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Quantifying Scanning Electron Microscopy of Semiconducting Materials

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ABSTRACT: Progress is being made in the quantification of SEM EBIC and CL through advances in instrumentation and in the application of Monte Carlo electron trajectory simulation to calculate signals as functions of SEM and materials parameters. Contrast simulation then becomes readily possible also. Recent developments in this field are outlined and some tasks for the future are pointed out.

1. Introduction

Quantitation and, so far as possible, automation are a long term aim in the field of scanning electron microscope (SEM) cathodoluminescence (CL) and electron beam induced current (EBIC) analysis. The analogy with the development of the X–ray mode of the SEM i.e. EPMA (electron probe microanalysis) with its well–known iterative ZAF (atomic number, absorption and fluorescence) correction programs, shows that two things are needed to make a technique convenient and at least semi–quantitative. These are reliable, sensitive linear instrumentation and some means of computerized interpretation.

Instrumentation has progressed considerably in recent years. EBIC imaging of silicon devices is relatively easy so any good video amplifier will do. However, to carry out quantitative work on less well developed materials and devices, especially on high resistivity ("semi–insulating") materials requires versatile, robust (student proof!) yet sensitive and reliable systems with computer interfacing to allow image processing and programmed operation. At least one such system is now commercially available[1].

Similarly, CL panchromatic imaging for GaAs and InP based materials and devices is relatively easy. ECL (emission cathodoluminescence) and TCL (transmission CL) are carried out simply by placing Si or Ge photodetectors to view the sample from above or below respectively. The signals can be handled by a special CL system (EDS (Curogne)) or by the Matelect system.

However, until recently spectroscopic CL (SCL) has required the experimenter to assemble his own system. Now, however, at least one complete SCL instrument is available[2].

There has also been progress in the development of interpretive software based on the use of Monte Carlo simulation of electron trajectories to calculate the distribution of energy dissipated in the specimen by the beam.

Suites of programs are available for simulating electron trajectories in solids and quantifying CL and EBIC signals for most semiconductor specimens and for simulating defect line scan profiles.

[1] The ISM5 (Induced Signal Monitor) from Matelect Ltd. 33 Bedford Gdns, London W8 7EF, U.K.
[2] The monoCL from Oxford Instruments Ltd., Eynsham, Witney, Oxon. OX8 1TL, U.K.

2. Quantitation of EBIC

Programs for this purpose were first written by Joy and Pimentel (1986) and Czyzewski and Joy (1990) for the strength of the EBIC signals detectable by silicon Schottky diodes and for the EBIC contrast due to dislocations lying at a constant depth below the Schottky contact[3].

Similar programs have now been written for the EBIC signal detectable by a p–n junction at a constant depth below the surface of the semiconductor and for the EBIC contrast of dislocations at a constant depth in such samples. A program for simulating the EBIC signal of charged grain boundaries[4], modelled as two Schottky barriers back-to-back (Figure 1) was written (Napchan 1987) and has now been used to analyse grain boundaries in ZnSe (Figure 2).

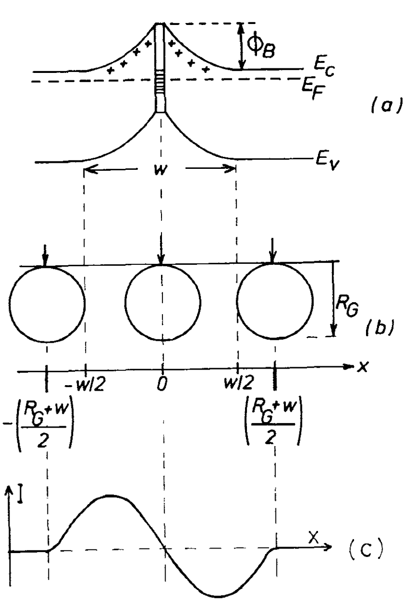

Figure 1

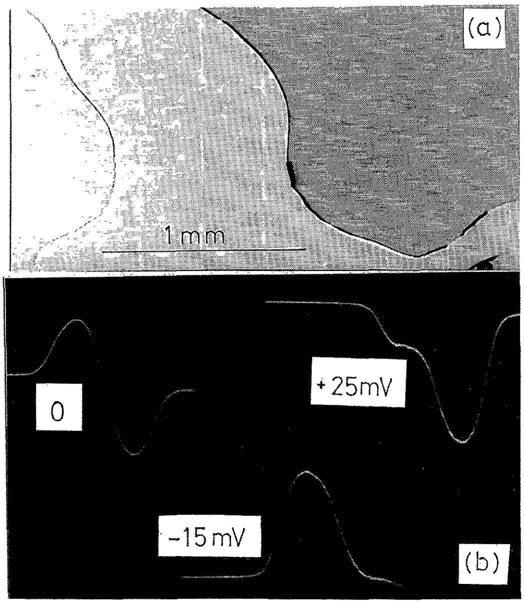

Figure 2

Figure 1. (a) The energy band diagram of a negatively charged grain boundary in an n–type semiconductor and (b) diagram of a uniform generation sphere scanning across it, and (c) the form of the resultant EBIC linescan profile.

Figure 2. (a) EBIC micrograph of a grain boundary in ZnSe and (b) EBIC line scan profiles across it under zero and small biases of opposite sign.

3. Quantitation of CL

The variation of the emitted CL intensity with the beam voltage can easily be calculated i.e. L_{CL} vs V_b can be found. This has been done and measurements made with the results shown in Figures 3 and

[3] These "Demo" programs are available from Prof. D.C. Joy, EM Facility, University of Tennessee, Knoxville, TN37996, U.S.A.

[4] These "MC–SET" programs are available from Dr. E. Napchan, Dept. of Materials, Imperial College, London SW7 2BP, U.K.

4 for GaAs and InP respectively.

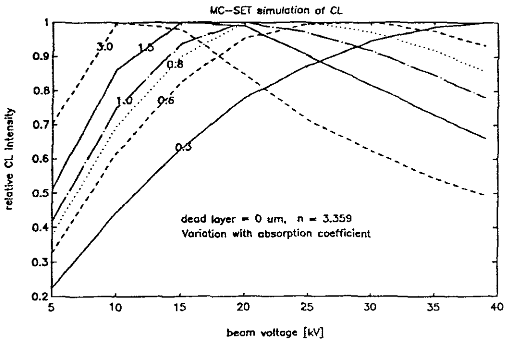

Figure 3. Variation of the emitted CL intensity with beam voltage at constant beam current for a series of values of the absorption coefficient, α, as marked on the curves.

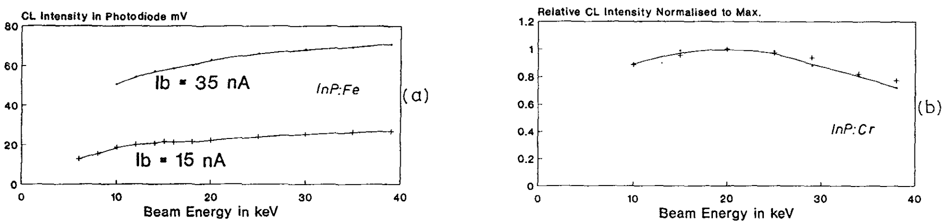

Figure 4. The variation of emitted CL with beam voltage in two samples of InP showing variation of the forms characteristic of material with (a) a relatively low value of the absorption coefficient α and (b) a relatively large one.

4. Dislocation Dark CL Contrast

A program for calculating dislocation CL contrast linescan profiles using the phenomenological model of Donolato has been written. Experimental curve fitting to such profiles will be discussed.

5. The extension of the EBIC Method to Semi–Insulators

It can be shown that the EBIC method can be extended to high resistivity materials such as semi–insulating GaAs, InP, and a number of II–VI compounds and to the study of e.g. grain boundaries in such materials (Figure 2). This opens the ceramic field for the application of EBIC and Monte Carlo analysis.

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