Y. Beddiafi[a], A. Saadoune[a], L. Dehimi[b]

Numerical simulation of radiation damage on the device performance of GaAs MESFETs

Y. Beddiafi[a], A. Saadoune[a], L. Dehimi[b]

[a]*Laboratory of Metallic and Semi- conducting Materials, B.P. 145, University of Biskra, Biskra, 07000, Algeria,*
[b]*Faculty of science, University of Batna 05000, Algeria*

Corresponding author: a.saadoune@univ-biskra.dz

Abstract

In this work, the effect of the radiation on the current-voltage characteristics of device GaAs metal Schottky field effect transistors (MESFET) at room temperature is investigated. Numerical Simulation tuned by means of a physics based device simulator. When the substrate of this transistor is subjected to radiations, structural defects, which are created, have undesirable effects and can degrade the performance of the transistors. These defects appear like deep traps. Results showed that in the presence of donor traps the current-voltage characteristics increases.However,acceptor traps have a significant effect on the current-voltage characteristics. In the presence of acceptor traps, the space charge zone in the channel increases, hence, reduces the current drain.

Keywords

Simulation, defects, silvaco, traps, GaAs

I. INTRODUCPION

The GaAs metal Schottky field effect transistors (MESFET) are one of important components used in electronic devices.

Deep traps are believed to be responsible for manyparasitic effects in GaAs FETs such as the gate lag and drain lag effects in which a slow transient isobserved in the drain current following a voltage applied to the gate or the drain.

The trap properties, energy and cross-section either measured by transient spectroscopy, voltage or optically excited deep level transient spectroscopy (DLTS).

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The transistor GaAs MESFETs is simulated for two dimensional on a semi-insulating substrate compensated by deep levels, and to clarify effect of impurity compensation by deep levels in the substrate [1].

In this work K. Horio et al, they simulate important case, that is, a case of GaAs MESFET on a Cr-doped semi-insulating substrate where deep Cr acceptors compensate shallow donors [1], and the compare the results with those obtained for a case with deep EL2 donors.

The objective of our work is to make modeling GaAs MESFET using Silvaco ATLAS TCAD simulator. We willdetermine the electrical characteristics I_{ds}-V_{ds}, with the influence of traps in low and high-resistivity material for two sample of transistor MESFET presented below.

2. PHYSICAL MODEL

A. *Device structure*

In this work,we will studytwo samples oftransistors MESFET. As to a model for the semi-insulating substrates, we adopt a two level compensation model as described below.
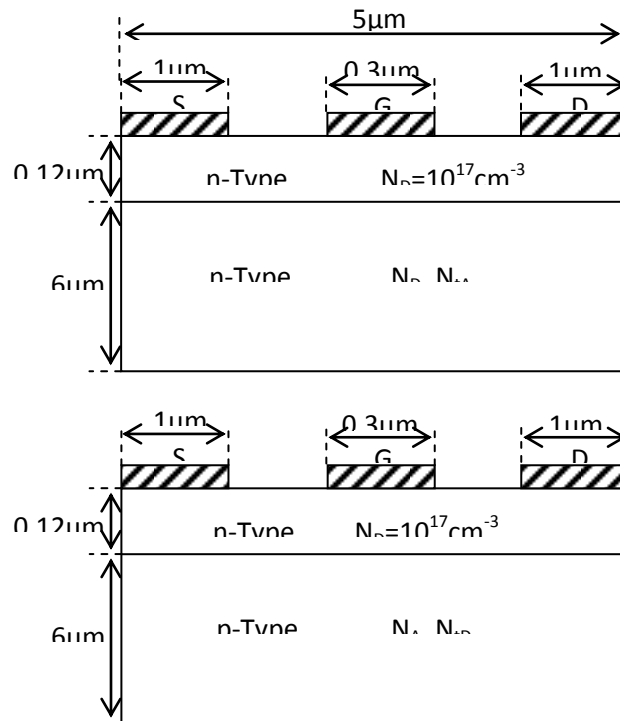

Fig. 1. Devices structures simulated in this study.

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In the semi-insulating substrate n-type, we assume that deep acceptors (N_{tA}) compensate shallow donors (N_D). In the p-type semi-insulating substrate, we assume that deep donors (N_{tD}) compensate shallow acceptors (N_A).

B. Numerical simulation

In this work, we used the simulator TCAD-SILVACO (two-dimensional ATLAS) to study the performance of transistors MESFETs GaAs in the presence of deep traps.The important advantage of this type of simulator is that it gives the ability to visualize physical phenomena inaccessible and therefore observable [2, 3].
The basic equations are the following:

Poisson's Equation relates the electrostatic potential to the space charge density:

$$\frac{\partial^2 \psi}{\partial x^2} = -\frac{q}{\varepsilon \varepsilon_0}\left(N_D - N_A + p - n + N_{tD}^+ - N_{tA}^-\right) \quad (1)$$

Where ψ is the electrostatic potential, $\varepsilon\varepsilon_0$ is the local permittivity, NA and ND are the shallow-acceptor density and shallow-donor density, respectively, p and n are the hole and electron densities,respectively, N_{tA}^+ and N_{tD}^+ are the ionized deep acceptors and deep donor's density, respectively.
The continuity equations for electrons and holes are defined by equations:

$$\frac{\partial n}{\partial t} = \frac{1}{q} \cdot div J_n + G_n - U_n = 0 \qquad (2.a)$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q} \cdot div J_n + G_p - U_p = 0 \qquad (2.b)$$

Where G_n and G_p are the generation rate for electrons and holes, respectively, and U_n, U_p are the recombination for electrons and holes respectively.

By default, ATLAS includes both Eqs. 2.a and 2.b In some circumstances, however, it is sufficient to solve only one carrier continuity equation.
Derivations based upon the Boltzmann transport theory have shown that a drift-diffusion model may approximate the current densities in the continuity equations. In this case, the current densities are expressed in terms of the quasi-Fermi levels ϕ_n and ϕ_p as:

$$\vec{J}_n = e\mu_n n \nabla \phi_n \qquad (3.a)$$

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$$\vec{J}_p = e\mu_p n \nabla \phi_p \quad (3.b)$$

Where μ_n and μ_p are the electron and hole mobilities. The quasi-Fermi levels are then linked to the carrier concentrations and the potential through the two Boltzmann approximations:

$$n = n_i \exp\left(\frac{\psi - \phi_n}{kT}\right) (4.a)$$

$$p = n_i \exp\left(\frac{\phi_p - \psi}{kT}\right) \quad (4.b)$$

Where n_i is the effective intrinsic concentration and T is the lattice temperature. These two equations may then be re-written to define the quasi-Fermi potentials:

$$\phi_n = \psi - \frac{kT}{q} \ln\left[-\frac{n}{n_i}\right] \quad (5.a)$$

$$\phi_p = \psi - \frac{kT}{q} \ln\left[-\frac{p}{n_i}\right] \quad (5.b)$$

By substituting these equations into the current density expressions, the following adapted current relationships are obtain

$$\vec{J}_n = qD_n \nabla n - q\mu_n n \nabla \psi - n\mu_n kT \nabla \ln(n_i) \quad (6.a)$$

$$\vec{J}_p = -qD_p \nabla p - q\mu_p p \nabla \psi + p\mu_p kT \nabla \ln(n_i) \quad (6.b)$$

The final term accounts for the gradient in the effective intrinsic carrier concentration, which takes account of band gap narrowing effects. Effective electric fields are normally defined where by:

$$\vec{E}_n = -\nabla\left(\psi + \frac{kT}{q}\ln(n_i)\right) \quad (7.a)$$

$$\vec{E}_p = -\nabla\left(\psi - \frac{kT}{q}\ln(n_i)\right) \quad (7.b)$$

Which then allows the more conventional formulation of drift-diffusion equations to be written see Eqs. 7.a and 7.b.

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$$\vec{J}_n = qD_n \nabla n + q\mu_n n \vec{E}_n \tag{7.a}$$

Deep level	Energy (eV)	Capture cross (cm^2)	
		Electron	Hole
Donor EL2	E$_c$-0.688	4.68×10^{-16}	2×10^{-18}
Acceptor Cr	E$_v$+0.755	1.17×10^{-19}	5×10^{-17}

$$\vec{J}_p = -qD_p \nabla p + q\mu_p p \vec{E}_p \tag{7.b}$$

It should be noted that this derivation of the drift-diffusion model has tacitly assumed that the Einstein relationship holds. In the case of Boltzmann statistics this corresponds to:

$$D_n = \frac{kT}{e} \mu_n \tag{8.a}$$

$$D_p = \frac{kT}{e} \mu_p \tag{8.b}$$

Theequations are solvedby theNewtonmethod.Several models areactivated inthesimulationincluding: Shockley-Read-Hall recombination (SRH Model), electric mobility dependent parallelfield(Fldmob model), concentration dependent mobility (Conmob model), and mpact ionization(impactofSelb model).

3. RESULTS AND DISCUSSIONS

Table. 1

Activation energies and capture cross sections of the traps used in this work [1, 4, 5].

The density of deep acceptors and deep donors in the substrate are variedfrom (5×10^{13} to $10^{16} cm^{-3}$)[5].

The conditions for high-resistivity material are given by relations following [6]:

For n-type substrate:$N_D>N_A$ then *(N_{tA}-N_{tD})> (N_D-N_A)*

For p-type substrate:$N_A>N_D$ then *(N_{tD}-N_{tA})> (N_A-N_D)*

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Where N_D and N_A are the concentrations of shallow donors and acceptors, respectively, and N_{tD} and N_{tA} are the concentrations of deep donors, and acceptors, respectively.
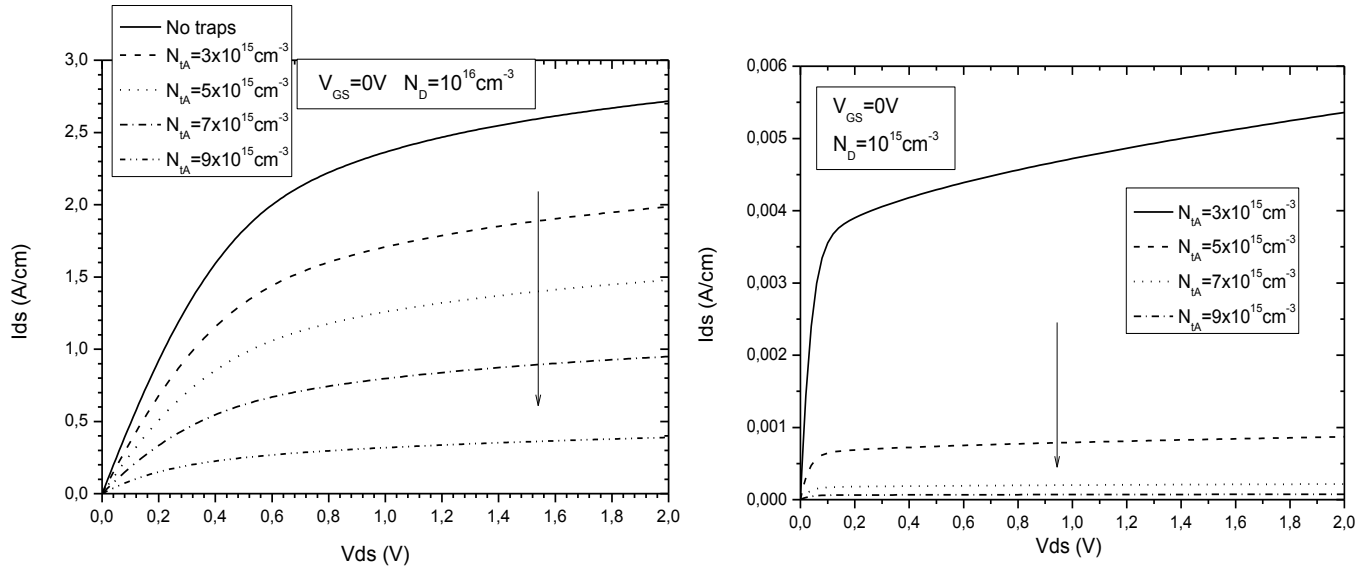

Fig.2. Simulation results of I_{ds}-V_{ds} characteristics for GaAs MESFETs with different deep-acceptor densities in the substrate. (a) low-resistivity material ($N_{tA}<N_D$), (b) high-resistivity material ($N_{tA}>N_D$).
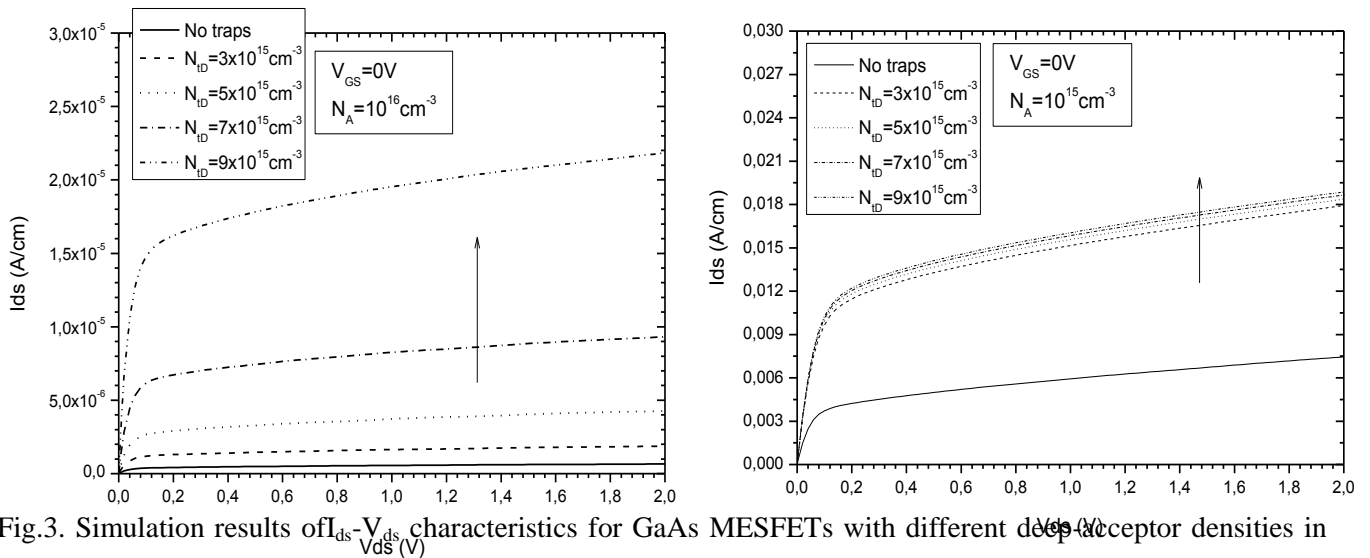

Fig.3. Simulation results of I_{ds}-V_{ds} characteristics for GaAs MESFETs with different deep-acceptor densities in the substrate. (a) low-resistivity material ($N_{tD}<N_A$), (b) high-resistivity material ($N_{tD}>N_A$).

Figs. 1 and 2 show the influencetrapsdonor and acceptorin the substratesonthe electrical characteristics(current-voltage).

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Figs.2 and 3shows simulated results I_{ds}-V_{ds} characteristics of GaAs MESFETs on the n-type and p-type substrate, respectively. Two cases with different deep-acceptor densities in the substrate are shown Figs. 2.a and 2.b. The results for a case with deep donors and shallow acceptors in the substrate are shown by Figs. 3.a and 3.b.

for a fixed voltage *Vds (Vgs = 0),* the current Ids decreases with increasing density of acceptor traps, this is because of the influence of trap densities acceptors on the area of space charge created in the interface of the substrate channel. The acceptor traps may compensate the shallow donors to reduce the free electron density. They are also negative when they have absorbed a free electron so that they also compensate the space charge.

Figs. 3.a and 3.bshows *Ids* versus *Vds* plot at *Vgs=0* with increasing density of donor traps, the current increases because the number of free carriers increases.

4. CONCLUSION

In the present work, the effect of the traps on the Id-Vd characteristics of The GaAs metal Schottky field effect transistors (MESFET) is studied numerically using the simulator TCAD-SILVACO (two dimensions ATLAS). The results showed that in the presence of donor traps the current-voltage characteristics increases because the number of free carriers Increases. However, the acceptor traps have a significant effect on the current-voltage characteristics. In the presence of acceptor traps, the load space area in the channel Increases, hence, Reduces the current drain.

REFERENCES

[1] K. Horio, K.Asada, H.Yanai, "Two-dimensional simulation of gaas mesfets with deep acceptors in the semi-insulating substrate" Solid-State Electron. 34 (1991) 335–343.

[2] B. Kaghouche "Etude par tcad-silvaco d'unestructure mos pour la realisation de capteurs isfet: parametrestechnologiques et electriques" mémoire de magister Université Mentouri – Constantine 2010.

[3] W. DIB "modelisation des structures photovoltaiques: aspects fondamentaux et appliques" mémoire de Doctorat université Abou bekr Belkïd de tlemcen 2011.

[4] Y. Beddiafi, "Modélisation d'un transistor MESFETen GaAs en utilisant le simulateur atlas-silvaco" mémoire de magister, université de biskra 2013.

[5]K. Horio, Y. Fuseya"Two-dimensional simulationsof drain-current transients in GaAs MESFET's with semi-insulating substrates compensated by deep levels"Electron Devices, IEEE Transactions on.

[6] C. Kokot, C. Stolte, "Backgating in GaAs MESFET's" IEEE Trans. Electron Devices 29 (1982) 1059–1064.