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A Monte Carlo software for the 1-dimensional simulation of IBIC experiments

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ABSTRACT

The ion beam induced charge (IBIC) microscopy is a valuable tool for the analysis of the electronic properties of semiconductors. In this work, a recently developed Monte Carlo approach for the simulation of IBIC experiments is presented along with a self-standing software equipped with graphical user interface. The method is based on the probabilistic interpretation of the excess charge carrier continuity equations and it offers to the end-user the full control not only of the physical properties ruling the induced charge formation mechanism (i.e., mobility, lifetime, electrostatics, device's geometry), but also of the relevant experimental conditions (ionization profiles, beam dispersion, electronic noise) affecting the measurement of the IBIC pulses. Moreover, the software implements a novel model for the quantitative evaluation of the radiation damage effects on the charge collection efficiency degradation of ion-beam-irradiated devices. The reliability of the model implementation is then validated against a benchmark IBIC experiment.

1. Introduction

In the last two decades the ion beam induced charge (IBIC) microscopy has been widely exploited to investigate the operation of semiconductor-based devices and microcircuits and to characterize the electronic properties of emerging materials [1,2]. Moreover, the technique has been used to study device- and material-related physical phenomena, such as single event [3], charge sharing [4,5] and radiation damage [6,7] effects in semiconductors and insulators. The IBIC technique is emerging as an ideal tool for radiation damage studies in semiconduting and insulating devices, as it offers the unique advantage of both monitoring the dose rate and the total implanted dose in selected regions of the sample [6], and simultaneously monitoring the charge collection efficiency (CCE) degradation as a function of the accumulated dose.

Moreover, the availability of a robust and reliable mathematical model based on the Shockley–Ramo–Gunn theorem [1,2,8,9] for the interpretation of the induced charge pulse formation allows an effective evaluation of the transport and electrostatic parameters for the electronic characterization of semiconductors.

The theory and the computational model has been developed in the last decade and has been validated by benchmark experiments [2,8].

Recently, a new Monte Carlo approach has been developed to realistically model the induced charge pulse formation [10,11] in order to include in the model variables following stochastic distributions, as statistical fluctuations in carrier generation, or randomly distributed recombination centres, electronic noise and thresholds.

To facilitate end users to simulate and interpret the experimental findings, a dedicated software, namely the IBIC Simulation Tool (IST) [12], offering a simple graphical user interface (GUI) has been recently developed.

Moreover, the IST is tailored to study, according to a recently proposed model [6], the radiation induced effects on the electronic properties of semiconductor and insulator devices.

In this paper, the main features of the Monte Carlo approach are discussed and validated against a benchmark experiment.

2. The Monte Carlo approach

The Monte Carlo approach relies on the Shockley–Ramo–Gunn theorem [1,2,9], which states that the total induced charge q_j induced at the j-th electrode by a point charge q moving in a device

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