Eur. Phys. J. Plus (2025) 140:609
https://doi.org/10.1140/epjp/s13360-025-06528-1

THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

The development of IBIC microscopy at the 100 kV ion implanter of the University of Torino (LIUTo) and the application for the assessment of the radiation hardness of a silicon photodiode

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Received: 30 January 2025 / Accepted: 6 June 2025
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Abstract The ion beam induced charge (IBIC) technique is widely used to characterize the electronic properties of semiconductor materials and devices. Its main advantage over other charge collection microscopies stems in the use of MeV ion probes, which provide both measurable induced charge signals from single ions, and high spatial resolution, which is maintained along the ion range. It is a fact, however, that the use of low-energy ions in the keV range can provide the IBIC technique with complementary analytical capabilities that are not available with MeV ions, for example, the higher sensitivity to the status, contamination and morphology of the surface and the fact that the induced signal depends on the transport of only one type of charge carrier. This paper outlines the upgrade that was made at the 100 kV ion implanter of the University of Torino, originally installed for material and surface modification, to explore the rather unexplored keV-IBIC field and to assess its potential to characterize semiconductor devices. Finally, we report the first IBIC application of our apparatus, which regards the assessment of the radiation damage of a commercially available silicon photodiode, adopting the IAEA experimental protocol and the relevant interpretative model.

1 Introduction

Techniques based on the use of accelerators to implant ions with energies in the keV range are widely used for material and surface modification, are the dominant method of doping semiconductors for integrated circuit processing [1, 2] and have the potential to significantly impact on the development of physical systems proposed for quantum technologies [3].

More restricted is the use of traditional keV accelerators to analyse materials and devices for their functional, and in particular electronic, characterization, as in the case of the ion beam induced charge (IBIC) technique, which has been extensively used since early 1990s for the characterization of semiconductor devices, as radiation detectors, high power transistors, solar cells, in conjunction with the study of their radiation hardness and Single Event Upset imaging [4]. Actually, the great majority of IBIC studies are carried out using light (typically H and He) focused MeV ions, since the beam tends to stay "focused" through many micrometers of materials allowing high spatial resolution analysis in thick layers and in buried structures. There are very few applications of IBIC with sub-MeV ion beams [5], which are mainly addressed to the detection of single dopants in silicon [3, 6] or diamond [7] using focused sub 30-keV ion beams (FIBs). However, there are at least two reasons, which make "conventional" ion implanters attractive for functional characterization of semiconductors: for example, the high sensitivity of low penetrating ion probes to the status and contamination of the semiconductor surface or the possibility to select only one charge carrier as the responsible of the formation of the induced signal.

In order to explore the analytical potential of the keV-IBIC technique, the Laboratory for Ion implantation at the University of Torino ("LIUTo"), mainly aimed to implant negative single charge ions in materials of interest for quantum technologies [8–10], has been recently upgraded to perform keV-IBIC experiments.

In this paper, we describe the novel IBIC set-up at "LIUTo", which uses (max) 100 keV H^- ions collimated beams; IBIC maps were obtained by the synchronous measurement of the photodiode position, which raster scans with respect to the fixed collimator, and of the induced pulse signals, which are processed by a low-noise charge sensitive amplification/acquisition system.

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Published online: 30 June 2025