Virtual Research Presentation Conference

Hydrogen contamination and its correlation on the defect build-up in Si/SiO2 interface

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Program: Spontaneous Concept

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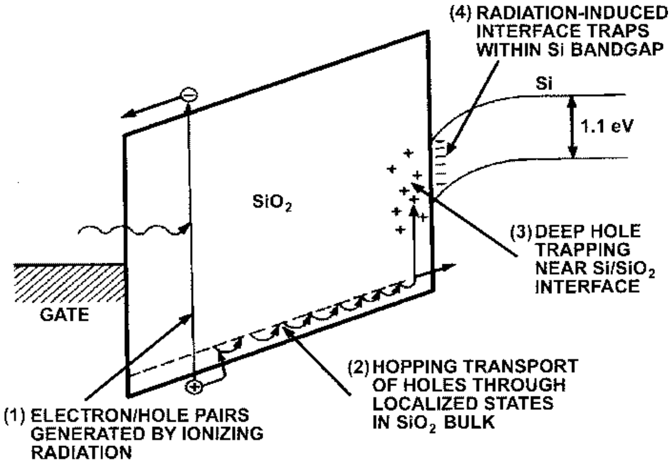
Tutorial Introduction

Abstract

Total Ionizing Dose (TID) degradation is a radiation effect characterized by progressive accumulation of charge within an electronic device, which results in parametric degradation over time and eventual device failure. The way that a given part will respond to TID depends heavily on factors in the fabrication process, which in turn leads to significant variability in TID performance between fabrication runs.

Arizona State University had previously developed the IMPACT modeling tool, a physics-based circuit-level model capable of accurately predicting TID performance for a given bipolar component. The model is capable of producing very accurate predictive results, with the caveat that some of the input parameters which feed into the model cannot be directly measured from an end-user component. Most notably, hydrogen contamination in the Si/SiO_2 interface, which has a dramatic effect on the predicted TID performance of a part.

The goal of this research was to assess the feasibility of and potentially begin developing a method for indirectly measuring hydrogen contamination levels in a given part, for the purpose of greatly reducing the spread on a part's TID performance, as predicted by the IMPACT modeling tool. Ultimately, the goal is for the IMPACT tool will be able to provide lower-budget missions with an accurate assessment of a part's expected TID performance, in lieu of performing a full Radiation Lot Acceptance Test (RLAT).



Schematic energy band diagram for MOS structure, indicating major physical processes underlying radiation response. [Oldham, T. and F. B. McLean. "Total ionizing dose effects in MOS oxides and devices." IEEE Transactions on Nuclear Science 50 (2003): 483-499.]

Problem Description

a) As JPL begins to take part in more and more Type-II/Class D missions, such as SmallSats or Technology Demonstrations, there is a growing need to explore and develop lower-cost radiation assurance methods, in order to provide some middle ground between a cost-prohibitive test and doing nothing. At the moment, Total Ionizing Dose degradation is one such area that lacks a lower-budget assurance path. For most Type-II missions, a Radiation Lot Acceptance test is cost-prohibitive. A lower-cost option more in keeping with typical Type-II risk posture would be of great benefit to current and future SmallSat assurance efforts.

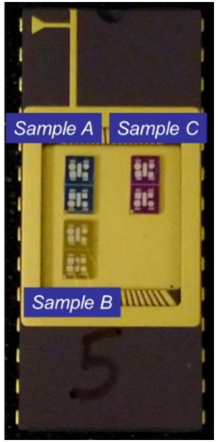
b) Many studies have investigated how hydrogen concentration impacts defect build-up in oxides; however, no correlation exists between the hydrogen content in the electronic devices and the defects build-up created in the oxide layer during irradiation. Additionally, cost-efficient predictive modeling for TID performance does not currently exist, insofar as, measurements taken to feed the models typically cost as much as simply performing a TID test. As such, the ability to return accurate predictive results using relatively inexpensive tests (e.g. Residual Gas Analysis) would constitute a state of the art capability.

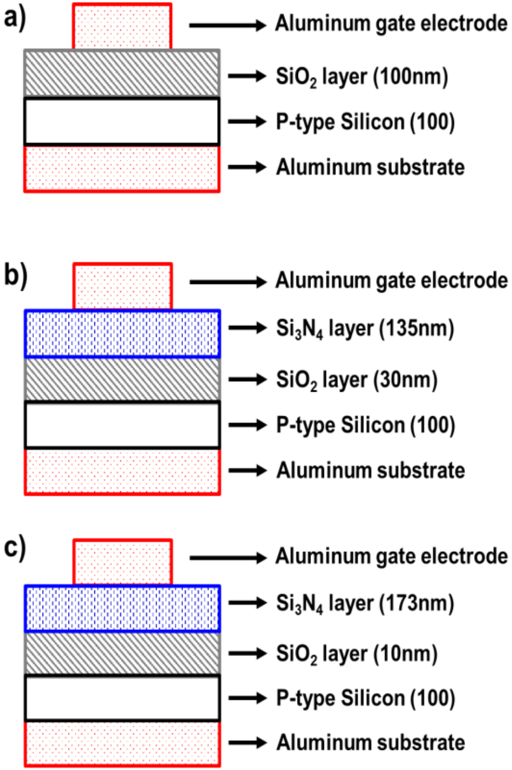
c) The ability to provide a lower-cost process for assessing TID performance (albeit at a slightly higher risk posture) would be of great benefit to SmallSat and Technology Demonstration missions at JPL and at other NASA Centers, who would otherwise, in the face of cost-prohibitive testing, be forced to disregard TID analysis, and assume it as a medium or potentially high risk.

Methodology

a) Linear bipolar circuits such as comparator, operational amplifier, and low-dropout voltage regulator exhibit ELDRS where at low-dose rate (LDR), the circuit shows more degradation than at high-dose rate (HDR). It has been shown that ELDRS depends on several factors such as oxide thickness, internal electrical field, final passivation material, and pre-irradiation elevated temperature stress. More recently, it was experimentally demonstrated that ELDRS is strongly related to the hydrogen content in the part's passivation layer and package. Indeed, hydrogen is used intentionally during fabrication process to improve the reliability of the electronic devices by reducing traps at the Si/SiO_2 interface.

b) In this work, conventional MOS and MNOS capacitors with **different passivation layer compositions** were fabricated and irradiated at **different hydrogen concentrations**. Nitride is known to be a barrier to hydrogen diffusion which prevent penetration of externally applied hydrogen. The defects build-up created during irradiation in each capacitor was extracted using TCAD simulations.



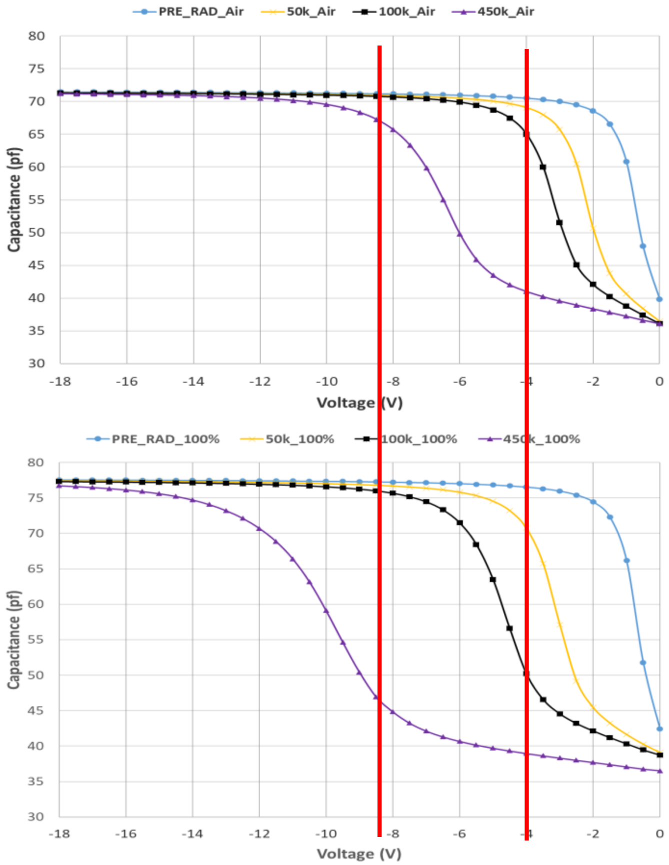


Results

a) This work has successfully established a clean correlation between passivation layer composition and defect built-up over a varied hydrogen environment.

b) The development of a correlation matrix comprising the results of easily-performed in-lab measurements (e.g. passivation layer composition analysis, residual gas analysis) is a crucial step towards indirectly measuring hydrogen contamination levels in a part, and allowing for effective predictive modeling of TID performance.

c) Having established the passivation layer component of the aforementioned correlation matrix, the next step for this effort would involve Residual Gas Analysis on the various test samples for inclusion in the correlation matrix. Following that, a proof of concept test on two separate lots of an actual EEE component (e.g. LM139) to demonstrate the ability of IMPACT to predict lot-to-lot variations.



Capacitance-Voltage measurement of the Sample A irradiated under a hydrogen environments: 0% (top) and 100% (bottom). Gate electrode is 500x500um. Clear differences in voltage shift with respect to TID (purple line) can be seen between samples.

Publications and References

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