Chapter 1

Method of simulation and modeling of semiconductors.

1- Introduction

Power electronics is switching electronics, sources and loads are subject to sudden changes in current or voltage when electrical switches open or close.

- Ideally, an open or closed switch does not dissipate energy.
- Thus, it is possible to transfer energy from the input source to the load (output) thanks to the functions which are mainly linked to the operations of control and conversion of electrical energy.
- For each switching cycle, a portion of energy is therefore transferred or stored between the input source and the output source.
- The basic material in power electronics is power semiconductors, the latter are mainly intended for switch functions in the implementation of energy converters (rectifier, chopper, inverter, cycloconverter, etc.).

In addition, specific protection functions for electrical equipment also involve power semiconductors.

2- Methods of simulation and modelling of semiconductors

Modeling and simulation represent an essential part of the path to power system design. the evolution of the design of power semiconductor components allows their use for increasingly powerful equipment.

This modeling makes it possible to both reduce the time and costs of developing components, as well as increasing the reliability of the circuits designed.

The modeling of bipolar components having an all-or-nothing behavior is no longer sufficient when it comes to analyzing switching phenomena and therefore dealing with the correction of circuits.

2-1- Different approaches of modelling

It is possible to classify the models under three categories:

2-1-1- Behavioral model

This model is defined as a black box having input and output terminals linked by a set of adjustable parameters. The procedure of this model ensures two main objectives:

- Use of only electrical parameters in order to be in agreement with the approach of the designers of the overall system. These parameters are easily modifiable and their impact on the functionality of the structure is quickly observable.
- The objective results from a compromise optimizing the simulation rapidity of a circuit with component models.

The models are based on the mathematical formulation of electrical behavior and on the experimental extraction of electrical parameters seen through input and output terminals of the cell.

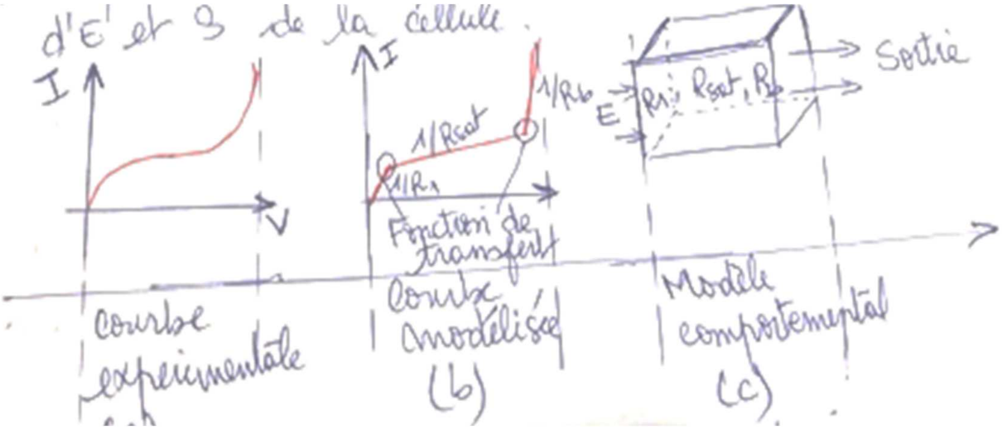

Figure 1.2 the principle of behavioral modeling.

It is a presentation by blocks (line, parabola or hyperbola) of the electrical characteristic linked together by transfer functions allowing the reduction of convergence problems.

2-1-2- Physical model

Since the fundamental work of Shockley, Ebers, Moll and Spenke, this modeling of semiconductor structures has been structured around a regional approach. The components are broken down into delimited regions that can be defined using considerations of a physical nature (heavily doped emitters, Mos gate, buffer layer, etc.) or of an electrical nature (space charge region, storage or accumulation region, ...)

The main difficulty in the physical modeling of power structures concerns the possible presence of "bipolar" type regions and in particular minority carrier storage zones (base region). The equation governing the carrier dynamics in the basic region "Ambipolar diffusion equation" obtained from the expressions of hole and electron current densities and the continuity equations:

$$\frac{\partial p(x,t)}{\partial t}+\frac{p(x,t)}{\tau}=D\frac{\partial^2 p(x,t)}{\partial x^2}$$

With:

$$D=\frac{2D_nD_p}{D_n+D_p}$$

Where:

P(x, t): Carrier concentration.

τ : lifetime.

D: ambipolar diffusion constant.

D and τ : are supposed independent from the position x.

The total current density J_{AK} passing through the base region is given as follows:

$$J_{AK} = (1 + \frac{\mu p}{\mu n})(J_n - qD\frac{dq}{dx})$$

J_n: electron current density.

J_p: hole current density.

µn: electron permeability.

µp: hole permeability.

$$J_{nd} - J_{ng} = J_{pg} - J_{pd} = \frac{Q_s(t)}{\tau} + \frac{\partial Q_s(t)}{\partial t}$$

With: $Q_s(t) = q\int_{xg}^{xd} p(x,t)dx$

Qs: the total charge stored in the base region.

(Jnd, Jpd) and (Jng, Jpg): couples of electron and hole current densities entering and leaving the base region.

2-1-3- finite element modeling:

The models used for numerical simulation are based on a very fine 2D or 3D description of the physics involved in the crystal based on fundamental equations. The simulation results give a local and global vision of the behavior of the region studied allowing the analysis of microscopic phenomena inaccessible to measurement.

These digital models are therefore intended for the analysis and design of semiconductor structures.

Here two categories of software are used:

Category 1: allows the preparatory study for the implementation of a technological process, the input parameters are: redistribution times, temperatures, doses, implantation energy and type of gas for the different technological stages (oxidation, metallization, diffusion,...). The simulation aims to validate the technological processes after having studied the influence of the sequence of all the technological steps on the doping profiles, the surface concentrations, the square resistances of the layers, the oxide thickness, etc.

Category 2: allows you to simulate the electrical behavior of structures defined by their technology. It is appropriate to define the two-dimensional mesh adapted to the structure studied, taking care to detail the influential zones (junction, MOS transition channel).

2-2- descriptive languages and simulation tools

2-2-1- builders Tools

According to certain manufacturers, simplified tools have been proposed to choose the best component for given standard applications independent of system simulation software.

Software includes Infineon's IPOSIM power structure simulator and Mitsubishi's MELCOSIM.

2-2-1-1- IPOSIM- Infineon

It is Infineon simulation software to help with the choice of bipolar modules as well as IGBT modules adapted to inverter or converter applications. This software performs an approximate calculation of switching and conduction losses for IGBTs and freewheeling diodes in a three-phase inverter configuration under the assumption of sinusoidal output current and inductive load. With this tool, a quick selection of a suitable Infineon IGBT module for an application is possible taking into account its average losses and thermal ratings.

The thermal conditions can be adapted by the user, defining the heat dissipations. Here the charge cycles can be calculated. The results will be displayed in tables and graphs and can be saved or printed as a PDF file.

2-2-1-2- MELCOSIM-Mitsubishi

It is software designed for the calculation of losses occurring in power modules under specific user application conditions and for junction temperature rises as a consequence of power loss. The algorithms used in MELCOSIM are based on the specified data and on a numerical approach and losses. MELCOSIM requires nine inputs called "application conditions" in order to be able to calculate the losses and the temperature of the junction.

The calculation results give the following information: average losses for the IGBT and the freewheeling diode, the results are divided into static and dynamic parts, the total losses for the power module, the case temperature, the average temperature and maximum of the junction in the transistor and in the freewheeling diode.

On the other hand, the graphic output offers the possibility of analyzing the losses and the junction temperature by changing a parameter of the application conditions within the limits of the specifications.

2-2-2- The different modeling languages

2-2-2-1- SysML (System modelling language)

It is a modeling language specific to the field of engineering systems. It allows the specification, analysis, design, verification and validation of numerous systems. These advantages are:

- Its semantics is richer and flexible, uses diagrams for performance analysis and quantitative analysis.
- Capable of modeling a wide range of systems including hardware, software, information, processes, personnel and equipment.
- It is a reduced language which makes it easier to learn and use.
- It better manages tabular notations, it provides tables of flexible allocations to requirements, functional and structural allocations, which facilitates the automation of verification and validation.

2-2-2-2- Mast

This language is essentially intended in electromechanics for analog and mixed signal simulation. it is still used in industry, but has disadvantages such as:

Its lack of standardization by the IEEE.

Its syntax far from VHDL.

Its poor adaptation to the description of digital systems.

2-2-2-3- Modelica

It is a computer modeling language adapted to the case of multi-technological systems. The associated simulation has the role of resolving the system of equations at each time step, but its use remains quite limited for the moment in power electronics.

2-2-2-4- VHDL-AMS

It is an IEEE standard. It is a derivative of the VHDL hardware description language, allowing the modeling and simulation of analog and mixed logic-analog circuits and systems.

(a) Language description: VHDL-AMS is a hierarchical description language that allows you to simulate continuous and mixed systems. It is a standard whose appearance made possible the coupling of the HDL level between the analog domains and the digital domains in terms of modeling.

VHDL-AMS allows the description and modeling of continuous and mixed conservative systems (continuous/discontinuous).

- It allows modeling on three levels: behavioral, functional and physical. The models written in VHDL-AMS allow all types of analysis: DC, transient, small signals, etc.

- It makes it possible to model and simulate complete power systems. The modeled analog circuits are described by systems of ordinary algebraic differential equations (with respect to time): EDA (algebraic differential ordinary equations). It supports Laplace and Z transformations.

- It is used to describe mixed continuous/discrete systems. The continuous character of these systems is described by EDA where time is considered as an independent variable. Systems that were modeled under Matlab, VHDL and SPICE can today be modeled under VHDL-AMS using a single, simple and powerful language since it offers the possibility of running a discrete event simulator simultaneously and a differential equation solver.

(b) Advantage of VHDL hardware

it is a standard product standardized by the IEEE which tends to be recognized by the greatest number of people. It gives the possibility for designers to approach their models at different levels of abstractions where the system is divided into subsets which can themselves be modeled using different abstractions, or of the work flow type (sequences of functional blocks whose inputs have no influence on the outputs of the previous blocks).

(c) Disadvantages and limitations

It is a powerful and general language, therefore complex, the possible constructions are numerous and the first steps are quite difficult.

- Models written in VHDL-AMS cannot be expressed with partial differential equations d/dx with x different from t. only temporal derivatives are accepted by the language, which makes geometric or distributed constant modeling delicate.
- On the other hand, even if the language is able to support the palliatives for its shortcomings thanks to these possibilities of interfacing with other languages (like C/C++) the form of these interfaces is not standardized.
- VHDL-AMS leaves users the possibility of defining their own natures, but it does not offer a possible alternative to the connection semantics involving generalized Kirchoff's laws. Which is a constraint when we want to deal with other systems of physical relations.
- Finally, the fact that current simulators are often based on extensions and modifications of old simulators and not on new specific simulation techniques, implies limitations in the simulation possibilities which prevent the implementation of certain language instructions .