Self Consistent Simulation of Tunneling Time in Silicon Nanocrystals Flash Memories

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Non-volatile memories has become one of the most promising technologies for nanocrystal based structures in ultra-dense memory applications [1,2]. The low dimensionality imposes an operation almost entirely ruled by the quantum mechanics laws, and the quantum tunneling of confined electrons between the QD and the channel is one the key mechanisms for the write/erase operations.

In this work we perform the numerical analysis of the tunneling time of electrons from the channel into the silicon nanocrystal (NC) by investigating the role of the applied voltage, shape of the NC, tunneling oxide thickness, charging and doping effects. The retention time of electrons inside the NC is also addressed.

Self consistent calculations of the Schrodinger and Poisson equations are performed in order to obtain the 3D device potential. The electronic states inside the NC and the channel are obtained by solving the 3D Schrodinger equations (1) corresponding to the three two-fold-degenerate valley band structure (v = 1,2,3). In Eq. 1, M_v is the electron effective mass tensor that describes different effective masses arising from anisotropy of the Si band structure. The tunneling time from a –m state in the channel to a –n state inside the NC is estimated by using the Fermi's Golden and the Bardeen Transfer Hamiltonian [3] (2).

$$-\frac{\hbar^2}{2}\nabla M_v^{-1}(r)\nabla\Psi_v(r)+[-q\phi(r)+\Delta E_C(r)]\Psi_v(r)=E_v\Psi_v(r) \qquad (1)$$

$$\frac{1}{\tau_{m\to n}}=\frac{2\pi}{\hbar}\sum_{k_{//}}|M_{mn}|^2 f_{2D}(Em)(1-f_{0D}(E_n))\delta(E_m-E_n) \qquad M_{mn}\approx-\frac{\hbar^2}{2m^*}\int_\Omega dr[\Psi_m^*\nabla\Psi_n-\Psi_n\nabla\Psi_m^*] \qquad (2)$$

The estimated tunneling times dependence on the tunneling oxide thickness for different shapes, gate voltages, charging and doping conditions for a 70Å wide NC based structure is investigated. We found that the tunneling process into the NC is very sensitive to the oxide thickness and changes of few angstroms can dramatically improve the tunneling time by several orders of magnitude. But the striking feature is that the shape of the NC plays significant role in the performance of the device. The spherical shape provides better confinement, resulting in smaller penetration in the oxide barrier, and consequently longer tunneling times. When hard walls are introduced, the wavefunctions reach longer penetration depths, causing a better coupling between the wavefunctions in the channel and NC, turning the tunneling easier. This is just the opposite of what would be expected, once the larger NC volumes provide larger density of states, and consequently increasing the number of states to be occupied for electrons coming from the channel.

References

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