Comparative study of Silvaco and Synopsys for GaN HEMTs

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Abstract: This paper gives a broad review of the theoretical comparison of TCAD software SILVACO and Synopsys (Sentaurus) for AlGaN/GaN HEMTs. In this, five sections are compared in details namely Structure specification, Material Models Specification, Numerical Method Selection, Solution Specification and Results Analysis. Under Structure specification section, Silvaco seems to be the best choice for doping. Sentaurus seems to have more mesh generators and more parameters options for electrodes. Under Material model specifications, both softwares contain similar models for mobility, drift diffusion, hydrodynamic, thermodynamic/lattice heating, Density gradient, Recombination and impact ionization. However Silvaco facilitates more mobility models for GaN HEMTs applications as compared to the Sentaurus. Similar numerical methods but with some extra linear solvers are found in Sentaurus. It is needed to switch to other 3D tool in Silvaco for visualizing 3D devices. However, in Sentaurus, both 2D and 3D devices can be visualized in the same tool.

Keywords: Device simulator GaN HEMT, Process simulator, SENTAURUS, SILVACO.

Introduction

During the past few years, enormous progress has been made in the development of Gallium Nitride (GaN) and its family of material alloys for communication, defense, optoelectronics applications, military applications and biomedical applications. Recently AlGaN/GaN High electron Mobility Transistor (HEMT) have established a well-reputed position in these areas. In order to design the device, it needs to be simulated first. Silvaco and Synopsys (SENTAURUS) are two such powerful tool swhich can be used for designing and analyzing the electrical behaviors of these devices.

It is required to get familiar with the advantages and disadvantages of software tool before to choose the proper one for an application, therefore we are doing a comparative study of Silvaco and Sentaurus tool in this paper.

Software comparison

In these two softwares there are two options to perform the simulations, either by using the structure editor or directly writing a code.

Considering first case, as a structure editor, DEVEDIT in SILVACO and Sentaurus structure editor in SENTAURUS can be used. After generating the structure the coding is automatically generated and the file can be saved in two formats, the structure file(.str in SILVACO and .tdr in SENTAURUS) and the command file(.cmd in both).Structure file can be directly used by the visualization tools for visualizing the structure and command file can be used later on for further simulations.

Devedit should be used when the mesh is no longer adequate for the next simulation step. If accuracy is needed then numerical process simulations cannot be changed in this. Therefore one needs to switch to process simulator or device simulator that is ATHENA and ATLAS respectively in SILVACO.
In second case, for writing the code two simulators are available, process simulator and device simulator. Process simulator is used to model the fabrication steps of semiconductor devices and Device simulator is used to simulate the electrical characteristics of semiconductor devices. As a process simulator ATHENA in SILVACO and SProcess in SENTAURUS and as a Device simulator ATLAS in SILVACO and SDEVICE in SENTAURUS can be used.

According to our application we can either use process simulator or device simulator. As shown in figure 1 path (b) and (c) follows device simulator and path (a) and (d) follows process simulator. For device simulator, the code is directly written in Silvaco ATLAS while in Sentaurus structure is generated in Sentaurus structure editor. After that the command file will be called in SENTAURUS DEVICE. Device simulator is much more complex in Sentaurus than in Silvaco. In case of process simulator after modeling the fabrication steps, Device simulator is required for simulating the electrical characteristics.
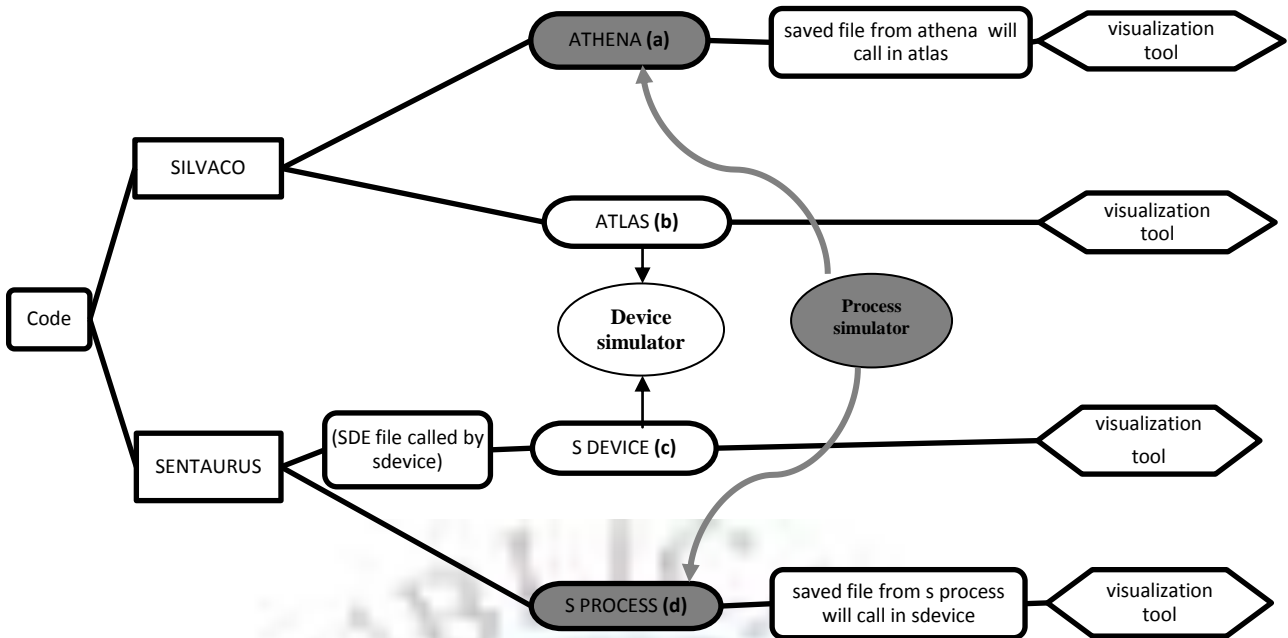
Figure 1.   Flow chart of process and device simulators

Comparison of TCAD Software

Basically we are focusing on device simulator. In order to write a code using Device simulator, five specifications are of interest. These are Structure specification, Material Models Specification, Numerical Method Selection, Solution Specification and Results Analysis**.**

Initially structure specification is considered. In structure specification mesh, region, electrode, doping are taken into account. Generally it takes too much time to obtain an optimized mesh. In Atlas there are two methods to specify the meshing. First method is auto meshing, in this, auto keyword should be included in the mesh statement and we don't need to specify any mesh statement in y direction. The locations of mesh in y direction are automatically determined by the region statement further used in coding. The second method is the standard methods in which mesh widths and the locations of X and Y mesh lines should be defined.

TCAD Sentaurus includes three different mesh generators: mesh, snmesh, and noffset3d. Each offers its own benefits and drawback.

Mesh: Produces axis-aligned (rectangular) meshes with minimal triangulation. As the most basic meshing program, it offers fewer options for accurate grid refinement, and usually it requires so much of manual instructions to produce a suitable grid.

SNMesh: A more advanced axis-aligned mesher, snmesh offers more convenient refinement options (e.g., specifying finer meshing at surfaces or region boundaries), and tends to produce more smoothly varying grids with greater overall connectivity.

NOffset3D: Produces meshes by distinguishing between material surfaces and boundaries based on specified grid densities and offset distances (i.e. after offsetting boundaries, it fills the remaining areas/volumes with triangular or tetrahedral meshes. It can produce very efficient grids for non-axis-aligned or 3D structures.

As per our theoretical study it is found that in comparison to SILVACO there are more mesh generators in SENTAURUS based on different applications.

After optimizing the mesh different regions should be specified. Syntax for defining region is almost same for both the softwares.

Regarding electrodes, up to 100 electrodes can be specified in Silvaco while nothing is specified in Sentaurus regarding the limit of electrodes. In Silvaco there are two methods to define the electrodes. In first the position parameters are specified in microns using the X.MIN, X.MAX, Y.MIN, and Y.MAX parameters. There is one other Syntax for electrode which specifies that the source electrode starts at the top left corner of the structure and extends to the right for the distance LENGTH. In Sentaurus electrodes are defined in SDevice under electrode section. All the electrodes to be used in the Sentaurus Device simulation are defined in the electrode section, with their respective boundary conditions (bias) and other specifications. Only those contacts that are named in the Electrode

section are included in the simulation. So it is observed that in Silvaco, the electrodes can be defined by just specifying the name of electrodes and the position parameters while in SENTAURUS electrodes are defined in electrode section together with the initial boundary conditions (bias) and other optional specifications (Resistor, Barrier, Current, Schottky Barrier, charge).Sentaurus is more flexible for defining the parameters of electrode.

After specifying the electrodes the doping can be defined in different regions. In both the softwares there are two types of doping i.e. constant doping and Analytic doping. In Silvaco there is a need to specify the DOPING keyword in the doping statement and then type of doping, concentration of doping and the region to specify the doping. In Sentaurus doping is defined in two steps. In the first step type of profile is defined. The second step is to associate the defined profile with a material type. Methods of specifying the doping in both the software are almost same but the syntax in Sentaurus is more complex.

Once defining the mesh, geometry, and doping profiles, we can modify the characteristics of electrodes, change the default material parameters and choose which physical models will be used during the device simulation. To accomplish these actions, use the Contact, Material, and Models statements respectively.

There are several contacts: Ohmic contacts, Schottky contacts and floating contacts. By default the contact is Ohmic in both the software. To specify a Schottky contact, work function should be specified using the WORKFUN parameter of the CONTACT statement. There are two distinctly different situations where floating electrodes are important. The first situation is for floating gate electrodes used in EEPROM and other programmable devices. The second situation is for contacts directly onto semiconductor materials such as floating field plates in power devices.

Voltage boundary conditions are normally specified at contacts. Current boundary conditions can also be specified. Additional boundary conditions have been implemented to address the needs of specific applications. One can connect lumped elements between applied biases and semiconductor device contacts. All these should be defined under contacts in Silvaco. But in Sentaurus, all should be defined under electrode section.

In Silvaco default values for materials parameters can be accessed by specifying "PRINT" on the "MODELS" statement while in Sentaurus default parameters can be accessed by the statement "Sdevice -P:Material".ATLAS has a built-in C language interpreter that allows many of the models contained in ATLAS to be modified and in Sentaurus models can be modified by C++ interpreter. The way of defining the traps is same in both the softwares, but the syntax is different. The syntax is much more complex in Sentaurus. There are a number of physical models which are available in both the softwares. These are mobility model, Recombination model(SILVACO)and Generation and Recombination (Sentaurus) ,Carrier statistics (SILVACO) and Band gap models(Sentaurus),Impact ionization, Tunneling, Hydrodynamic Transport, Density Gradient Transport, Hot-carrier Injection Models, Monte carlo Transport, Drift-Diffusion transport, Quantization models.

According to our survey, mobility, drift diffusion, hydrodynamic, thermodynamic/lattice heating, Density gradient, Recombination and impact ionization are found to be used for HEMT.

Mobility models are used to define the local electric field, lattice temperature, and doping concentration. In Silvaco FMCT.N, FLDMOB and CONMOB can be used for composition and temperature dependent low field, velocity saturation effect and concentration dependent mobility model respectively while in Sentaurus no such type of models are available. For high electric field dependency GANSAT in Silvaco and High Field saturation in SENTAURUS is available.

There are some models which are available in both the softwares with the common name. Drift diffusion is the simplest model of charge transport. It is for Isothermal simulation suitable for low-power density devices with long active regions. Hydrodynamic is used typically for hetero structure device simulation when energy transport across hetero interfaces plays an important role. Drift diffusion is not accurate for deep submicron devices. Thermodynamic transport/lattice heating extends the drift diffusion approach to account for electro thermal effects, under the assumption that charge carriers are in thermal equilibrium with lattice. It solves the lattice temperature (heat flow) equation in addition to Poisson equation and carrier continuity equation. Density gradient solves the quantum potential equation self consistently with the Poisson equation and carrier continuity equation. The quantum models apply to the HEMT channel confinement simulation. The effects due to confinement of carriers associated with variations of local potential on the scale of the electron wave functions (i.e., quantum effects) can be modeled using a density gradient. Generation–recombination (srh) is used to define the process that exchange carriers between the conduction band and the valence band. They are very important in device physics. Fermi-Dirac (FERMI) can be used for reduced carrier concentrations in heavily doped regions.

The carrier must gain the ionization energy between collisions. If the generation rate of these free carriers is sufficiently high this process will eventually lead to avalanche breakdown, in this case Selberher's Model in Silvaco and Van-Overstraeten De Man in Sentaurus impact ionization model can be used. Several different numerical methods can be used for calculating the solutions to semiconductor device problems. Numerical methods are given in the METHOD statements of the input file. For each of the model, there are basically three types of solution techniques decoupled (GUMMEL), fully coupled (NEWTON) and BLOCK. The GUMMEL method will solve for each unknown in turn keeping the other variables constant, repeating the process until a stable solution is achieved. The NEWTON method solves the total system of unknowns together. The BLOCK methods will solve some equations fully coupled while others are de-coupled.

In Sentaurus similar numerical methods are found but with different name. Plungin command is used as a gummel solver. It is rarely used. Coupled command activates Newton Solver. Blocked is same as in Silvaco. Three extra linear solvers are also available in the Sentaurus; these are ILS, Pardiso and Super.

RESULT can be analyzed by various parameters. Run time output is provided at the bottom of deckbuild and Sdevice window. Log files stores all the runtime information relevant to simulation. In Silvaco parameters can be extracted by EXTRACT statement while in Sentaurus a script of commands should have to be specified for extracting the parameters. TONYPLOT is used as a visualization tool in Silvaco while there are three visualization tools in Sentaurus that are Tecplot, inspect and Svisual. **Tecplot** is a plotting tool with extensive 2D and 3D capabilities for visualizing data from simulations and experiments. **Inspect** is a plotting and analysis tool for x-y data such as doping profiles and terminal characteristics of semiconductor devices. **Sentaurus Visual** is a plotting tool for visualizing data from TCAD simulations and experiment. Silvaco requires extra tool for visualizing 3D devices while in Sentaurus 2D and 3D devices can be visualized in the same tool.

Acknowledgment

Summary

In this paper, a theoretical comparison of TCAD software SILVACO and Synopsys (SENTAURUS) for AlGaN/GaN HEMTs is summarized. It is observed that in some sections Sentaurus is better while in others Silvaco is better.Suitable software can be chosen as according to the application area

Process simulator is almost same in both softwares. But Device simulator is much more complex in sentaurus than in Silvaco. In case of structure specification section for meshes, Sentaurus is better option because of more mesh generators based on different applications. But it has complex doping syntax. Hence Silvaco is better option for doping. Syntax for defining regions is almost same for both the softwares.

In Silvaco, the name of electrodes and the position parameters need to be specified while in SENTAURUS electrodes are defined in electrode section together with the initial boundary conditions (bias) and other optional specifications(Resistor, Barrier, Current, Schottky Barrier, charge) so Sentaurus is more flexible for defining the parameters of electrode. Maximum limit of 100 electrodes is defined in silvaco but nothing is mentioned about the limit in Sentaurus. Parameters for specifying contacts are same for both the software but all these parameters should be defined in electrode section in case of Sentaurus. The way of defining the traps is same in both the softwares, but the syntax is different. The syntax is much more complex in Sentaurus. Silvaco use C language interpreter for modifying the models while Sentaurus use C++ interpreter. There are a number of physical models which are found to be used for GaN HEMTs in both the softwares. These are mobility, drift diffusion, hydrodynamic, thermodynamic/lattice heating, Density gradient, Recombination and impact ionization. We don't have any model for composition and temperature dependent low field, velocity saturation effect and concentration dependent mobility in Sentaurus which are present in Silvaco.

Similar numerical methods with different name are found in Sentaurus. Plugin command is used as a gummel solver. It is rarely used. Coupled command activates Newton Solver. Blocked is same as in Silvaco but there are some extra linear solvers in Sentaurus, these are ILS, Pardiso and Super.

For visualizing the results, Silvaco provides one visualization tool that is Tonyplot while there are three visualization tools in Sentaurus that are Tecplot, Svisual and inspect. For visualizing 3D devices, Silvaco requires an extra tool tonyplot3D whereas Tecplot and Svisual is 2D as well as 3D visualizing tool.

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