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Nuclear Instruments and Methods in Physics Research B 249 (2006) 213–216

NIM B
Beam Interactions with Materials & Atoms

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Angle resolved IBIC analysis of 4H-SiC Schottky diodes

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Abstract

We present a new experimental procedure based on the ion beam induced charge collection (IBIC) to characterise semiconductor detectors and devices. It consists in measuring the charge collection efficiency (η) as a function of the angle of incidence (α) of a strongly penetrating MeV ion beam focussed onto a partially depleted semiconductor detector. The unidimensional model based on the drift-diffusion model derived from the Shockley–Ramo–Gunn's theorem gives the theoretical background to fit the $\eta(\alpha)$ curve and to estimate both the extension of the depletion layer, the dead layer thickness and the minority carrier diffusion length.

To illustrate the analytical capability of this technique, a 2 MeV proton beam was focussed at different incident angles onto a 4H-SiC Schottky diode; the experimental results and the theoretical approach are presented and discussed.

PACS: 73.40.Sx; 72.20.Jv; 29.40.Wk

Keywords: IBIC – Ion beam induced charge collection; Silicon carbide Schottky diode; Dead layer

1. Introduction

The charge collection efficiency η, defined as the ratio of the induced charge collected at the sensing electrode of a semiconductor detector to the total charge generated by ionisation induced by MeV ions, is the usual physical observable in IBIC experiments.

In partially depleted semiconductor devices, and considering a simple one-dimensional drift-diffusion transport model, it is a function of the depletion layer thickness w and of the ionisation profile $\mathrm{d}E/\mathrm{d}x$, through the following expression [1,2]:

$$\eta = \frac{1}{E_{\mathrm{ion}}} \cdot \left[\int_t^w \frac{\mathrm{d}E}{\mathrm{d}x}\mathrm{d}x + \int_w^d \frac{\mathrm{d}E}{\mathrm{d}x} \cdot \frac{\sinh\left(\frac{d-x}{L}\right)}{\sinh\left(\frac{d-w}{L}\right)}\mathrm{d}x \right], \qquad (1)$$

where E_{ion} is the energy of the incident ion, $\mathrm{d}E/\mathrm{d}x$ is the specific ion energy loss, d is the device thickness, w is the depletion layer thickness, L is the minority carriers diffusion length and t is the "effective" thickness of the window through which the incident ion must pass before reaching the depletion (i.e. active) layer.

The first term in the square brackets represents the contribution of carriers generated within the depletion region and drifted towards the electrode by the strong electric field, assuming that the transit time is much shorter than the carrier lifetime. The second term represents the contribution of minority carriers generated within the neutral region and injected by diffusion into the depletion region.

Such an expression is a consequence of the Shockley–Ramo–Gunn's theorem [2] under the assumption that plasma effects do not play a dominant role, and it was extensively used to characterize SiC Schottky diodes [3];

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0168-583X/$ - see front matter © 2006 Published by Elsevier B.V.
doi:10.1016/j.nimb.2006.03.168