

Tunneling current, impact ionization, and photon emission in MOSFETs

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Scaling theory and the SIA roadmap predict that MOS devices with 1.5 nm gate oxide equivalent thickness will be available by the year 2005. At this scale, gate current leakage may become very large, particularly if no high- κ dielectric material is used. In addition, important physical phenomena as hot carrier luminescence and impact ionization of electrons and holes in silicon may become relevant in presence of large gate tunneling currents and cause severe reliability limitations to further device scaling.

We present a new physically based model of the MOS capacitor including tunneling currents, impact ionization in silicon, photon emission, and photon re-absorption mechanisms. Our model can explain some relevant features of substrate minority carrier currents in saturated n -MOSFETs, and provides a better understanding of the origin of substrate currents in tunneling MOS capacitors.

The contribution of each quantized level in the cathode to the gate current I_G is computed following a semiclassical approach which includes self-consistent Schrödinger-Poisson solutions of the Si-SiO₂-Si stack incorporating poly-Si quantization. This I_G is fed to a full eight-band Monte Carlo device simulator that includes a calibrated SiO₂ transport. This allows us to suitably treat the very high-energy carriers resulting from the injection of tunneling electrons. Direct and phonon assisted spontaneous emission rates for inter- and intra-band transitions are computed employing k -dependent matrix elements from the extended full-band structure. Second order corrections accounting for the finite lifetime of the virtual state in phonon assisted events and for the energy dependence of the refractive index are also included. The spectrum of the emitted light intensity is computed at each grid point based on the fill band Monte Carlo carrier distributions.

We present results on n^+n - n^+ diodes that yield a reliable limit for the relative efficiency of electron-hole pair generation processes involving absorption of photons and impact ionization.

When a thin oxide MOS capacitor is biased at high gate voltage, highly energetic electrons are injected into the anode. Thus many holes are generated, some of which are injected back into the cathode, where they also generate electron-hole pairs. Alternatively, pairs can be generated by photons emitted by hot carriers.

Our results on tunneling capacitors predict a very small ratio (typically $< 10^{-4}$) between the carrier pair generation efficiency of photons emitted by hot carriers during intraband transitions and the impact ionization generation rate. Our results support the validity of quantum yield experiments as a probe of impact ionization in MOS capacitors. They also set a lower limit on the probability of hole back-injection into the anode that can make photon emission the dominant substrate current generation mechanism during carrier separation experiments in MOS capacitors.