Modeling and Characterization of Radiation Effects in CMOS Devices and Circuits

Abstract

Use of commercial off the shelf electronics for space applications, in nuclear power plants as well as in high-energy physics experiments has led to an increase in research for radiation tolerant technologies. The main objective of this thesis is to investigate and study the radiation response of advanced CMOS technologies through TCAD simulation and characterization. In this thesis, first the single event transient effect is studied and analysed at the device level for planar as well as advanced MOS devices using TCAD simulations. The effect of alpha-particle and heavy-ion irradiations on the single event transient (SET) response of silicon on insulator (SOI) technology is evaluated. For this, thickness scaled fully depleted SOI (FD-SOI) and partially depleted SOI (PD-SOI) devices conforming to 0.18µm technology node are used. With advancements in semiconductor technology, the sensitivity of Integrated Circuits (ICs) to radiation has increased significantly. Inserted oxide FinFET (iFinFET), which is an evolutionary transistor design, provides better electrostatic integrity compared to FinFETs. The iFinFET device architecture can be of interest for low-power space applications due to its improved performance compared to FinFET. In this thesis, the heavy-ion induced SET response of SOI-FinFETs and iFinFETs conforming to 14 nm technology node is analysed using calibrated TCAD simulations. Transient response of SOI-FinFETs and iFinFETs with varying fin widths, gate lengths, and number of inserted oxides under heavy-ion irradiation are compared. At the system level, embedded memories such as SRAM and embedded-DRAM (eDRAM) are extensively used electronic systems operating under harsh environments. Therefore, to analyse the single event upset (SEU) sensitivities of such memory cells, mixed mode TCAD simulation is utilized. First, heavy-ion induced SEUs are evaluated for SRAM bit-cells designed using these FD-SOI and PD-SOI devices conforming to 0.18 µm technology node. Next, as eDRAM has emerged as a high-speed and high-density replacement for SRAM in embedded memory of the mobile electronic systems requiring large on-chip memories, they may prove to be fatal in presence of ionizing particles. Therefore, next in this thesis, the heavy-ion induced SEU sensitivity of eDRAM designed using a SOI-FinFET conforming to 14-nm technology and deep trench (DT) capacitor is evaluated.

The degradation in electrical performance of these MOS devices under radiation is collectively referred to as total ionizing dose (TID) effect. In this thesis, the deterioration in 180nm n-channel bulk MOSFETs caused by 1 Krad(Si) and 1 Mrad(Si) dose gamma-ray radiations has been investigated. Since TID effect is one of the major concerns for semiconductor devices operated in space, the DC and RF characteristics of advanced devices need to be highly reliable under harsh environmental conditions. Therefore, in this thesis the effect of gamma-ray radiation on DC response of 10-nm bulk FinFETs is demonstrated, where the changes in major DC parameters such as off-state drain current (I_{OFF}), on-state drain current (I_{ON}), threshold voltage (V_{TH}), subthreshold-swing (SS) are reported and analysed for various FinFET geometries. The devices are exposed without any applied bias to a maximum cumulative dose of 42 Mrad(Si). Further, a detailed analysis on the impact of gamma-ray radiation on RF performance of 10-nm bulk FinFETs is reported and an empirical model is developed to demonstrate degradation in the maximum oscillation frequency, f_{MAX} across the device geometry.