SSMod. AN INTERACTIVE TOOL IN SILICON SEMICONDUCTOR MODELING

Romero-Troncoso, René de J.[*] Loyo-Maldonado, Valentín[**]

[*] Depto. de Electrónica, Universidad de Guanajuato
Prol. Tampico s/n, Col. Bellavista
36730 Salamanca, Gto., México
Tel. +52 (464) 80911, Fax. +52 (464) 72400
e-mail: troncoso@salamanca.ugto.mx
[**] Dept. of Electronics and Electrical Engineering, U. of Glasgow
Glasgow, G12 8QQ, Scotland, UK
e-mail: vloyo@elec.gla.ac.uk

ABSTRACT

In this paper is shown the development of an interactive tool for silicon semiconductor modeling. In this tool are included four physical phenomena, two passive devices and two active devices. We encourage the use of this tool in electronic physics lectures to help the complete understanding of this phenomena and devices.

1. INTRODUCTION.

The behavior of solid state electronic devices is based mainly in four basic physic phenomena: Fermi Level, Mobility, Carrier Concentration and Resistivity. Quantum physics laws, basically the Schrödiger equation, determine a full description of this phenomena. Any analytical attempt to solve the wave equation is impractical and highly complicated for any phenomena involving more than a single particle. The electronics professional finds several problems when trying to solve the wave equation for any particular case present in his daily work. Due to that, several professionals have developed specific models based on experimental data. To date, many models have been developed by this mean, more or less accurate with the real behavior. Models are, generally, equations "forced" to fit with experimental data and therefore the relationship in most cases is not able to show the physical phenomena.

Literature related to this area provides a set of graphics that shows the behavior of the physical phenomena as one variable function, or as a family of curves at the best. However, due to the nature of this phenomena, in most cases the relationship involves more than three variables and this graphics do not have flexibility for showing the full interaction among all the variables. This is a problem when you try to cover enough cases to show the full interaction in a printed way, because the overwhelming amount of space required. The complexity of the models in addition to the lack of interactive electronic engineering tools focused to education, have encouraged us to develop a didactic tool capable to cover this lacks. This tool provides a new vision to study electronic physics inside the classroom. The Silicon Semiconductor Modeling (SSMod) interactive software tool shows, in a qualitative way, the behavior of the physical phenomena or device under study. SSMod does not show the equations nor data, but curves that can be modified by the user in a valid range. In order to illustrate the behavior, each option has parameters that can be modified by the touch of few keys changing the curve in the screen. The options included in SSMod are: Fermi Level, Mobility, Carrier Concentration, Resistivity, Silicon Resistor, p-n Junction, MOS Capacitor and MOS Transistor.

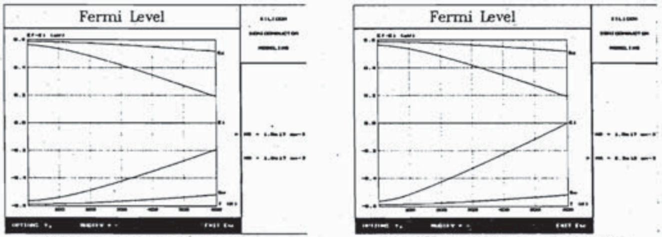
We hope that SSMod interactive software tool helps electronic engineering students to better understand physical phenomena and basic devices in electronics. As our aim is not to provide specific data or quantities, we focused this work to show high quality graphics. In order to make accessible SSMod to most of the students, the environment is a stand-alone system for PC's.

2. MODELS.

To develop this work we used several models, which are valid in all range and agree whit experimental data. Next are shown the typical screens for some phenomena implemented in SSMod.

2.1. Fermi Level.

Fermi Level E_F is the probability for an energy level to be occupied by an electron. It determines semiconductor types and doping concentration. In Fig. 1 are shown two graphics for different parameters affecting Fermi level.

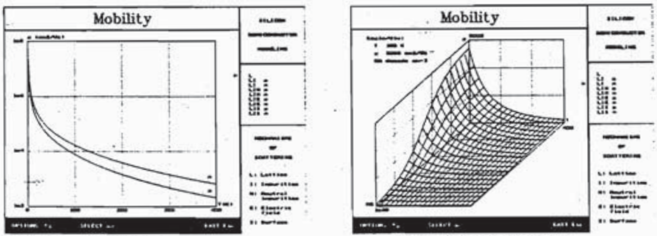


a) Equal donor and acceptor   b)Different donor and acceptor

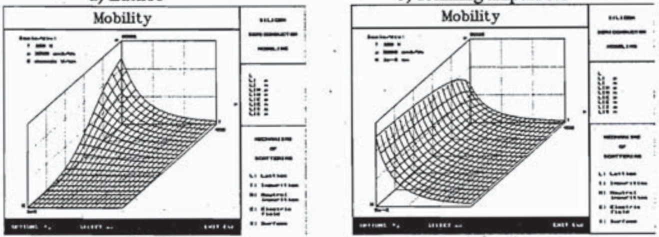
Fig. 1. Fermi level for different concentrations.

2.2. Mobility.

The change in the drift velocity v_d respect to the electric field E is known as mobility μ. This variable is one of the most important in the study of semiconductors behavior an it is present in practically all the models of electronic devices. In Fig. 2 are shown typical graphics given by SSMod for various scattering phenomena.



a) Lattice b) Ionizing Impurities

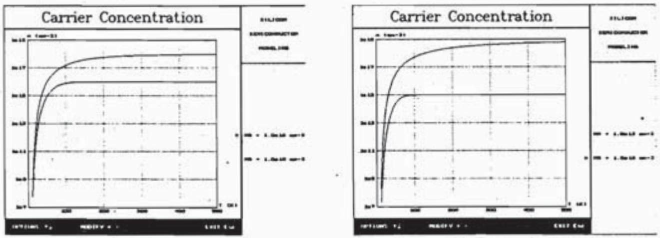


c) Transversal Field d) Surface

Fig. 2. Scattering effects on mobility.

2.3. Carrier Concentration.

A carrier available for conduction in a Semiconductor sample is known as free carrier. The concentration of this carriers is determined by the amount of active impurities present in the lattice. Among other parameters, free carrier concentration determines mobility and resistivity. In Fig. 3 are shown several graphics displaying different behaviors for carrier concentration.

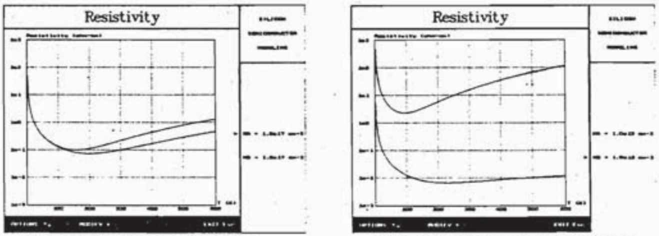


a) Example 1 b) Example 2

Fig. 3. Carrier concentration.

2.4. Resistivity.

The flow capacity of carriers under an applied electric field is known as Conductivity σ, its reciprocal is Resistivity ρ and determines the electric characteristics on devices. The Fig. 4 shows two graphics for different parameters.



a) Equal donor and acceptor b) Different donor and acceptor

Fig. 4. Resistivity for different concentrations.

2.5 Silicon Resistor.

A doped silicon sample acts like a resistor. The resistor value will be determined by dimensions and doping (type of impurities and concentration). This physical parameters modify the resistivity of the sample and depends on temperature, mobility and carrier concentration as seen in previous section. In Fig. 5 are shown the variations of the silicon resistor behavior for various changes in the parameters.

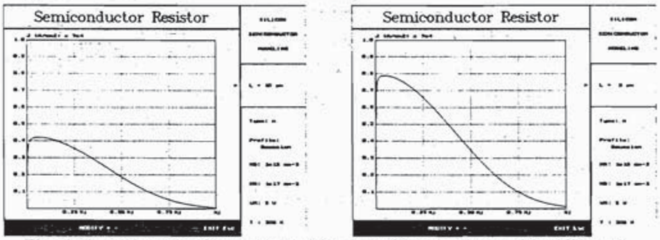
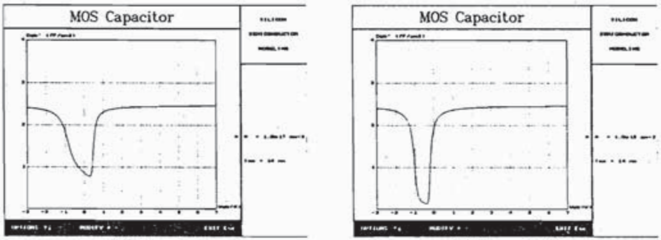


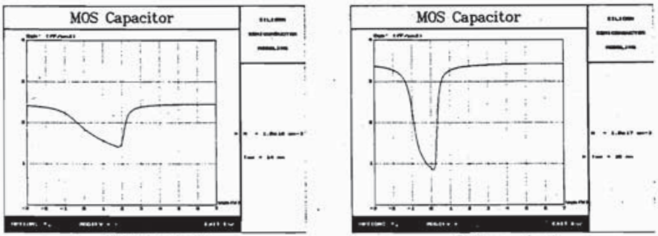
Fig. 5. Two examples for the conduction in a silicon resistor with different L.

2.6. MOS Capacitor.

MOS Capacitor is a very important device, because its behavior is the MOS Transistor basis. Typically, it is manufactured with 3 different layers. The first layer, normally the bulk, is doped silicon, the second one is the isolator (silicon oxide) and the last one is a polysilicon layer acting like a metal. The graphical behavior of the MOS capacitor is shown in Fig. 6.



a) Example 1 b) Example 2

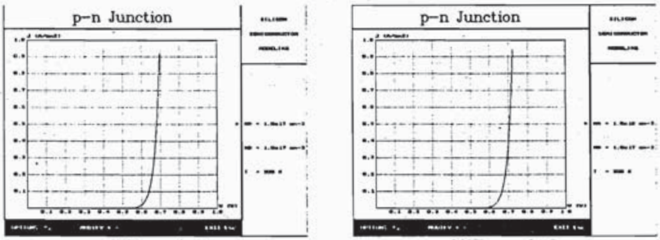


c) Example 3 d) Example 4

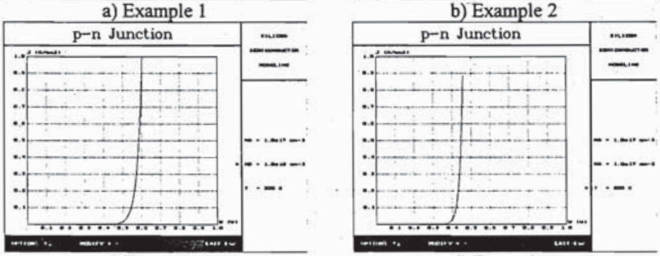
Fig 6. MOS capacitor.

2.7 p-n Junction.

When we join a p-type material with an n-type material, the result is a p-n junction or diode. The parameters that characterize this device are threshold voltage and its driven current capability. This parameters are affected mainly by doping. Diodes are very sensitive to temperature variations. The typical SSMod screen for this option is shown in Fig. 7.



a) Example 1 b) Example 2



c) Example 3 d) Example 4

Fig. 7. p-n Junction.

2.8 MOS Transistor.

MOS Transistor is a three terminal device and is the basic building block in modern IC design. The MOS Transistor has three operating regions: cutoff, linear and saturation. Cutoff and saturation are important to digital electronics, saturation rules the analog world and low power applications needs the linear region to operate. In Fig. 8 are shown the typical graphics for the MOS transistor modeled by SSMod.

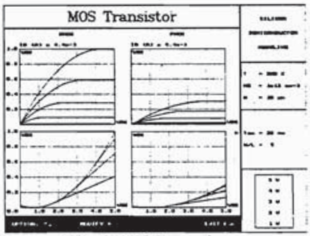


Fig. 8. MOS transistor.

3. CONCLUSIONS.

This program was developed under Borland C v. 2.0 and runs under PC (386 or better with math co-processor). This program was developed with the intention of provide the electronics students with a graphical interface to better understand physical phenomena related to silicon semiconductors. Graphics shown by SSMod are precise, as far as the models used to calculate them ([1] - [8]), but the goal in our design is to provide the student with a graphical environment for physical phenomena visualization to help him better understand electronics physics.

4. REFERENCES.

[1] S. Grove, "Physics and Technology of Semiconductor Devices", Wiley, New York, 1967.

[2] Sah, et al, "Effect of Zinc Impurity in Silicon Solar-Cell Efficiency", *IEEE Trans. Electron Dev.*, Vol. 28, No. 3, pp 304-313, 1981.

[3] R. Romero and V. Loyo, "Modelado de Fenómenos Físicos del Silicio", *XVIII Congreso Internacional Académico de Ingeniería Electrónica* ELECTRO'96, Instituto Tecnológico de Chihuahua, México, pp 15-19, 1996. ISSN 1405-2172

[4] S. Li, et al, "Dopant Density and Temperature Dependence of Electron Mobility and Resistivity in n-type Silicon", *IEEE Journal of Solid State Electronics*, Vol. 20, pp 609-616, 1977.

[5] G. Sabnis, et al, "Characterization of the Electron Mobility in the Inverted (100) Si Surface", *IEDM*, pp 18-21, 1979.

[6] Selberherr, et al, "Two Dimensional MOS-Transistor Modeling", *in Process and Device Simulation for Integrated Circuit Design*, pp. 490-581, 1983.

[7] Y. P. Tsividis, "Operation and Modeling of the MOS Transistor", McGraw-Hill Book Company, New York, 1987.

[8] M. Sze, "Physics of Semiconductor Devices", 2nd. Ed., Wiley, New York, 1981.