Reliability and Failure Processes in Thin Silicon Dioxide

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Hyper-thin films (~1nm or thinner) of SiO_2 or silicon oxynitride will be used as the gate insulator in high-performance MOSFETs. Similar thin layers may be used as the interfacial layer in high-k stacks for low power applications. The large tunneling current which flows through such thin dielectric layers causes a gradual build-up of defects, leading eventually to the formation of a localized breakdown conduction path.

This talk will review the physics and statistics of dielectric wearout and breakdown in ultra thin SiO_2-based gate dielectrics. Estimating reliability requires an extrapolation from the measurement conditions (e.g., higher voltage) to normal operation conditions. To reduce the error in this extrapolation, long-term (>1 year) stress experiments have been used to measure the wearout and breakdown of ultrathin (<2 nm) dielectric films as close as possible to operating conditions. Measured over a sufficiently wide range of stress conditions, the time-to-breakdown (T_{BD}) does not obey any simple “law” such as exponential dependence on electric field or voltage, as has been commonly assumed in reliability extrapolations. Thus, the interpretation of T_{BD} data remains somewhat controversial.

In spite of this uncertainty, there is general agreement that the reliability margin is greatly diminished compared to thicker films, if the time to first breakdown is assumed to correspond to product failure. There is increasing evidence, however, that this assumption is not valid in every case. Present research is aimed at better understanding the evolution of the electrical conduction through a breakdown spot, and the effect of the oxide breakdown on device and circuit performance. In most cases an oxide breakdown does not lead to immediate circuit failure. Different circuits may have various degrees of sensitivity to the erosion of noise and voltage margins resulting from oxide breakdown. The present oxide reliability methodology is evolving from characterizing oxide degradation and breakdown, to the more complex problem of characterizing the response of circuits to oxide breakdown.