Modeling of the bipolar transistor under different pulse ionizing radiations

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Abstract. This paper describes a 2D model of the bipolar transistor 2T312 under gamma, X-ray and laser pulse ionizing radiations. Both the Finite Element Discretization and Semiconductor module of Comsol 5.1 are used. There is an analysis of energy deposition in this device under different radiations and the results of transient ionizing current response for some different conditions.

1. Introduction
Significant radiation tolerance is one of the main requirements for integrated circuits operating in extreme environment. There was created a 2D- model of the bipolar transistor (BT) using a general-purpose software platform COMSOL Multiphysics. The article presents an analysis of energy deposition in this device under gamma, X-ray and laser radiations. Besides, there are some graphs showed possibility recalculation different types of radiation interaction having application in the studying of transient radiation effects (TRE) under gamma, X-ray and radiation and laser radiations.

2. Model of the bipolar transistor
2.1. Using numerical modeling method
The analysis in the area of extreme dose rates required using numerical modeling methods of ionization reaction. The authors have modeled an impact of different pulse ionizing radiations on the semiconductor devices. Authors before have modeled this BT under Gamma-ray pulse ionizing radiation [1]. In this article function of transient ionizing current under various radiation conditions are received.

Comsol 5.1 solves the differential equation using Finite element discretization or Finite volume discretization. The authors have created the two-dimensional model of the both carrier (electrons and holes) BT, therefore Finite element discretization was used. The Semiconductor Module was used by us for modeling the BT, which modeled by a conventional drift-diffusion approach using partial differential equations (PDE).

2.2. Mathematical and Physical model of BT
The usual bipolar transistor 2T312 is a test object of modeling Comsol 5.1. Physical and topological parameters of this transistor are well known by us. The BT is described by three PDE: the electron and holes continues equations and the Poisson equation.

The electron and hole concentrations in BT are defined by Boltzmann distribution. Boundary conditions are the grounded ohmic contact. In this case, mesh triangular elements are used.
2.3. Mathematical and Physical model of different radiation interaction

When radiation impinges on a semiconductor, it generates electron/hole pairs in the material by ionization. Absorbed dose rate determines the intensity of ionization. Further, intensity ionization is defined by an electron density per rad $G_n$ and a hole density per rad $G_p$. In the general case, an electron density per rad $G_n$ and a hole density per rad $G_p$ are functions of the time and the coordinates. The authors neglect the influence of the processes at the transistor’s surface. Therefore nonequilibrium carriers are created equally in the volume. The electron/hole pairs are generated simultaneously however their spatial distribution may be significantly different.

When gamma-radiation interact then the electron/hole pairs are generated uniformly over the volume of device as

$$G_n(t) = G_p(t) = G(t) = g_0 P(t)$$

(1)

here $P(t)$ is the absorbed dose rate in rads(Si)/s, $g_0$ is coefficient of ionization efficiency in pairs/cm$^3$ per sec.

In the case of X-ray pulse ionizing radiation, the electron/holes pairs are generated non-uniformly due to radiation absorption and surface electron emission from metals. Measure of the ionization intensity is the rate of the change carrier generation, defined by the formula:

$$G(x,y,t) = \begin{cases} 
  g_0 P(t), & \text{if } x < x_1, x_2 < x < x_3 \ldots \\
  g_0 P(t) \exp(-\alpha_x y) + K \exp(-\beta y), & \text{if } x_1 < x < x_2, x_3 < x < x_4 \ldots 
\end{cases}$$

(2)

here $K$ is the coefficient of dose increasing; $\alpha_x$ is the linear coefficient of energy transfer (here X-ray energy) and $\beta$ is the linear coefficient of electron emission attenuation. The bell-shaped IR pulse is a function of time as $P(t)$.

First formula describes ionization under empty surface of semiconductor, the second – under heavy metallization. The coefficient $K$ describes the dose increasing due to the emitting of the electrons from the metallization. In this model a bands $x_i$ was added; here ionization intensity is a function of the coordinate $y$.

In the case of laser radiation, the ionization takes place if the photon energy exceeds the semiconductor bandgap energy. The ionization distribution may be described as shown lower

$$G(x,y,t) = \begin{cases} 
  g_0 P(t) \exp(-\alpha_x x), & \text{if } x < x_1, x_2 < x < x_3 \ldots \\
  0, & \text{if } x_1 < x < x_2, x_3 < x < x_4 \ldots 
\end{cases}$$

(3)

here $\alpha_x$ is the linear coefficient of laser energy transfer. The lower formula describes the absence of laser penetration through metallization.

2.4. Results

The figure 1 shows a non-uniform distribution of the electrons over the BT cross section under three types of radiation. You can see that carrier distributions are different from each other.

The figure 2a shows the graphs of transient ionizing collector current vs. time for different types of radiation. One can see the slightly difference between ionizing current amplitudes. However, the ionizing current forms are not very different.

Figure 2b shows the given to equal amplitude transient ionizing collector currents for different radiations. These figures are practically similar.
Figure 1. Log of electron concentration for BT cross section under gamma (a), X-ray (b), and pulse laser (c) ionizing radiations, time (after beginning of X-ray interaction) is 12 ns, for the BT structure with concentrations of the carriers.

Figure 2. Plot of transient ionizing collector current vs. time for different types of radiation: I: gamma, II: X-ray, III: pulse laser.
3. Conclusion
Using Comsol 5.1, it is shown that pulse gamma and X-ray ionizing dose rate BT reaction may be modeled by pulse laser radiation.

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