

In-Situ EBIC STEM: Automated Quantification

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There is a need to measure the electrical properties in semiconductor devices with nm-scale resolution. One of the strengths of electron microscopy is that the electrical properties can be related to the structure and composition of the same specimen containing the device. This is an emergent area in electron microscopy, with several techniques that can be applied such as electron holography or pixelated STEM. However, it is possible to apply Electron Beam Induced Current (EBIC) STEM in a transmission electron microscope, which can be to reveal internal electric fields [1], measure diffusion lengths [2] and determine recombination strengths [3] at high spatial resolution compared to the SEM based equivalent. Here, we present recent developments and applications of EBIC STEM, with a particular focus on quantification. Quantification is an important aspect of the technique as it enables measurement of fundamental material properties, direct metrology of devices with different processing parameters, as well as electrical failure analysis.

EBIC STEM is very straightforward, a focused electron beam is used as a virtual electrical probe to induce current into the device, which is measured using electrical connections to a low-noise high-speed imaging unit [4]. Image interpretation for the case of simple structures is very straightforward, as induced current is only present in areas with an internal electric field, which may be locally broadened by diffusion of charge carriers, and locally reduced by increased recombination activity at defect sites. Figures 1-2 below give two examples to illustrate these important points where EBIC has been performed in a probe corrected FEI Titan Ultimate. Interpretation becomes more difficult for the case of samples with complex structures, not only because the amount of induced current varies with local composition and thickness, but also because Secondary Electrons (SE) give rise to an additional current overlaying onto the induced current [5].

We will show that the key advantage of EBIC STEM over other techniques is the ability to bridge between experimental images and device modelling as measures the signal in the μA to fA range at each point on the sample. We will also discuss the electronic setup; automatic quantification is achieved through factory calibration of amplification, image acquisition through the TEM manufacturer, and calibration of the dark current by the STEM operator. Dedicated software is used to provide values that are automatically managed by the acquisition application into a suitable file format [6]. Therefore, image interpretation can always be assisted by an understanding of quantified values, from simple 2D devices to complex heterostructures with varying composition.

With regards to SE signal, automated quantification means that the measured pixel value can be transformed into thickness or composition. As it will be further illustrated, the reverse is also possible using Monte Carlo simulations, where a model is given as input to calculate the expected SE signal. This then provides a basis for interpretation of complex structures with overlapping SE and EBIC contrast. By analogy with simulation of SE signal, it is in principle also possible to simulate EBIC images using finite element analysis, however this is beyond the scope of this contribution [8].

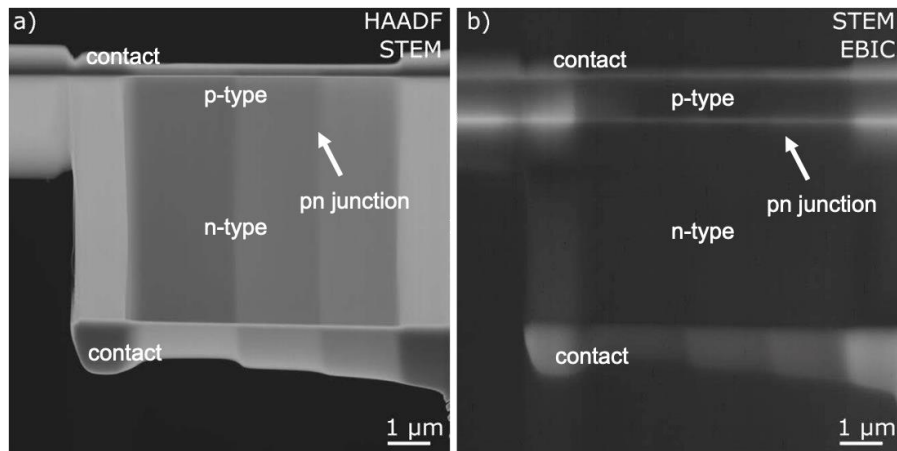


Figure 1. (a) Simultaneous HAADF STEM and (b) EBIC STEM images of a Si diode test structure, prepared at increasing lamella thickness [7].

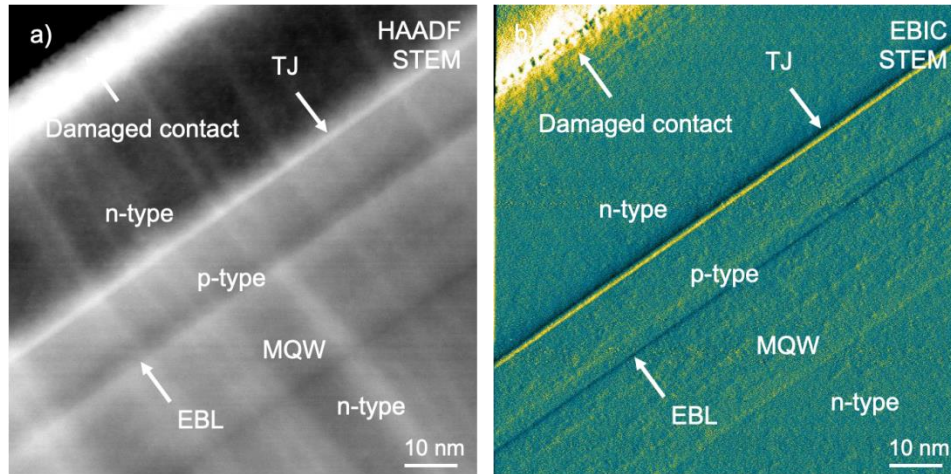


Figure 2. (a) Simultaneous HAADF STEM and (b) pseudo-color EBIC STEM images of an AlGaIn/GaN LED device showing Multiple Quantum Wells (MQW), a Tunnel Junction (TJ) and an Electron Blocking Layer (EBL).

References:

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