Modeling and Simulation of Electron Injection during Programming in Twin Flash™ Devices Based on Energy Transport and the Non-Local Lucky Electron Concept

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The functionality of Twin Flash™ memory cells is based on localized charge trapping in the nitride layer of an ONO stack (Fig. 1) [1]. The localization of the trapped charges gives rise to the storage of two separated bits in each cell. The programming mechanism is governed by hot electron injection. For an efficient cell optimization it is important to know at which positions the electron injection takes place and how local distributions of injection current and trapped nitride charge evolve during the programming time frame. Therefore, a simulation setup was developed to study the details of electron injection during programming of Twin Flash™ cells.

A prerequisite for accurate modeling of injection phenomena caused by high electric fields is the consideration of hot carrier effects. This means that energy transport has to be included in the modeling of charge carrier behavior. This can be done most predictively by solving Boltzmann's transport equation for electrons using the Monte Carlo technique. Alternatively, an energy transport term can be integrated into the classical continuity equation combined with the solution of an additional differential equation for the energy transport. The carrier injection during programming is modeled by the application of a non-local lucky electron model which is based on field line tracing taking into account those electrons having enough energy to overcome the oxide barrier [2] (Fig. 2). Fig. 3 illustrates the comparison of simulated programming injection currents of a virgin Twin Flash™ cell for different transport models: Monte Carlo (MC), energy transport model (also known as hydrodynamic transport model, HD), and the drift diffusion model (DD). The MC simulations were taken from Ingrosso et al. [3], for the HD and DD simulations the device simulator GALENE [4] was used. Good agreement between MC and HD simulation results is observed. The DD model fails to predict the injection current in the channel region.

Based on the device simulator GALENE, a simulation environment was developed to simulate iteratively the time dependent evolution of local distributions of injection current and nitride charge during programming. The basic principle of the iterative simulation algorithm is shown in Fig. 4. Fig. 5 shows the local distributions of the injected nitride charge for selected iteration steps. At the beginning of programming, the majority of the charge carriers is injected above the n^+ region of the drain. With proceeding programming time, the fraction of electrons injected in the channel region increases. This leads to the effect of threshold voltage increase.

In conclusion, we have shown that it is insufficient to simulate the initial injection current and trapped charge distribution of Twin Flash™ cells. Since the injected charge itself influences the characteristics of subsequent injection processes, it is necessary to simulate iteratively and self-consistently the evolution of injection current and trapped nitride charge during program-ming. It was found that the DD model fails to predict the injection behavior in the channel region. The HD transport model and the non-local lucky electron concept have to be applied in order to obtain reasonable results for the continuum approach and within acceptable computation time.

References

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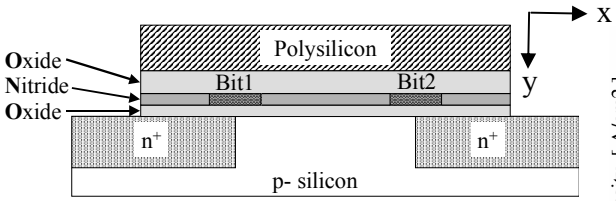
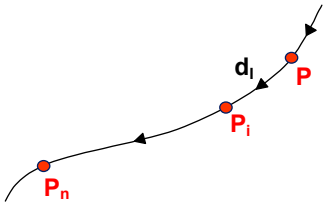


Fig. 1: Simulated Twin Flash™ cell.



Part of field line crossing P

$$j_{inj}(P) = A \cdot n(P_n) \cdot v_S \cdot \exp\left(-\frac{d}{\lambda_{ph}}\right) \cdot \exp\left(-\frac{d_i}{\lambda_i}\right)$$

P: point at interface between silicon and oxide
P_i: found by the condition $\Psi(P_i) - \Psi(P_n) = V_i$
$eV_i = 1.75eV$, threshold energy for impact ioniz.
d_i: length of the field line section between P_n and P_i
P_n: found by following the field line crossing P until an potential difference of V_B is reached, eV_B is the field dependent oxide barrier height (see Ref. [5])
A: leading factor, suitable for calibration
v_S: saturation velocity of electrons
d: length of the field line section between P_n and P
λ_{ph}: mean free path for optical phonon scattering
λ_i: mean free path for impact ionization

Fig. 2: Non-local lucky electron model and equation for electron injection current density (see Ref. [2]).

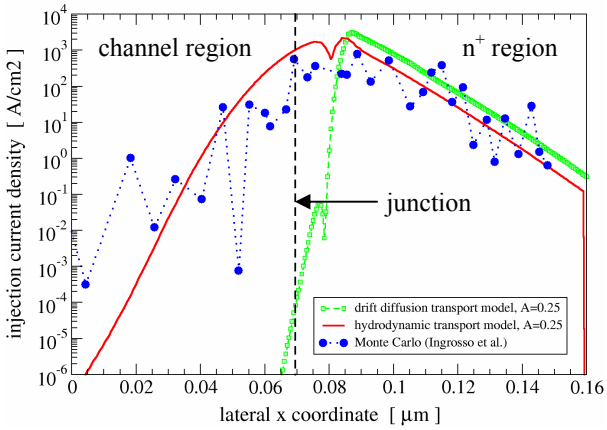


Fig. 3: Comparison of simulated programming injection currents for a virgin Twin Flash cell and different transport models.

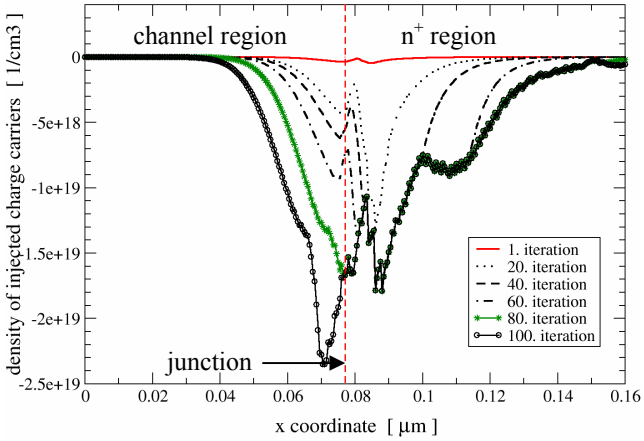


Fig. 5: Iterative simulation of programming, evolution of position dependent nitride charge density.

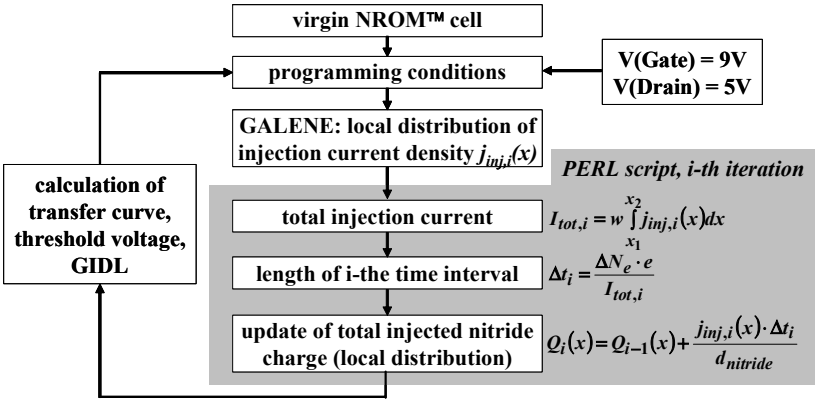


Fig. 4: Flow chart of iterative algorithm for simulation of programming.
w: channel width of Twin Flash™ cell device, ΔN_e: fixed number of injected electrons per iteration, $j_{inj,i}(x)$: electrical injection current density at position x [A/cm^2], $Q_i(x)$: nitride charge density at position x (i-th iteration) [As/cm^3].

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