

ABSTRACT

The continuous scaling of semiconductor devices to meet the increasing need for high-speed processing and greater integration levels has introduced critical reliability challenges that include Time-Dependent Dielectric Breakdown (TDDB), Bias Temperature Instability (BTI), Hot Carrier Degradation (HCD), and Electromigration (EM). Among these, TDDB has always emerged as one of the significant issues, particularly in advanced CMOS technologies. As the industry moves towards novel applications such as quantum computing, millimeter-wave (mm-wave) communications, and low-power digital circuits, understanding and addressing TDDB concerns across these diverse technology spaces is of utmost importance. The increasing power dissipation in these applications further necessitates the study of reliability at elevated temperatures, where device lifetime and performance are adversely affected. Therefore, both DC and AC TDDB analysis at high temperatures is critical for enhancing reliability predictions and improving device design.

In this thesis, an extensive experimental investigation of TDDB in 45nm RFSOI-based MOSFETs is conducted under DC, AC, and RF stress conditions. This study systematically explores the influence of key parameters, such as device layout, operating temperature, and stress characterization techniques, on dielectric breakdown. The generation of defects, including oxide and interface traps, is examined to provide a deeper understanding of breakdown mechanisms. A detailed analysis of the relationship between device geometry—specifically the gate area-to-perimeter ratio—and TDDB is performed on both DC and RF FETs fabricated using 45nm RFSOI technology. The results reveal significant deviations from the power-area scaling law and underscore the need for critical reassessment of reliability models in advanced technology nodes.

Furthermore, for the first time, this thesis investigates TDDB behavior at cryogenic temperatures in MOSFETs used in quantum computing control circuits. The results demonstrate that the characteristic breakdown time (t_{63}) tends to increase with decreasing temperature, exhibiting a minor saturation effect at cryogenic temperatures. Additionally, the Weibull slope (β) exhibits an inverted U-shaped dependence on temperature, with its maximum observed between 100K and 200K across all voltage levels. Both the trap generation rate and

critical defect density are estimated, and the observed trends in β are interpreted in the context of multiple breakdown origins within the cryogenic temperature range. These findings provide valuable insights for optimizing gate oxide thickness in cryogenic CMOS circuits, crucial for future quantum applications.

In addition, this thesis presents a comprehensive experimental study on AC-TDDB in 45nm PDSOI-based MOSFETs with varying gate oxide thicknesses and polarities. The lifetime of devices under AC stress conditions, including frequencies up to 1 GHz and varying duty cycles, is predicted using the frequency power law. A significant 90X increase in t_{63} is observed at RF frequencies compared to DC stress in thin NFETs. This investigation, performed using SILC spectroscopy, reveals that the breakdown behavior and trap generation rate are functions of frequency, duty cycle, and gate sense voltage. These findings enhance our understanding of dielectric reliability under AC stress and enable more accurate lifetime predictions for digital circuits.

Finally, the mechanisms of TDDB in RF devices are explored under both DC and RF stress in 45nm RFSOI technology. The analysis shows that RF devices exhibit a reduced lifespan under combined DC and RF stress, with an inverse correlation between t_{63} and input power (P_{in}) at millimetre-wave frequencies. The impact of peak voltage (V_{Peak}) on device lifetime is also modelled, providing further insights into the degradation mechanisms at high input powers. This research lays a strong foundation for future advancements in RF TDDB reliability, offering crucial insights for both RF device applications and the design of next-generation high-frequency circuits.

This comprehensive work bridges the gap between fundamental TDDB analysis and practical applications in advanced technology nodes, offering significant contributions to the fields of semiconductor reliability, cryogenic CMOS, and RF device design.