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InGaAs Implant-Free Quantum-Well MOSFETs – Performance Evaluation Using 3D Monte Carlo Simulation

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Summary

In this paper we use numerical simulations to evaluate the performance of III-V Implant-Free Quantum-Well (IFQW) MOSFET devices that offer simultaneously high channel mobility, high drive current and excellent electrostatic integrity. Using 3D Monte Carlo simulations we show that to fully understand the performance of this device architecture, Fermi-Dirac statistics and quantum-corrections must be considered to account for the impact of low density-of-states and quantum confinement in the channel layer respectively.

The optimal 15nm gate length IFQW device structure [1-3] used in this paper is depicted in Fig 1 and has InGaAs source/drain regions with doping $N_D=9.1\times10^{19}\text{cm}^{-3}$, an InGaAs channel of thickness 3.75nm with doping $N_A=1.82\times10^{17}\text{cm}^{-3}$, an InAlAs substrate with doping $N_A=3.65\times10^{18}\text{cm}^{-3}$, a high-κ Al_2O_3 gate oxide with EOT=0.51nm, and Si_3N_4 lateral spacers with t_{spc}=1nm-5nm. Sub-diffusion of dopants from the source/drain regions into the channel layer has also been incorporated.

The 3D Monte Carlo module of GARAND [4] has been used to simulate this IFQW device over the range of lateral spacer thicknesses and with various physical models including Maxwell-Boltzmann (MB) and Fermi-Dirac (FD) statistics, and density-gradient (DG) quantum corrections using a full analytical description of the non-parabolic band structure of the III-V materials.

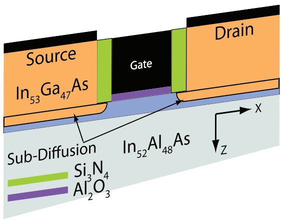

Fig 1. Cross section of IFQW device.

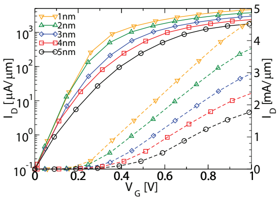

Fig 2. Scaled lateral spacer I_{ON} performance with Boltzmann.

The I_{ON} performance for a fixed I_{OFF}=100nA/μm has been simulated with MB in Fig 2 and it highlights the impact of the lateral spacer thickness on device performance. We see a large increase in I_{ON} as the spacer is thinned leading to a peak value of 4.5mA/μm. This value for I_{ON} is very large due to the use of MB where the Pauli-Exclusion principle is neglected.

In Fig 3 we have repeated the simulations with FD and the impact on I_{ON} is evident with a peak of 1.7mA/μm. With the inclusion of FD the carriers in the channel have a reduced velocity due to greater occupation of the higher mass valleys in InGaAs.

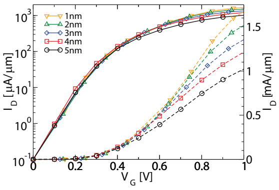

Fig 3. Scaled lateral spacer I_{ON} performance with Fermi-Dirac.

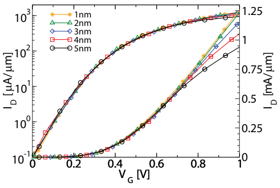

Fig 4. Scaled lateral spacer I_{ON} performance with Fermi-Dirac & quantum corrections.

As this device includes a quantum-well, it is vital that quantum corrections should be modelled. In Fig 4 we show the I_{ON} performance of the device with DG and FD. The I_{ON} is further degraded with a peak of 1.25mA/μm at the smallest lateral spacer thickness. This is due to the reduction in electron sheet density under the gate that is caused by the effective increase in gate capacitance from the quantum corrections.

In conclusion, we show that for accurate performance evaluation of high-mobility III-V IFQW MOSFETs it is vital to use 3D Monte Carlo simulation that includes Fermi-Dirac statistics and quantum corrections.

Publications

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