EBIC STUDIES OF INDIVIDUAL DEFECTS IN LIGHTLY DOPED SEMICONDUCTORS:

CdTe AS AN EXAMPLE

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INTRODUCTION

Electron beam induced current (EBIC) experiments performed in the scanning electron microscope (SEM) are well-known to provide unique information, at a local scale, on bulk inhomogeneities and on electrically active extended defects in semiconductors\(^1\). The EBIC current arises from the collection of minority carriers created by the incident electron beam which are drifted by the electric field of a Schottky diode or of a p-n junction; they have been created in the space charge region (SCR) of the junction or they have reached the SCR by diffusion in the bulk of the semiconductor. The EBIC current is therefore material dependent through the minority carrier diffusion length \(L\) and through the SCR width \(W\) (\(W\) decreases when the doping level increases). Only the Schottky diode configuration where the junction is parallel to the surface and perpendicular to the electron beam, will be discussed in this paper, as it allows both imaging and quantitative characterization of bulk parameters of the semiconductor, as well as of extended defects. The accelerating beam voltage \(E\) used in EBIC experiments is also an important parameter, as it controls the electron penetration depth \(R\) of incident electrons in the material, and thus the depth from which the electrical information comes. The minority carriers created at a depth from the surface greater than \(W+L\) do not contribute to the collected current. Thus, the EBIC image is, for a semiconductor such as GaAs or CdTe (where \(L\) is of the same order of magnitude as \(R\)), a rapid and straightforward tool of characterization of its local inhomogeneities: for instance, at high accelerating voltages (\(E\approx30\) kV), the areas which exhibit the highest EBIC current can be directly identified to those with the highest diffusion length. A local quantitative determination of \(L\) and \(W\) can furthermore be made at a scale of the order of the generation and diffusion volumes of electron-hole pairs: the EBIC current is collected as a function of \(E\); the variation of the collection efficiency \(e\) with \(E\) \((e\approx E_0\) is the experimental gain to the theoretical gain ratio) is representative of the SCR width for small \(E_0\) values, and of the diffusion length for high \(E_0\) values\(^2\).

The bulk diffusion length is limited by impurities and point-defects present in the semiconductor, and the recombination of carriers can be...
either radiative or non-radiative. Such a process is locally enhanced by dislocations, grain-boundaries, clusters, precipitates present in the specimen. As a matter of fact, it has been demonstrated quite a long time ago that such extended defects can act as recombination centres for electron-hole pairs. This can occur via the core of the defect, if it introduces for instance levels in the band gap of the semiconductor, or via impurities which have segregated around it. The EBIC mode of the SEM provides an unique way to image these defects which usually give rise to dark contrasts when they are scanned by an electron beam. They appear as dark spots if they are dislocations perpendicular to the surface or precipitates and clusters located under the surface; dislocations parallel to the surface and GBs are displayed on the EBIC image as dark lines. The resolution, of the order of one micron, decreases when E increases. This could be considered as a disadvantage in comparison with other electron microscopy techniques; but it is the only one, with cathodoluminescence which can bring local information on the electrical activity of defects.

In contrast to the bulk parameters which can be determined by routine experiments from now about 10 years, the identification of dark spots is quite recent. The first EBIC contrast theory of defects has been described by Donolato in 1978/79. Based on a phenomenological model, it allows the characterization of dark spots in semiconductors in which the SCR width W can be neglected in comparison with the electron penetration depth R. But this assumption does not remain valid for all the doping levels of semiconductors; therefore, this model has been extended by Sieber to 'lightly' doped semiconductors where the SCR width is of the same order of magnitude as R; CdTe was taken as an example. This extension is quite necessary, since it has been shown experimentally in silicon and CdTe that recombination at extended defects can take place even in the presence of an external electric field.

In the following we will describe these EBIC models, emphasizing, in each case, how routine experiments can be conducted in the SEM in order to assess the nature of the dark spots. It will be shown that, if such an identification can be performed in the case of 'doped' semiconductors by varying only one parameter, namely E₀, another one is necessary in the case of 'lightly' doped semiconductors; it will be demonstrated that the reverse bias applied to the junction is an appropriate parameter, as it acts on the SCR width. This will be illustrated by experiments made on a n-type CdTe specimen.

EBIC CONTRAST OF DEFECTS

Continuity Equation

The generation of electron-hole pairs, their diffusion and their recombination are described by the well-known continuity equation which, in the absence of any external electric field and under steady-state and low injection conditions is written, for a n-type semiconductor:

\[
D \text{ div grad } \Delta p(x) - \frac{\Delta p(x)}{\tau(x)} = - g(x)
\]

(1)

D is the minority carrier diffusivity, \( \Delta p(x) \) the excess minority carrier density and \( \tau(x) \) the minority carrier lifetime such that \( L=(D\tau)^{1/2} \).