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Ionizing Radiation Influence on 28-nm MOS Transistor's Low-Frequency Noise Characteristics

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In this paper, we explore Total Ionizing Dose (TID) effects on low-frequency noise characteristics of 28-nm bulk CMOS transistors. In order to better understand the bias dependence of noise characteristics, measurements were performed at several operating points, both in linear and saturation regions. The challenge of differentiating between DC-induced shifts and newly generated Random Telegraph Noise (RTN) centers contribution to the Power Spectral Density (PSD) curve change demonstrates the insufficiencies of current analysis methods. We present examples of irradiation-generated RTN defects as well as various TID effects on noise PSD curves with pre-existing RTN sources.

Summary (500 words)

The origin of low-frequency noise in planar MOSFET transistors has been a point of debate for over 50 years, and it remains unresolved to this day. For older technology nodes, it has a Power Spectral Density (PSD) curve that is proportionally dropping with the frequency; hence, it was named 1/f, or as it is commonly referred to, flicker noise. With the rapid decline in transistor dimensions, occurrence of dominant Random Telegraph Noise (RTN) with a Lorentzian PSD shape (Figure 1) became more frequent. Additionally, for electronics manufactured in deep sub-micron technologies, noise is becoming one of the most prominent reliability concerns. This is especially the case for electronics that are operating in conditions with constant stressing, such as ionizing radiation environments in high-energy physics experiments. Therefore, it is important to understand what effects can irradiation have on the noise characteristics of transistors used in novel radiation-robust ASIC designs.

Consequently, we exposed transistors fabricated in 28-nm bulk CMOS technology to Total Ionizing Dose (TID) of 1 Grad (SiO2). The irradiation campaign was carried out in the Seifert XRD Cabinet, at room temperature, with a tungsten tube biased at 40 kV and 70 mA, resulting in a 6.2 Mrad/h dose rate. The transistors were biased in a diode configuration with 0.9/-0.9 V at the gate and drain terminals of the NMOS/PMOS transistors during the 7-day period of irradiation stressing, as that is the reported worst-case scenario for performance degradation under TID influence. Low-frequency noise was measured before and after the stressing procedure on a custom-built noise-measurement setup, allowing for both time and frequency domain noise data acquisition.

Normalizing the current noise spectral density for the DC current is a common tool used in the pre- and post-stressing analysis. This technique proved valid for PSD spectra with 1/f-like curve shapes, where the existing noise models suggest that taking the DC current into account should negate the difference in noise PSD associated with the irradiation inflicted DC parameter degradation. However, in cases where a dominant RTN defect exists, we demonstrate that normalizing is not an applicable method. This is due to different bias dependencies of RTN defects and 1/f-like noise, indicating an alternative origin.

Firstly, it is important to point out that the pre-irradiation measurements of noise current on minimum-sized transistors exhibit a very high variability (Figure 2). Results of our measurements show that irradiation does not necessarily only increase the noise PSD, but it can also have a non-existent effect and even decrease the overall noise characteristic at a given operating point (Figure 3). Additionally, an example of new dominant RTN trap generation having a great impact on RMS value of noise is shown on Figure 4. Transistors with pre-existing Lorentzian-shaped noise spectra demonstrate a variety of possible changes. In the final paper, we will discuss the multitude of observed variations. The work so far is of qualitative character, as statistically representative data would require more experiments.

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