

Space-Radiation Effects in Advanced SOI Devices and Alternative Gate Dielectrics

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Space systems rely on advanced microelectronic devices to perform functions including communication, control, imaging, and power conversion. While in space, they are exposed to various forms of radiation, including high-energy photons and energetic particles. This radiation may cause problems, ranging from temporary loss of data to catastrophic failure, that depend strongly on the specific technology and the radiation environment. Most space systems are designed conservatively using electronic parts that are several generations behind the current state of the art, but the demand for higher performance and reduced time from design to flight has increased the pressure to use advanced technologies. The effects of radiation in some advanced technologies are poorly understood or, in some cases, completely unknown. At present it is not clear whether some advanced technologies are usable in space at all, no matter how impressive their performance. In addition, highly scaled devices may be sensitive to the naturally occurring radiation at the earth's surface, even though the atmosphere provides significant protection. Here we consider trends in the radiation response of silicon integrated circuits due to two important technology developments: silicon-on-insulator (SOI) substrates and alternative gate dielectrics.

Silicon-on-insulator technology has significant advantages for use in transient radiation environments. When exposed to heavy ions in space, devices fabricated on SOI substrates are less likely to exhibit single-event upset (SEU) because of their reduced charge-collection volume. However, SOI devices may be more vulnerable to long-term degradation caused by continuous exposure to the space-radiation environment (total-dose effects). Ionizing radiation produces electron-hole pairs in the buried oxide layer, typically leaving a net positive charge in the oxide that leads to the formation of an inversion layer and increased back-channel leakage. In addition, charge may be collected through the buried oxide layer in deep submicron SOI devices when they are exposed to heavy ions. The mechanisms responsible for this enhanced charge collection are uncertain, although displacement-current effects and enhanced recombination have been suggested as possibilities. We will discuss the current understanding of this phenomenon and present recent simulation results of radiation effects in SOI MOSFETs.

Radiation effects in gate dielectrics depend strongly on the thickness and composition of the film. The threshold voltage shifts due to charge trapping typically vary as t_{ox}^2 for thicker oxides; in thin oxides the dependence is even stronger. Radiation hardness improves as oxides become thinner because both the volume in which charge is generated and the moment arm of the trapped charge decrease. Recent total-dose results obtained for several alternative dielectrics suggest that radiation hardness decreases compared to oxide films of equivalent electrical thickness because of the greater physical thickness and potentially lower film quality. While the voltage at which catastrophic failure occurs decreases with film thickness, the operating voltage also decreases. The results of heavy-ion irradiation at Brookhaven National Laboratory suggest that alternative dielectrics will be less sensitive to heavy ion-induced failure because the failure threshold scales with the physical thickness rather than the electrical thickness.