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Review Article

Semiconductor Characterization by Scanning Ion Beam Induced Charge (IBIC) Microscopy

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The ion beam induced charge (IBIC) technique is a scanning microscopy technique which uses finely focused MeV ion beams as probes to measure and image the transport properties of semiconductor materials and devices. Its success stems from the combination of three main factors: the first is strictly technical and lies in the availability of laboratories and expertise around the world to provide scanning MeV ion beams focused down to submicrometer spots. The second reason stems from the peculiarity of MeV ion interaction with matter, due to the ability to penetrate tens of micrometers with reduced scattering and to excite a high number of free carriers to produce a measurable charge pulse from each incident ion. Last, but not least, is the availability of a robust theoretical model able to extract from the measurements all the parameters for an exhaustive characterization of the semiconductor. This paper is focused on these two latter issues, which are examined by reviewing the current status of IBIC by a comprehensive survey of the theoretical model and remarkable examples of IBIC applications and of ancillary techniques to the study of advanced semiconductor materials and devices.

1. Introduction

A charged particle with energy higher than 10 eV (i.e., charged particulate ionizing radiation) passing through a material deposits energy mainly through Coulomb interactions with the electrons within the absorber atoms [1–3].

If the primary charged particles are electrons, a large fraction of their energy can be lost in a single interaction, and their trajectories within the material are very tortuous because their mass is equal to that of the orbital electrons with which they are interacting.

Also in the case of energetic (MeV) ions, most of their energy is lost in collisions with the atomic electrons; the interactions with the atomic nuclei occur much more rarely.

Therefore, the ion undergoes a huge number of interactions and gradually loses its kinetic energy: the net effect is a gradual decrease of its velocity until the particle is stopped. The range of MeV light ions in matter is mainly determined by the electron stopping power (i.e., the average energy loss of the ion per unit path length) and depends on both the ion and target masses, atomic number, and ion velocity; for MeV light (H or He) ions, it extends to distances of the order of tens of micrometers (an exhaustive review of ion energy loss mechanisms in matter can be found in chapter 2 of [1]).

Moreover, because of the high ion/electron mass ratio, the trajectories of MeV ions undergo few large angle scattering interactions with the sample nuclei owing to their high momentum; accordingly, ion trajectories are nearly straight lines until they are close to the end of their range, where the nuclear stopping cross section becomes no more negligible. Monte Carlo simulators of ion energy loss such as stopping range in matter (SRIM) [4] are readily available for estimating the depthwise energy-loss profile of an MeV ion.

The interaction of the primary ions with the atoms in the material induces the release of energetic electrons (delta rays) with eV to keV energy, that subsequently lose their energy through the interaction with the orbital atomic electrons. In a semiconductor, the overall significant effect is the production of many electron-hole pairs (EHPs).

The net result of such a process is the generation of a plasma volume along the ion track, with a submicrometer radial extension and a characteristic cone shape due to