Use of Proton SEE Data as a Proxy for Bounding Heavy-Ion SEE Susceptibility

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Abstract: We examine use of proton data to constrain heavy-ion SEE susceptibility. We discuss limitations due to short range proton recoils and develop an approach for using proton data to constrain on device sensitive volumes.

Introduction, Data and Method

Although heavy-ion single-event effects (SEE) pose serious threats to our nation’s space and ground-based technologies, there remain significant challenges in predicting the effects of SEE in integrated circuits. Protocols for testing that provide useful bounds on susceptibility are not yet established, with both overestimates and underestimates possible.  As a result, many components are designed with a conservative margin, while others may not be hardened enough.  In a community-driven approach, a common test framework is being developed as part of the SEU-2020 project, in which computer simulations are coupled with data-driven approaches to constrain SEE risk.  To validate this approach, we conducted a range of tests using both test vehicles and COTS systems with little insight into their components.  Heavy-ion testing for large volumes of components is challenging, requiring a focus on testing a representative sample of components with a spectrum of LET.

Table I: Proton vs. Heavy Ion Testing

Radiative Energy Deposition (MRED) package, which in turn uses the LET fluctuations away from the average indicated by LET. See Figs. 1-2, irregular and regular dependence of SEER and SEEB suggest proton testing will significantly underestimate the SEE impact of heavy ions.

The situation is more favorable for SEER. However, improperly accounting for the angular and Z dependence of SEER results in significant overestimates in high-Z materials. As a result, the SEER test fluence to exceed the SEEB test fluence by a factor of 1.2. The results of would likely match those of [4] for SEER significantly larger than 22 nm. This effect stems from the model for the angular and Z dependence of high-energy ions that can trigger error modes that would not be revealed by heavy-ion testing. At the 22 nm node and below, this could be a significant concern for multi-level stacks and upset hardened, featureless devices in spatially separated redundant nodes for their hardening.

Generalized Linear Model

Although proton SEE test data can constrain heavy-ion SEE susceptibility, the SEE-induced SEE mechanisms pose significant challenges. The possible dependence of SEE mechanisms on proton energy and LET indicated by LET in the physics models. To verify this, we combined differential energy cross section vs. LET curves that are consistent with the proton data to a linear model to constrain the Weibull parameters and determine the heavy-ion LET cross section.

Using Monte Carlo simulations, we can differentiate between candidate SV and better constrain SEE rates. With heavy ions, we parameterize the Weibull distribution and use a Generalized Linear Model to constrain the Weibull parameters and determine the heavy-ion LET cross section. We assume that the cross section follows a Weibull and use a Generalized Linear Model to constrain the Weibull parameters and determine the heavy-ion LET cross section. This is not only lower for onset voltage but only for large fluences of high-energy protons. We defined an equivalent LET as the average energy loss of a 100 MeV proton recoiling in the SV normalized to the material density.  The results of this would likely match those of [4] for SEER significantly larger than 22 nm. This effect stems from the model for the angular and Z dependence of high-energy ions that can trigger error modes that would not be revealed by heavy-ion testing. At the 22 nm node and below, this could be a significant concern for multi-level stacks and upset hardened, featureless devices in spatially separated redundant nodes for their hardening.

Hardness Assurance Assumptions

We have examined the effect on device SV geometry on the consequences of using a proton LET as a proxy for heavy-ion LET. We find that for device SV with depths greater than about 5 microns, the LET of heavy ions is largely determined by the ion range rather than the LET. However, on devices with less depth, the LET can be be determined by the ion range rather than the LET. This means that for devices with less depth, the LET can be significantly underestimated if the ion range is neglected.

Conclusions

The overall conclusion is that we need to incorporate proton reactions into our efforts to understand heavy-ion SEE susceptibility. We have shown that the use of proton testing can provide useful bounds on SEE susceptibility at low energies, but cannot predict the SEE effects for high-energy heavy ions. We have also shown that the use of proton testing to predict the SEE effects of heavy ions is risky for high-Z materials, with the potential to significantly underestimate SEE/SEGR risk if it detects the susceptibility at all. For high-Z materials, the use of proton testing to predict the SEE effects of heavy ions is risky.

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