A NUMERICAL MODEL TO DETERMINE THE DIFFUSION LENGTH BY EBIC METHOD. STUDY OF Si CASE

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Résumé

Le silicium est très important pour la fabrication des cellules solaires. La caractérisation des semiconducteurs par le microscope électronique à balayage (SEM) en utilisant les technique associées, telle que le courant induit par le faisceau électronique (EBIC) et cathodoluminescence (CL), est très intéressante. Actuellement, la méthode Monte Carlo devient un bon outil pour simuler l'interaction électron-matière et la longueur de diffusion. Dans ce travail, on propose un nouveau modèle de calcul Monte Carlo permet d'étudier la profondeur des électrons et la dissipation d'énergie dans le silicium. Nos résultats sont comparés avec ceux obtenus par d'autres modèles analytiques. Concernant la profondeur de pénétration, il y a un bon accord avec les autres modèles, en particulier, dans le domaine de faible énergie d'accélération.

Mots clés : *Technique EBIC, Longueur de diffusion, Calcul, Silicium.*

Abstract

Silicon is a very important material used in solar cells fabrication. The characterization of semiconductors by a scanning electron microscopy (SEM) using techniques like electron beam induced current (EBIC) and cathodoluminescence (CL) is of great interest. Nowadays Monte Carlo (MC) method becomes a very important tool to simulate the diffusion length. In this work, we propose a new Monte Carlo calculation of electron depth and energy dissipation in silicon. Our results are compared with other analytical analysis. Concerning the electron depth, there is a good agreement with other models, in particular at low beam energy.

Keywords: *EBIC techniques, diffusion length, Calculation, Silicon*

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ملخص

يعتبر السيليكون من المواد الصلبة الهامة والمستعملة في صناعة الخلايا الشمسية، وبالتالي فإن دراسة وتحليل خصائص أشباه الموصلات بواسطة التقنيات المعتمدة على القذف الإلكتروني مثل تقنية التيار المحرض بواسطة الحزمة الإلكترونية وتقنية التألق المهبطي، تعتبر ذات أهمية كبرى. في الوقت الحالي تعتبر طريقة مونتي كارلو أحسن وسيلة لأجل محاكاة الحركة العشوائية للإلكترونات المتغلغلة داخل المادة وبالتالي تحديد طول الإنتشار. في هذه المقالة نقترح طريقة حساب جديدة تعتمد على طريقة مونتي كارلو لتحديد عمق الإلكترونات المتغلغلة و صرف طاقتها داخل مادة السيليكون. النتائج المتحصل عليها تمت مقارنتها مع نماذج تحليلية سابقة وتبين أن هناك تطابق جيد معها وخصوصا من أجل طاقات التسريع الضعيفة.

كلمات مفتاحية: تقنية التيار المحرض بالحزمة الإلكترونية، طول الانتشار، المحاكاة والحساب، السيلكون

With the progress of computer capacity and processor speed; Monte Carlo (MC) simulation becomes an important method in studying typical effects in semiconductor devices[1]. Silicon is a very important material used in solar cells fabrication. Some parameters such as diffusion length, surface states and crystalline structure influence on solar cells efficiency. The characterization of semiconductors by techniques associated to scanning electron microscopy (SEM) like electron beam induced current (EBIC) and cathodoluminescence (CL) is of great interest. The studies of Silicon properties by Electron Beam Induced Current (EBIC) need a good MC simulation of electron-matter interaction, in particular, the electron energy loss inside the semiconductor. In this paper, a MC model is proposed to simulate the electron-matter interaction.

1- Basics of EBIC

Upon penetration into a semiconductor the energetic primary electrons of an SEM collide with the electrons of the valence band and ionize the atoms by producing excess n electrons in the conduction band and excess p holes in the valence band. In the absence of an electric field these carriers diffuse randomly, become trapped or annihilate each other until disappear. If a, electric field is present, like the one supplied by built-in p-n junction or a Schottky diode, the motion of the carriers is no longer random as they drift in the electric field and are collected by it. This produces a current that can be detected in an external circuit. A such current is due to the electron bombardment, is called Electron Beam Induced Current (EBIC)[2].

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The interaction volume of the primary electrons with the semiconductor (silicon) is described by the uniform generation pear approximation. This approximation is in good agreement with Monte Carlo simulation[2].

2- Model

2-1 theory

In the EBIC mode the energy of an incident electron E_0 is essentially larger than the average energy $E_{é\text{-}h}$ of an electron-hole pair production, so one electron (with energy E_0 ranged from 10 to keV) can generate several thousands of electron-hole (e-h) pairs along its trajectory in the excitation volume. The total e-h pairs number is a generation factor given by [3]:

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

where γ is the backscattered energy rate (γ and other constants for Si are reported in table1).

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

The step distance S is written as [3]:

$S = -\lambda \ln (R)$

where R is a random number between 0 and 1 (if R equal to zero the computational program rejects the step and choices another random number)

The mean free path λ can be obtained from the total scattering cross section[3]:

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

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.

Scattering mechanisms can be divided into elastic and inelastic. 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[3]:

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

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

The screening parameter δ is given by[3]:

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

The angle for a particular scattering event can be obtained from the probability distribution[3]:

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

R is a number between 0 and 1.

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

In, any applications, knowledge of the carrier generation distribution is important. Three approximations that have often used are the point source, the uniform sphere, and the Gaussian (or a modified Gaussian) distribution functions [3].

2-2 Calculation

The sample is divided by a several zones, Z_1, Z_2, Z_3 ……. Z_n (fig1). At each zone, a quantity of electron-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). After each collision the electron losses an energy $E_{e\text{-}h}$ to generate one pair electron-hole. To simplify the calculation, two dimensions, X and Z are considered. The maximum of Z is considered as the electron range R_e.

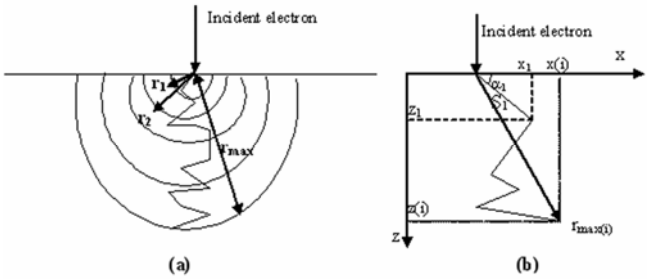

Fig.1 :(a) Schematic representation of Monte Carlo method used in this calculation model.
(b) The step distance S and the angle alpha (α) are two random values.

A-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.

In order to compare the electron range with other models, our calculation is extended to three models, Kanaya-Okayama, Wittry-Kyser and Everhart-Hoff[4-6].

B- EBIC intensity (I_{cc})

The collection of pairs is given by an exponential law. Hence, the EBIC intensity (I_{cc}) is given by:

$$I_{cc} \propto \int_0^{\infty} \Delta n(z) e^{-\frac{z}{Ln}} dz$$

The previous division of the interaction volume (fig.1) is valid to calculate the electron range but it is not valid to calculate I_{cc}, because the distance should be the same between Z_i zone and the Schottky contact between in the case of I_{cc}. therefore, another division of the sample is make as a number of horizontal zones(fig.2).
Consequently the relation in equ.8 is transformed into summation of discrete values as:

$$I_{cc} = \sum_{i=1}^{n} \Delta n_i e^{\frac{-Z_1}{L_n}} = \Delta n_1 e^{\frac{-Z_1}{Ln}} + ... + \Delta n_n e^{-\frac{Z_n}{L_n}}$$

Where L_n is minority carrier diffusion length.

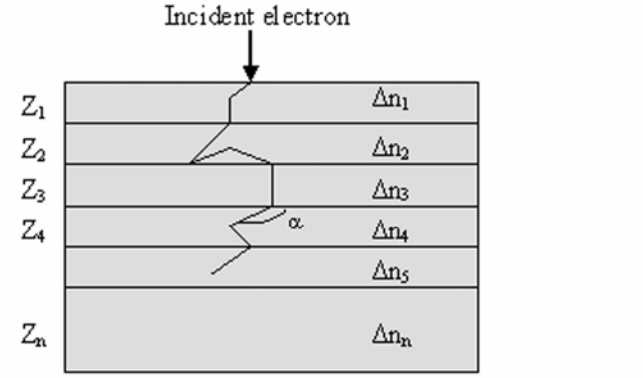

Fig. 2: schematic representation of EBIC technique and Monte Carlo calculation model

Calculation procedure

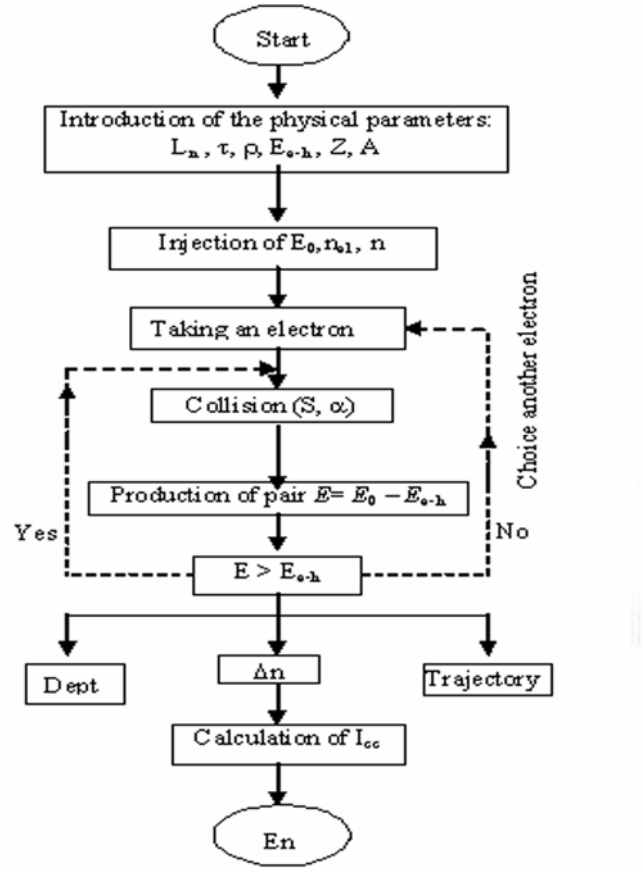

Fig. 3: Calculation procedure of incident electron (depth, trajectory, EBIC intensity).

L_n : minority carrier diffusion length
τ : minority carrier lifetime
ρ : Density of material
$E_{e\text{-}h}$: creation energy of a pair
Z : atomic number
M : atomic mass
E_0 : primary electrons energy
n_{el} :electrons nu,ber
n : the germ (MC)

3-Results

3-1-Electron range

The penetration depth is calculated as a function of accelerating energy E (Fig.4) for Si material. Our calculation coincides in the interval 0 to 30 keV) with Kanaya-Okayama [5] and Wittry-Kyser models [6]. However, the Everhart-Hoff results[7] is different to all models.

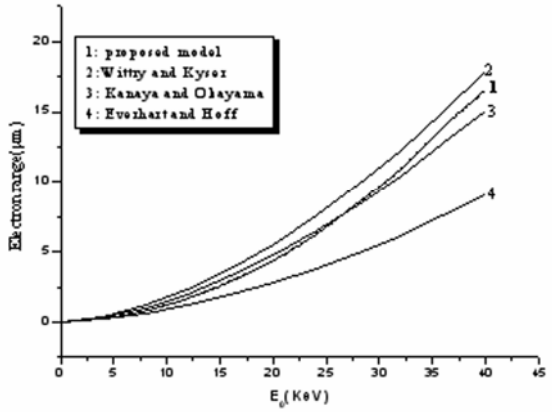

Fig.4: Electron range as a function of accelerating energy Eo for Si material. A comparison with other models is represented.

3-2-Generation volume

Fig.5 represents the trajectory of five electrons in Si sample for two energies, 5 and 20 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 [4].

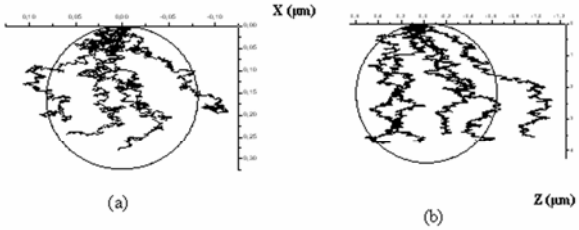

Fig.5 : Trajectories of five electrons in Si sample for two energies, (a) 5 and (b) 20 KeV.

Fig.6 represents the trajectory of five (a) and twenty (b) electrons in Si sample for electron energy equals to 10 keV. It is noticed that the generation volume takes a pear form, which is the form considered by all the researchers in the case of silicon.

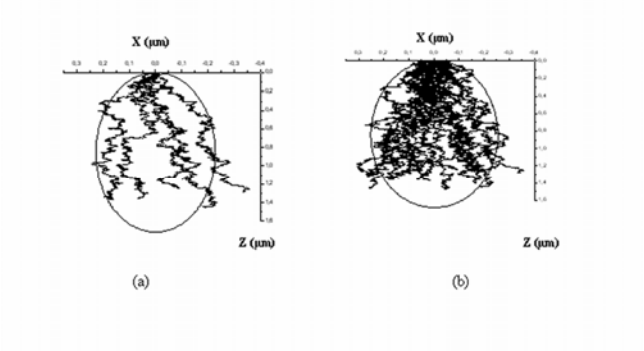

Fig.6: Trajectories of 5 (a) and 20 (b) electrons in Si sample for E_0 = 10 keV.

3-3-EBIC intensity (I_{cc})

Fig.7 (a) represents the EBIC current obtained for various values of minority carrier diffusion length, while fig.7(b) shows the influence of the electron-hole pair energy on EBIC signal.

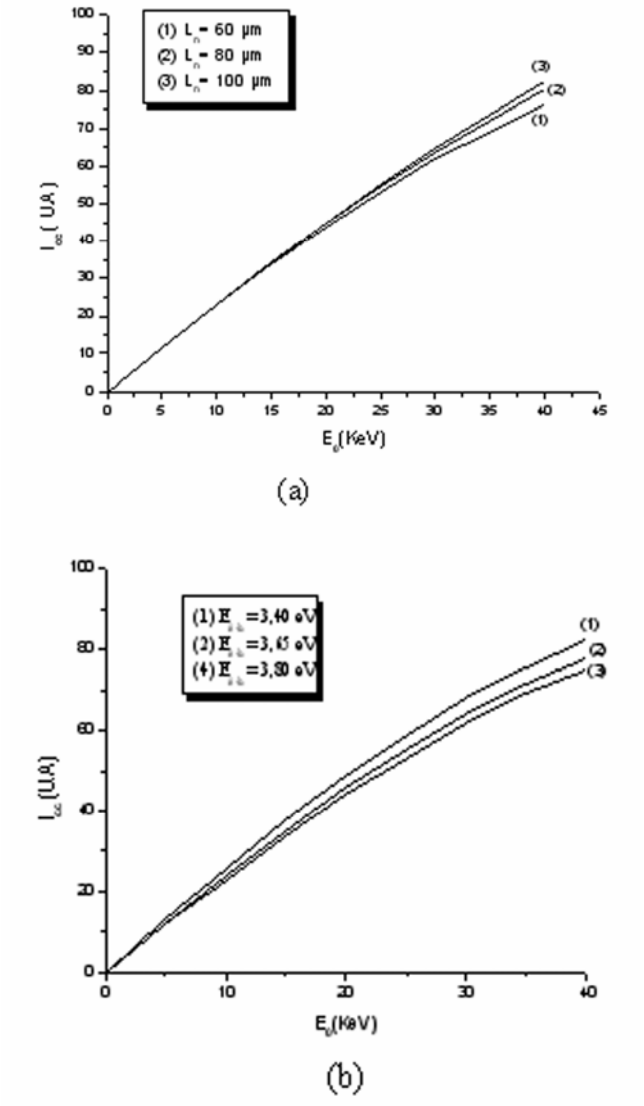

Fig.7: EBIC current for various values of (a) minority carrier diffusion length, (b) pair (e-h) formation energy

Conclusion

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

- The generation volume takes the pear shape (case of silicon), and it is a function of accelerating energy Eo.
- 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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