
Copyright © 2012 The Author

A copy can be downloaded for personal non-commercial research or study, without prior permission or charge

The content must not be changed in any way or reproduced in any format or medium without the formal permission of the copyright holder(s)

When referring to this work, full bibliographic details must be given

http://eprints.gla.ac.uk/78455/

Deposited on: 18 April 2013
InGaAs Implant-Free Quantum-Well MOSFETs – Performance Evaluation Using 3D Monte Carlo Simulation

Ewan Towie\textsuperscript{1}, Si-Yu Liao\textsuperscript{1}, Craig Riddet\textsuperscript{1}, Asen Asenov\textsuperscript{1,2}

\textsuperscript{1} Device Modelling Group, School of Engineering, University of Glasgow, G12 8LT Glasgow, U.K
\textsuperscript{2} Gold Standard Simulations Ltd., G12 8LT Glasgow, U.K

Ewan.Towie@Glasgow.ac.uk

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-$\kappa$ Al$_2$O$_3$ gate oxide with EOT=0.51nm, and Si$_3$N$_4$ lateral spacers with $t_{spc}=1-5$nm. 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.](image)

The I$_{ON}$ performance for a fixed I$_{OFF}=100\text{nA}/\mu\text{m}$ 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/$\mu$m. This value for I$_{ON}$ is very large due to the use of MB where the Pauli-Exclusion principle is neglected.

![Fig 2. Scaled lateral spacer I$_{ON}$ performance with Boltzmann.](image)

In Fig 3 we have repeated the simulations with FD and the impact on I$_{ON}$ is evident with a peak of 1.7mA/$\mu$m. 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.](image)

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/$\mu$m 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.

![Fig 4. Scaled lateral spacer I$_{ON}$ performance with Fermi-Dirac & quantum corrections.](image)

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