Electron beam induced current at a Schottky nanocontact

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Abstract: The electron beam induced current (EBIC) collection efficiency η of a circular nano Schottky contact of radius r_c perpendicular to the electron beam was simulated using a Monte Carlo (MC) algorithm. The EBIC was obtained by simulating the random diffusion and collection of the minority carriers that are generated at point-like sources S_i randomly distributed within the generation volume. The profile of the EBIC collection versus the distance to the nanocontact is simulated for two extreme values of the free surface recombination velocity v_s (v_s=0 and v_s=∞). The dependence of the maximum value of the collection efficiency η_{max}, obtained as the electron beam impinges the surface at the centre of the nanocontact, was simulated as a function of radius r_c. In addition, the variation of η_{max} versus the incident beam energy was obtained.

Keywords: electron beam induced current; EBIC; nanocontact; Monte Carlo simulation; collection efficiency.

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Biographical notes: Mohammed Ledra received his PhD from University of Constantine, Algeria and holds a teaching position of 'Maître de Conférences' at the Physics Department of the University of Biskra since 2006.

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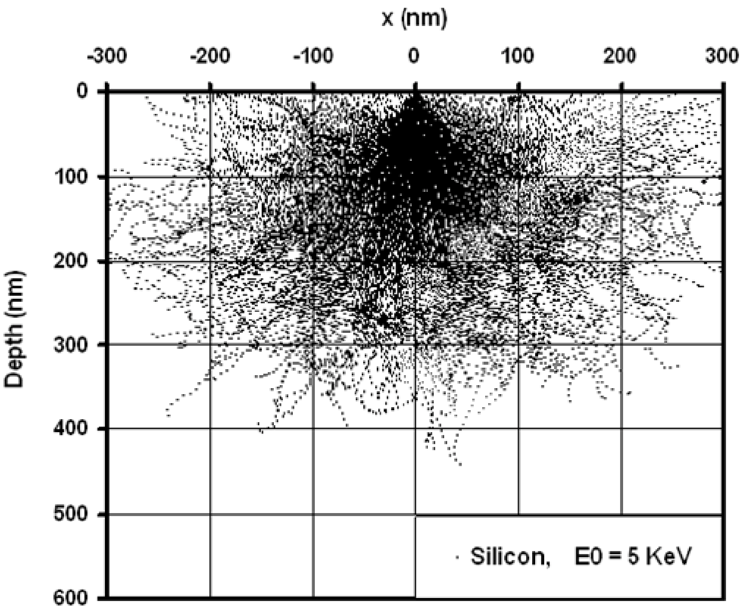
1 Introduction

The scanning electron microscope (SEM) in the charge-collection mode EBIC has been extensively used to characterise the electrical properties of semiconductors (Leamy, 1982; Holt and Joy, 1989; Donolato, 1978/79; Akamatsu and Henoc, 1981; Tabet and Ledra, 1996). The lifetime, diffusion length and surface recombination velocity of minority carriers can be measured and the electrical activity of defects such as grain boundaries and dislocations can be imaged using this technique. The development of nanotechnology has induced the need for a good modelling of the EBIC signal measured at nanosize devices. In this work, we simulate the electron beam induced current (EBIC) collection efficiency of a nano Schottky contact perpendicular to the incident electron beam. The nano Schottky contact is described as a disc of radius r_c, the depletion region and the thin metallic film of the contact have been neglected. The collection efficiency was obtained by simulating the random diffusion and collection of the minority carriers that are generated at point-like sources randomly distributed within the generation volume.

2 Monte Carlo algorithm

In the first step, our algorithm simulates the electron trajectories and the energy dissipation within the semiconductor as in Tabet and Ledra (1996) and Tabet (1998). Figure 1 shows the electron trajectories for a 5keV beam impinging a silicon sample at the normal incidence. The beam size was taken equal to zero.

Figure 1 Electron trajectories in silicon substrate for 5keV incident energy beam



The generation function was obtained in the form of a three dimensional distribution of pointlike sources S_i localised at the middle of the path between two successive primary electron collisions.

In the second step, our algorithm simulates the random diffusion and collection of the minority carriers that originate from S_i.

The random diffusion of the minority carriers emitted from each pointlike source S_i was simulated by considering successive small steps of constant duration Δt. The time interval Δt was taken as a small fraction of the minority carrier lifetime τ:

$$\Delta t = \frac{\tau}{N}$$

The minority carrier that originates from the point-like sources S_i was considered as collected if it reaches the surface taken as the edge of the nano Schottky contact. It was considered as recombined in the volume after a large number, $N_t \geq N$, of diffusion steps. For infinite recombination velocity v_s the carrier is assumed recombined if it reaches the surface or goes beyond it. In the case of $v_s = 0$, the carrier reaching or crossing the surface is 'forced' to diffuse along a trajectory within the surface or towards the bulk of the sample.

For each position x_{cb} of incident primary electron beam, the simulated EBIC collection efficiency $\eta(x_{cb})$ was calculated as following:

$$\eta\left(x_{cb}\right) = \frac{\sum_{i=1}^{N_S} N_{ci}}{\sum_{i=1}^{N_S} N_{gi}}$$

N_{ci} and N_{gi} are respectively the number of collected and generated minority carriers for each source S_i. N_S is the total number of sources S_i. The parameter N_t is adjusted using a procedure detailed in Ledra and Tabet (2005).

3 Results

Taking values of the parameters: silicon sample, L=1,000 nm, E_0=5 keV, the Schottky contact radius r_c=50 nm and two different values of the recombination velocity v_s (v_s=0 and ∞) at the free surface of the semiconductor, we obtain the simulated EBIC efficiency profiles $\eta(x_{cb})$ reported in Figure 2. Notice that the maximum value of η is obtained when the electron beam impinges the contact at its centre (x_{cb}=0). Moreover, the values of EBIC collection efficiency corresponding to v_s=0 are greater than those obtained for $v_s=\infty$ as expected.

We have also carried out computations to establish the variation of the maximum value of the collection efficiency (η_{max}) upon the nano contact radius r_c for two different values of the free surface recombination velocity v_s=0 and v_s infinite. The results are displayed on Figure 3. The results show that, as the radius r_c increases, η_{max} increases then saturates at a constant value for large values of r_c. The values of η_{max} corresponding to v_s=0 are greater than those obtained for $v_s=\infty$ for values of r_c less than 1,000 nm.

Figure 2 EBIC collection efficiency of a nano Schottky contact of radius r_c = 50 nm in a silicon sample at 5 KeV for two different values of the free surface recombination velocity v_s (v_s= 0 and ∞)

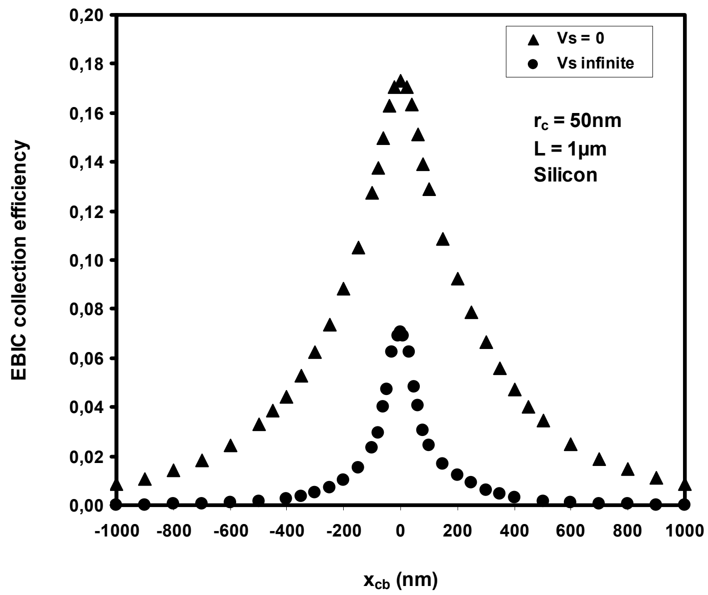
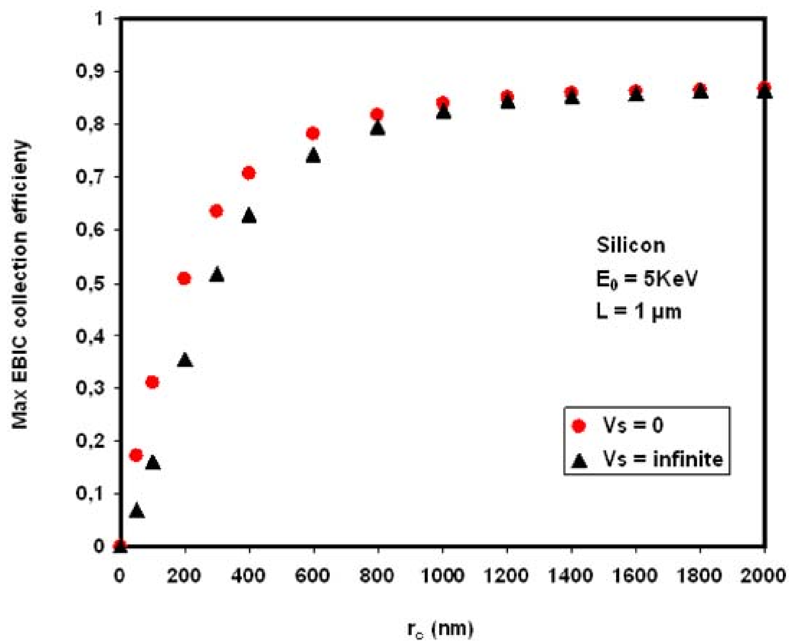


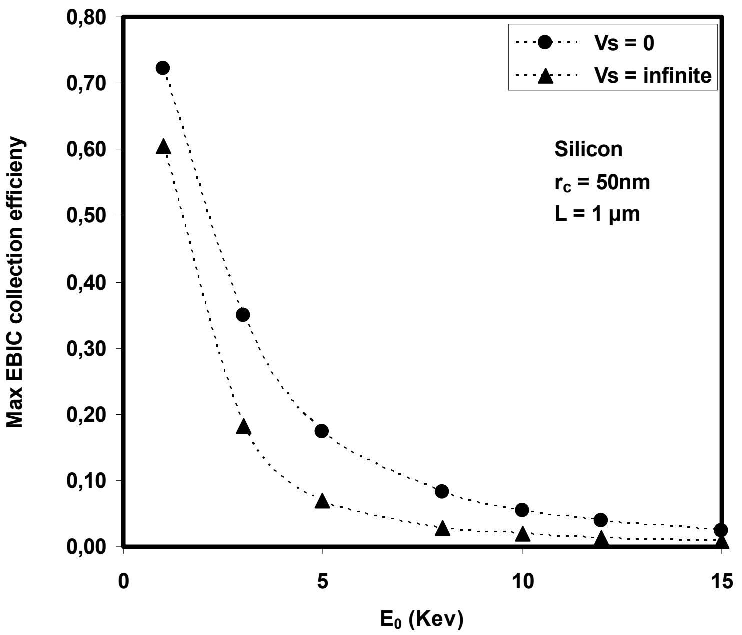
Figure 3 Variation of the simulated maximum collection efficiency upon the nano Schottky contact radius in a silicon sample at 5 KeV for two different values of the free surface recombination velocity v_s=0 and v_s infinite (see online version for colours)



Notice that the value of 1,000 nm corresponds to the value of the minority carrier diffusion length L. At 5keV incident energy, the lateral extension of the generation volume does not exceed 300 nm (see Figure 1), therefore, a significant fraction of the generated carriers diffuse beyond the generation volume and have a chance to reach the free surface, hence the observed difference between the values obtained for v_s=0 and v_s infinite. However, as the radius of the contact increases and exceeds the diffusion length, the fraction of the carriers that reach the free the surface become negligible, thus the convergence of the two curves to the same saturation value.

The variation of the max-EBIC efficiency $\eta_{\max}$ upon the primary energy of the electron beam E_0 for $v_s = 0$ and $v_s = \infty$ in a silicon sample are shown in Figure 4. It is shown that with increasing E_0 the max-EBIC efficiency $\eta_{\max}$ decreases as observed for an infinite Schottky contact. This is due to an increasing part of excess minority carriers recombining before reaching the contact. In addition, the values of $\eta_{\max}$ corresponding to $v_s = 0$ are greater than those obtained for $v_s = \infty$ as expected. Furthermore, it can be observed that the reduction of the collection efficiency for v_s infinite is more important at low E_0 as a result of an increasing role of the surface recombination as compared to the bulk recombination.

Figure 4 Variation of the maximum collection efficiency upon the incident energy E_0 in a silicon sample for two values of the free surface recombination velocity: v_s=0 and v_s infinite



4 Conclusions

We have developed a Monte Carlo algorithm that simulates the three dimensional generation, the random diffusion and collection of carriers in semiconductors. The algorithm is used to compute the EBIC collection efficiency of a nano Schottky contact represented as disc of finite diameter. The collection efficiency η_{max} (x_{cb}) was calculated as a function of nanocontact radius for two extreme values of the free surface recombination velocity (v_s=0 and v_s=∞) at 5 KeV. It is observed that the values obtained for v_s=0 are greater than those obtained for v_s=∞ as expected. The results show that the maximum value η_{max} of the collection efficiency increases as the radius of the Schottky, r_c, increases and saturates as r_c exceeds the diffusion length.

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