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Global Modeling of High-Frequency Devices

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ABSTRACT

In this work, we utilize the Finite-Difference Time Domain (FDTD) Method coupled to a full band, Cellular Monte Carlo simulator to model high-frequency devices. Replacing the traditional Poisson solver with a more robust electromagnetic (EM) solver provides a complete solution of the Lorentz force resulting in a more accurate model for determining the small-signal response of microwave transistors and various other high-frequency devices.

INTRODUCTION

We have improved upon a previously developed and reported on simulator [1][2] extending its capability to accurately model high-frequency devices. In particular, we have improved the performance of the employed perfectly matched layer (PML) absorbing boundary conditions (ABC) and are now able to simulate electric, magnetic, and current excitation sources within the full-wave module of the simulation tool. This new feature extends the most recent simulation work performed in this area within our group [3][4] providing a more accurate method for (i) modelling the high-field transport in semiconductor devices and (ii) calculating the characteristic figures of merit such as the cutoff frequency and the maximum frequency of oscillation often used to measure performance characteristics of electron devices.

In extending the development of this new simulator, particular emphasis has been placed upon both the implementation and testing of Berenger's PML [5] and the self-consistent coupling of the particle-based section to the full-wave solver. Furthermore, the new EM solver has been extensively tested and benchmarked against established work [6] and more recent results [7] in the current EM literature providing a high level of confidence in its ability to accurately calculate the time-varying EM fields within a given device structure of interest.

Another critical challenge faced when solving Maxwell's equations involves the maximum timestep over which the resulting finite-difference expressions can be resolved. The inherent stability limit, known as the Courant-Frederichs-Levy (CFL) criterion [8], severely limits the timestep for precisely the submicron scale dimensions we are interested in investigating and thus dramatically increases the number of simulation timesteps required. We have, therefore, developed a 3D FDTD algorithm based upon the recently developed ADI-FDTD method [9][10]. This new formulation relaxes the above CFL criterion allowing one to solve Maxwell's equations using timesteps several orders of magnitude greater than that dictated by the conventional limit. Finally, we are enhancing our simulator's internal architecture by including the standard MPI protocol providing it with the capability of being run on a large cluster of parallel nodes providing a further decrease in the overall simulation time required.

SIMULATION AND MODELING

Monochromatic sinusoidal excitation and Fourier decomposition are being used to study the small signal response of high-frequency electron devices and to investigate the overall performance of the latter including metal semiconductor field-effect transistors (MESFETs), and high electron mobility transistors (HEMTs). In particular, a 3D MESFET device shown in Fig. 1 is currently being tested via sinusoidal source excitation.

Using this technique, a high-frequency, sinusoidal perturbation of 80GHz is applied to either the gate or drain electrode after the device has reached a certain, steady-state DC bias point as shown in Fig. 2. A sampling of the subsequent time-domain fields computed by the full-wave solver then allows one to determine the time-varying electric potentials (as shown in Fig. 3), currents, and the frequency-dependant Y-parameters (i.e.

transconductance, output resistance, and the open-circuit voltage gain.) used to characterize the device performance.

CONCLUSIONS

A more detailed description of the simulation tools, the device structures investigated, and the resulting figures of merit for various excitation schemes will be provided during the presentation format selected for this work.

ACKNOWLEDGEMENT

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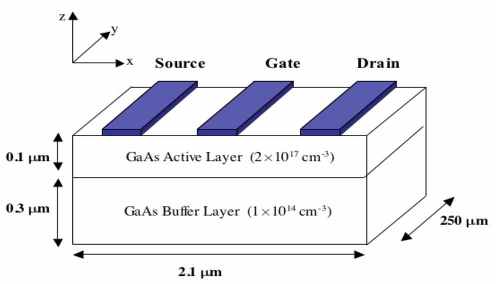
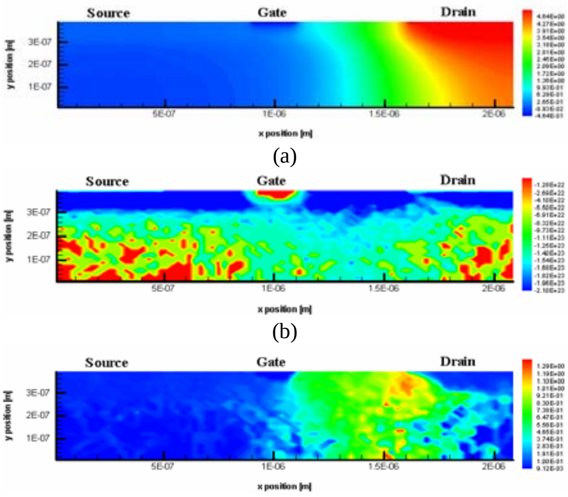


Fig. 1. 3D MESFET device currently being investigated



(a)

(b)

(c)

Fig. 2. Contour plots of (a) electric potential, (b) average electron concentration [m^{-3}] , and (c) average electron energy [eV] for DC bias point: V_{Source} = 0V, V_{Gate} = -0.5V, and V_{Drain} = 5.0V.

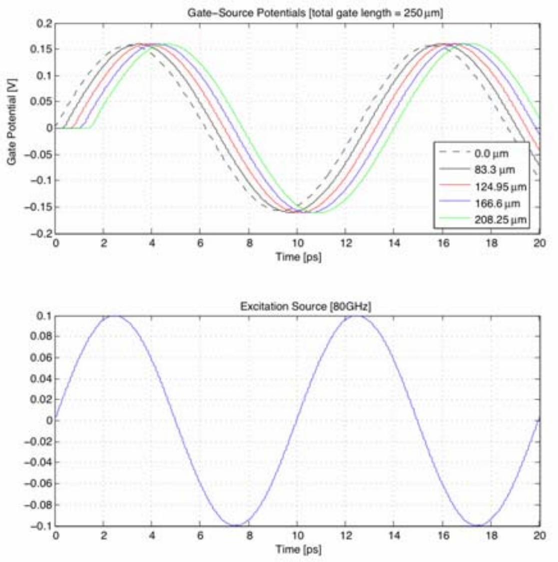


Fig. 3. Propagation of applied small-signal perturbation between gate and source electrodes in the 3D MESFET structure shown in Fig.1.