2D Maxwell/Transport time domain modeling of THz GaN distributed transferred electron device

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INTRODUCTION

The description of the influence of the free electric charge is still today a challenge in the semiconductor device electromagnetic modeling. In this context, we are presently developing a 2D/3D time-domain electromagnetic physical simulator including the non linear transport phenomena description following the macroscopic approach. It has been originally devoted to the mm-wave distributed IMPATT diode modeling [1]. It is now used in the modeling of THz distributed Transferred Electron Devices (TED).

THE ELECTROMAGNETIC SIMULATOR

The electromagnetic (EM) simulator is split in two main entities (figure 1). The first one is devoted to the numerical solution of the Maxwell equations in the whole considered physical volume. This solution must be associated with the solution of the electrostatic Poisson/Ampere equations in order to account for the initial net electric charge distribution and the semiconductor device DC bias conditions. Thus, the electric field is split in DC and RF components. The calculated electromagnetic field $(\vec{E},\vec{H})$ is the input quantity for the second entity which is devoted to the free carrier transport modeling. It relies on the macroscopic conservation equation sets issued from the moment method applied to the Boltzmann general transport equation. The conduction current density $\vec{J}_c$ is the quantity required by the Maxwell model.

The numerical method of solution is the FDTD Alternating Direction Implicit method (ADI) [2]. The spatial mesh is variable and the position of both the scalar and vector physical quantities is defined following the Yee’s topology. The implicit method allows the use of time increment values close to those imposed by the macroscopic transport models.

THz DISTRIBUTED TED

A study is devoted to the GaN N^+NN^+ distributed TED at THz. The RF operation fundamentally results from the semiconductor material physical properties namely the existence of an electron negative differential mobility zone in the velocity/field characteristics (figure 2). From an EM point of view, the 2D structure is similar to an active multilayered parallel plate waveguide (figure 3). The device RF operation is based on the non linear interaction between a transversal EM wave, propagating in a parallel to the N active zone, and the electrons mainly drifting perpendicular to the epitaxial layers.

Firstly, the RF operation of the vertical N^+NN^+ TED structure is investigated by means of a one dimensional time domain quasi-electrostatic energy-momentum modeling. The N active zone parameters are optimized under CW pure sine mode ($V(t)=V_{DC}+V_{RF}\sin\omega t$) (figure 4). The RF operation is an electronic longitudinal wave propagating through the N zone namely the electron accumulation layer and transit mode. Figure 5 shows the device the negative resistance level, RF emitted performance and conversion efficiency.

The 2D EM/energy-momentum model is used to investigate the distributed TED RF operation (figure 6). In CW oscillation operating mode, the device is “RF short-circuited” in the input plan and the RF component of the electromagnetic field is considered as zero (figure 6). Mur first order boundary conditions are applied in the device output plan. Figure 7 shows the instantaneous evolution of the Y direction transverse RF voltage V_{RFy} along the propagation X direction. This quantity is calculated from the circulation of the Y direction RF electric field component E_y along the Y direction. This result clearly illustrates how the EM field amplitude increases when propagating along the structure.

REFERENCES

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[2] T. Namiki, *3-D-ADI-FDTD method – Unconditionally stable time-domain algorithm for solving full vector Maxwell's equations*, IEEE Trans. Microwave Theory and Techniques, **48**, **10**, 1743(2000)

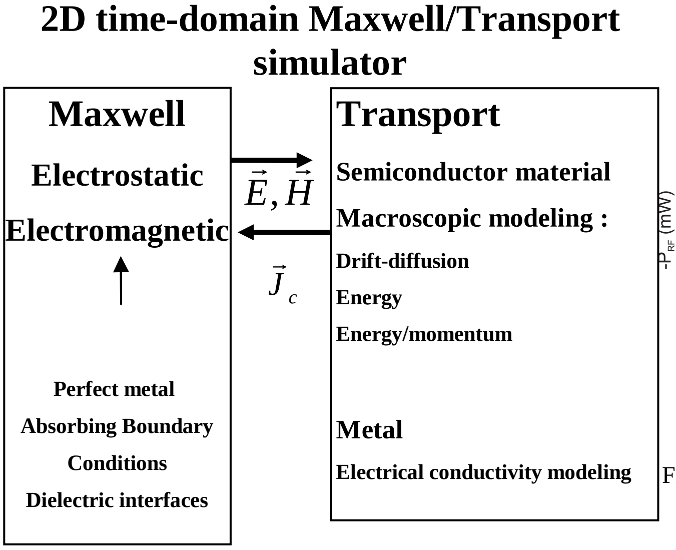

Figure 1.

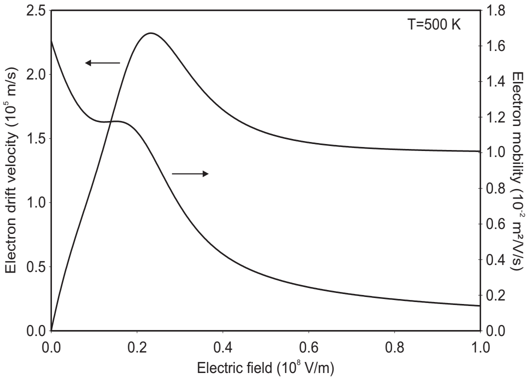

Fig. 2. GaN velocity/field characteristic

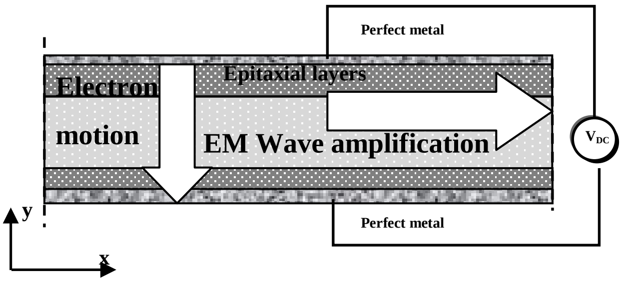

Fig. 3. Distributed transferred electron device

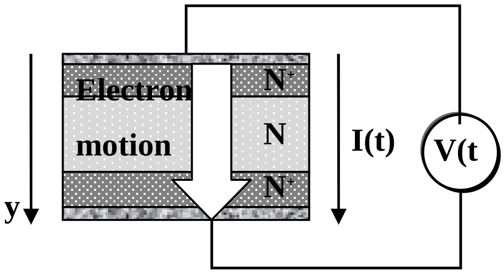

Fig. 4. Mesa GaN TED's modeling

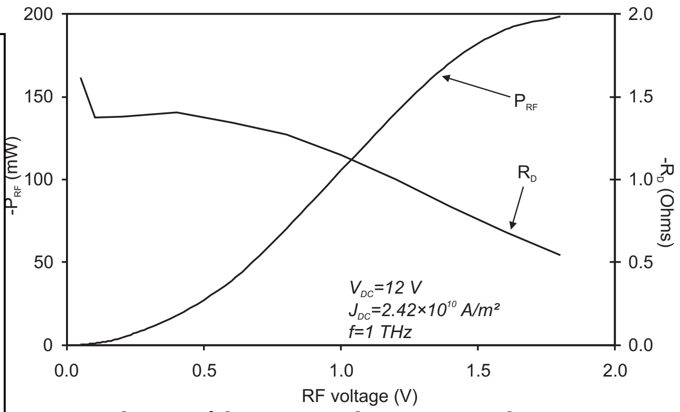

Fig. 5. Evolutions of the RF emitted power P_{RF} and negative resistance level R_d as a function of the RF voltage for the optimum DC bias point. Diode area is 10^{-10} m^2.

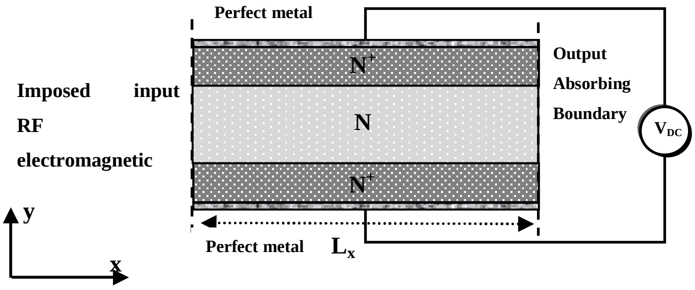

Fig. 6. 2D distributed GaN TED modeling

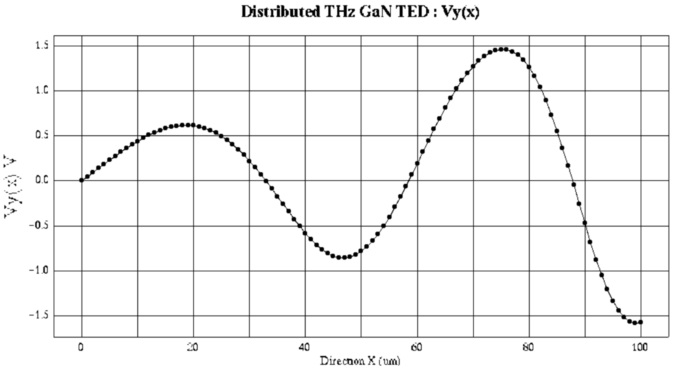

Fig. 7. Instantaneous Y direction RF voltage component along the X propagation direction under oscillation operating mode.