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Polychromatic angle resolved IBIC analysis of silicon power diodes

M. Pezzarossa [a], E. Cepparrone [b], D. Cosic [d], M. Jakšić [d], G. Provatas [d], M. Vićentijević [d], E. Vittone [b,c,*]

[a] *Department of Applied Science and Technology (DISAT), Politecnico di Torino, Italy*
[b] *Department of Physics, NIS Interdepartmental Center, University of Torino, via P. Giuria 1, 10125 Torino, Italy*
[c] *INFN Torino Unit, via P. Giuria 1, 10125 Torino, Italy*
[d] *Department for Experimental Physics, Ruđer Bošković Institute, Bijenička Cesta 54, 10000 Zagreb, Croatia*

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ABSTRACT

This paper describes both an experimental methodology based on the Ion Beam Induced Charge (IBIC) technique and the relevant interpretative model, which were adopted to characterize the electronic features of power diodes.

IBIC spectra were acquired using different proton energies (from 1.2 to 2.0 MeV), angles of incidence, and applied bias voltages.

The modulation of the ion probe range, combined with the modulation of the extensions of the depletion layer, allowed the charge collection efficiency scale to be accurately calibrated, the dead layer beneath the thick (6 μm) Al electrode and the minority carrier lifetime to be measured.

The analysis was performed by using a simplified model extracted from the basic IBIC theory, which proved to be suitable to interpret the behaviour of the IBIC spectra as a function of all the experimental conditions and to characterize the devices, both for what concerns the electrostatics and the recombination processes.

1. Introduction

Power electronics is the key technology to control the flow of electricity from the source to the load and is the backbone of the whole power supply infrastructure in our society from the energy generation, transmission, distribution and, for its pervasiveness in a huge variety of applications, it plays a fundamental role in energy saving and improved energy efficiency [1].

Power electronics is mainly based on power semiconductor devices [2]. Their main attractiveness in this sector derives from their ability to fast switching from the “on–” to “off-” state, where “on-state” corresponds to the condition in which the current can ideally flow without losses and “off-state” the condition in which the current is ideally blocked, without leakages.

Among the many key parameters, which influence device performances, carrier lifetime plays a dominant role due to its impact on the determination of the reverse recovery time, i.e. the duration of the recovery transient from the highly conductive to the blocked states, which controls the efficiency for power conversion [3 4].

It is then unavoidable to develop and to apply experimental methods and models, possibly with non-invasive or non-destructive approaches, to assess the efficiency of processes adopted to control the carrier lifetimes [56].

In the literature, the several methods that have been proposed to reach this goal are essentially based on the measurement of effects related to the decay of excess carriers generated in the neutral region.

The injection of excess carriers is usually performed by electrical or optical means [78]. For the former, carriers are injected by the heavily doped region and the open-circuit voltage or the diode current transient measurements allow the extraction of carrier lifetimes. However, the reliability of these measurements, which is bound to an accurate knowledge of the diode structure, of the surface and of the heavily doped region recombination lifetimes, was proven to be inadequate for the Si power diode characterization [9],

Optical methods are extensively used for photonic [10] and wide bandgap [11] devices, offering the advantage of a local characterization, by scanning the focused laser beam. However, these techniques are limited to the study of the periphery of the active junctions or devices with transparent electrodes, rarely encountered in the field of power semiconductor devices.

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* Corresponding author at: Department of Physics, NIS Interdepartmental Center, University of Torino, INFN, Torino Unit, via P. Giuria 1, 10125 Torino, Italy.
E-mail address: ettore.vittone@unito.it (E. Vittone).

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