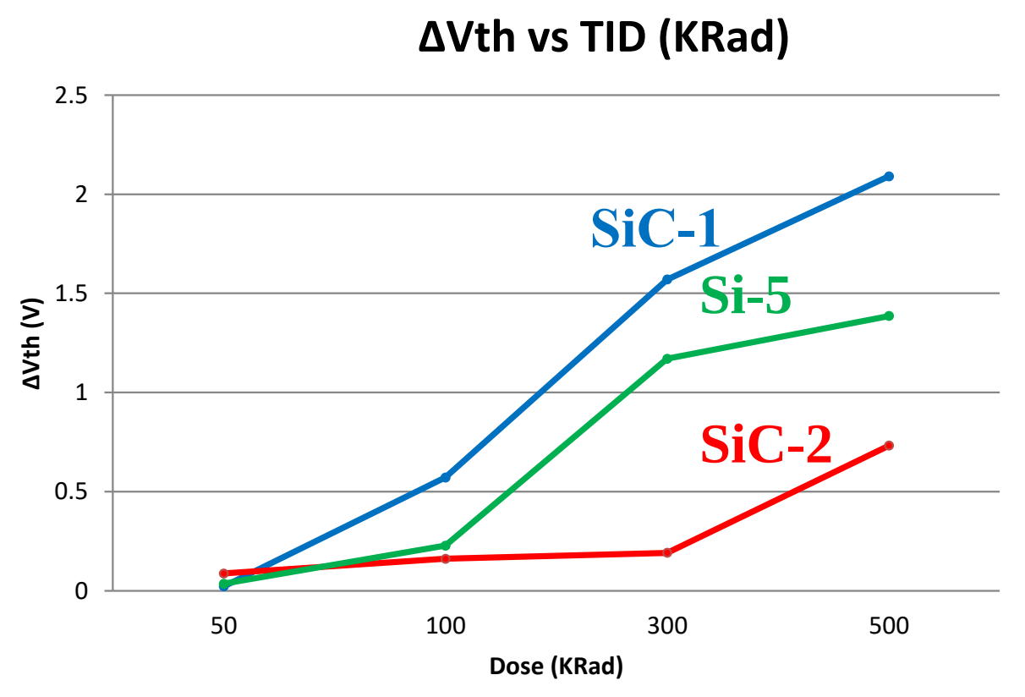
For SiC-1, flatband voltage shifts to positive voltage indicating negative fix charge. The source of fixed charge is attributed to trapped hydroxyl groups in the film.[8] Flatband shift follows the same trend of control Si-5 after radiation exposure. And the flatband voltage shifts to the left after the 500 Krad exposure, also indicating a net increase in positive charge within Al_2O_3.





For SiC-2, the flatband voltage shifts to more positive than SiC-1 indicating more negative charge in Al_2O_3. That is believed to due to the oxy-nitride interface pretreatment. Flatband shift follows the same trend as control Si-5 and SiC-1 after radiation exposure. And the flatband voltage shifts to the left after the 500 Krad exposure, also indicating a net increase in positive charge within Al_2O_3.





Even though the flat band voltage and the threshold voltage have different values, the change due to radiation exposure in the two parameters is practically an overlay, indicating there is very little radiation induced trapped or interface charge. This is a promising result to demonstrate that a thick Alumina can be allowed as a gate dielectric to improve the single event radiation hardness.

Summary

1. Different surface treatments alters the nonstoichiometric initial Al_2O_3 growth regime, which is responsible for the charge formation. It will affect the flatband voltage shifts along with fixed charge in Al_2O_3 . he combination of Oxygen and Nitrogen pretreatment cause more negative charge along the surface.

2. The change due to radiation exposure in the flatband and threshold voltage is practically an overlay, which indicates there is very little radiation induced trapped or interface charge. It shows that Alumina is promising as a gate dielectric will allow for thicker gate oxides to improve the Single Event hardness.

Acknowledgements

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