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Study of the Electron-Matter Interaction (Silicon Case)

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Abstract: The characterization of semiconductors by a Scanning Electron Microscopy (SEM) using techniques like Electron Beam Induced Current (EBIC) and Cathodoluminescence (CL) is great interest. Nowadays Monte Carlo (MC) method becomes a very important tool to simulate the diffusion length by electron-matter interaction. In this research, we propose a new Monte Carlo calculation of electron depth and energy dissipation in silicon.

Key words: EBIC, minority carrier, diffusion length, calculation, Si

INTRODUCTION

With the progress of computer capacity and processor speed; Monte Carlo (MC) simulation becomes an important method in studying typical effects in semiconductor devices (Lando and Binder, 2000). Silicon is a very important material used to fabricate the solar cells. The studies of Silicon properties by Electron Beam Induced Current (EBIC) need a good MC simulation of electron-matter interaction. In this research, a MC model is proposed to simulate the electron-matter interaction.

MODEL

Theory: In the EBIC mode the energy of an incident electron E_0 is essentially larger than the average energy $E_{e\text{-}h}$ of an electron-hole pair production. The total e-h pairs number is a generation factor given by Yacobi and Holt (1990).

$$G = \frac{E_0(1-\gamma)}{E_{e-h}}$$

where γ is the backscattered energy rate (γ and other constants for Si are reported in Table 1.

The electron penetrated in solid losses its energy $E = E_0(1\text{-}\gamma)$ by random successively collisions until the end of trajectory.

The step distance S is written as: $S = -\lambda \ln(R)$ where R is a random number between 0 and 1.

The mean free path λ can be obtained from the total scattering cross section:

$$\lambda = \frac{A}{N_A \rho \sigma}$$

Table 1: Parameters of Si used in calculation

	$E_{e\text{-}h}$ (eV)	γ (%)	A(g)	ρ(g.cm^{-3})	Z
Si	3.68	10	28.086	2.33	14

Where A is the atomic weight, N_A is the Avogadro's number, ρ is the density of the material and σ is the total scattering cross section.

The elastic scattering of electrons by the nuclei of the atoms, which are partially screened by the bound electrons, can be analyzed by using the Rutherford model. The total relativistic Rutherford scattering cross section is given by Yacobi and Holt (1990).

$$\sigma = (5.21.10^{-21})\left[\frac{Z}{E}\right]^2 \left[\frac{E + m_0c^2}{E + 2m_0c^2}\right] . \frac{4\pi}{\delta(\delta+1)}$$

where Z is the atomic number of the scattering atom, E is the energy of electron in KeV, C is the light speed, m_0 is the mass of electron and δ is a screening parameter.

The screening parameter δ is given by Yacobi and Holt (1990).

$$\delta = (3.4.10^{-3})\frac{Z^{0.67}}{E}$$

The angle for a particular scattering event can be obtained from the probability distribution Yacobi and Holt (1990).

$$\cos\theta = 1 - \frac{2\delta R}{1+\delta - R}$$

Calculation: The sample is divided by a several zones, Z_1, Z_2, Z_3 …… Z_n. At each zone, a quantity of electron-

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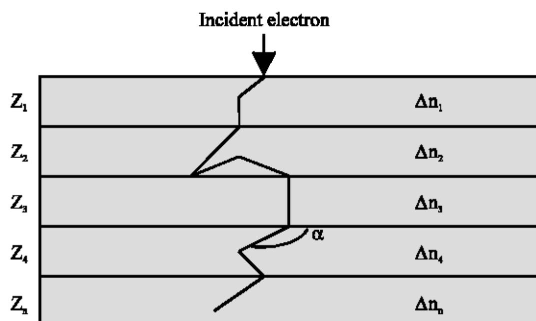

Fig. 1: Theoretical division of the sample in a number of horizontal zones

hole pairs (Δn) is generated. This carrier excess will be transformed into photocurrent by application of an exterior electric field (EBIC case). In our calculation we are interesting by electron-hole pairs generated during the collision of incident electron by the atoms of material (random walk). The maximum of Z is considered as the electron range R_e.

Electron range:

$$R_e = \frac{\sum_{i=1}^{nel} r_{max\,i}}{n_{el}}$$

Where $r_{max\,I}$: The maximum distance traversed by the i electron.

n_{el} : Number of incidents electrons.

EBIC Intensity (I_{cc}): The preceding division of volume is not valid in this case, because the distance between two pairs (e-h) which belongs to the same circle and the Schottky contact is not the same one.

It for that, that one is obliged to make another division (Fig. 1) which is based on the theoretical division of the sample in a number of horizontal zones.

Therefore the relation that we go considered will be (Si-p case):

$$I_{cc} = \sum_{i=l_1}^{n} \Delta n_i e^{\frac{-Z_1}{L_n}} = \Delta n_1 e^{\frac{-Z_1}{Ln}} + ... + \Delta n_n e^{-\frac{Z_n}{L_n}}$$

Where L_n: is minority carrier diffusion length.

Calculation procedure: (Figure 2).

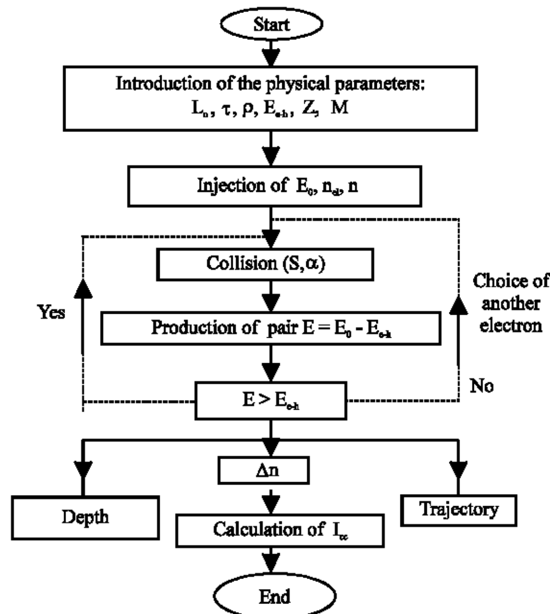

Fig. 2: Calculation procedure of incident electron (depth, trajectory, intensity)

RESULTS

Electron range: The penetration depth is calculated as a function of accelerating energy E (Fig. 3) for Si material. Our calculation is coincided interval (from 0 to 30 KeV) with Kanaya-Okayama (1972) and Wittry and Kyser models (1967). The Everhart and Hoff model is different to all models.

Generation volume: Figure 4 represents the trajectory of five electrons in Si sample for twoelectron energy, 5 and 10 KeV. It is clear that the penetration depth depends on electron energy as well as the generation volume. This result is obtained by other models (Nouiri, 2000).

EBIC Intensity (I_{cc}): Figure 5 represents the EBIC signal as a function of accelerating energy for different values of minority carrier diffusion length Ln. we distinguish to regions; the first is between 0 and 20 keV, the second is for accelerating energies greater than 20 keV. At the first region, there is no influence of Ln on EBIC signal because

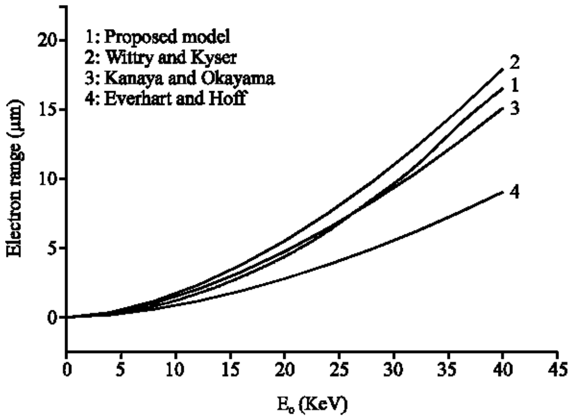

Fig. 3: Electron range as a function of accelerating energy E for Si material. A comparison with other models is represented

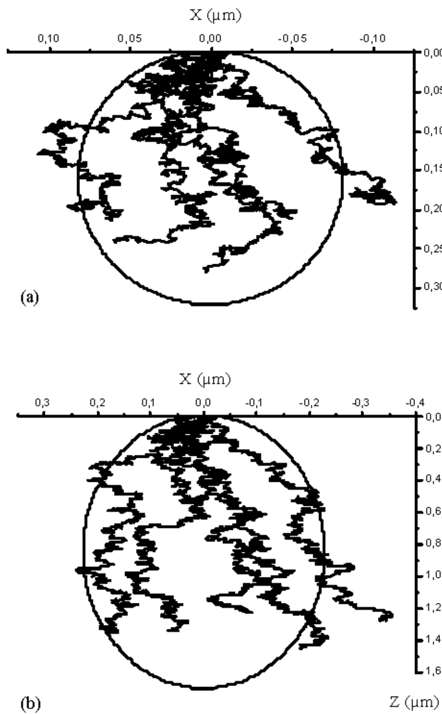

Fig. 4: Trajectories of five electrons in Si sample for two electron energy (a) 5 and (b) 10 KeV

all the excess carriers have the possibility to achieve the Schottky contact. Concerning the second region, we remark that the EBIC signal decreases for decreasing Ln, because the excess carriers have not the big probability to attain the Schottky contact.

Figure 6 shows a comparison between the proposed model and some experimental data found in the literature

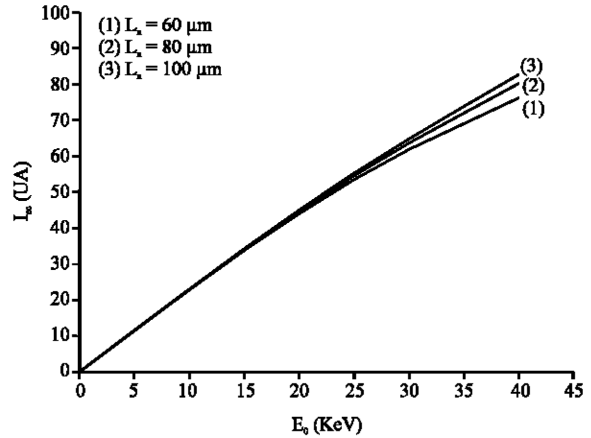

Fig. 5: EBIC current for various values of minority carrier diffusion length

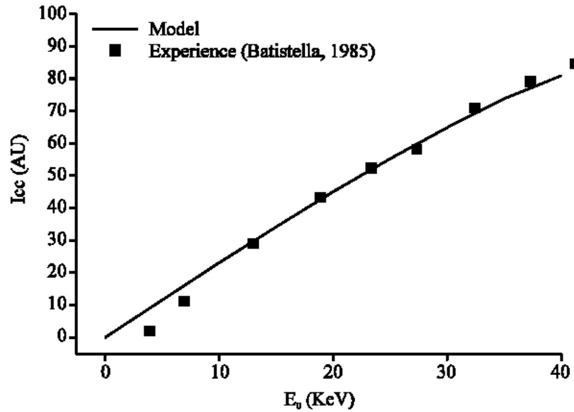

Fig. 6: A comparison between the proposed model and some experimental data

(Silicon annealed at 450°C during 24 h) (Batistella, 1985). The best fitting is obtained for Ln equals to 72 µm, this value is near to that obtained by Berz and Kuiken method (Berz and Kuiken, 1976), but it is not coincided with that obtained by Donolato model (1978/79, 1979, 1983, 1992, 1987, 1988).

CONCLUSION

A numerical model of EBIC is developed. This model enabled us to prove that:

- The volume of generation takes the pear shape (case of silicon) and it is a function of E.
- The penetration depth coincides with that obtained by other researchers, especially in low energy, excluded that of Everhart-Hoff.

- The distribution has a Gaussian form.
- The influence of two parameters (minority carrier diffusion length and pair formation energy) on I_{cc} can be studied.

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