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Measuring the minority carrier diffusion length in n-GaN using bulk STEM EBIC

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Gallium nitride is currently being investigated for demanding applications such as high-temperature and high-power electronics as well as space-based or other high radiation exposure applications. It has a wide bandgap and is more resistant than Si to high fluxes of proton and electron radiation [1]. Electron irradiation of GaN is believed to create both N and Ga vacancies, as well as to induce threading dislocation glide. These defects can act as recombination centers which reduce the overall minority carrier lifetime and mobility. Measurements of the minority carrier diffusion length in GaN can be studied using cathodoluminescence (CL) or electron beam induced current (EBIC) in a scanning electron microscope (SEM). However, as recently reported in Yakimov et. al. [2], the EBIC planar geometry in SEM often leads to an over estimation of the minority carrier diffusion length in n-type GaN. This over estimation is attributed to the interaction volume in SEM, which is on the order of hundreds of nanometers to a few microns and overlaps with the measured minority carrier diffusion length of n-GaN, reported to be between a few tens of nanometers to a few microns [2].

Here we report on scanning transmission electron microscopy (STEM) EBIC characterization of Schottky diodes consisting of hydride vapor phase epitaxy (HPVE) grown n-GaN and patterned Ni contacts. We demonstrate that by using a bulk STEM EBIC technique, the minority carrier diffusion length, L_d, can be separated from the interaction volume diameter, R. An accelerating voltage of 100 kV or 200 kV in STEM gives a much larger interaction volume than an accelerating voltage of 5 to 30 kV does in SEM. We have shown previously [3] that the interaction volume is approx. 4 µm for 100 kV and 14 µm for 200 kV, which are both much larger than the expected diffusion length, L_d for n-type GaN. Since the length scales for R and L_d are quite different, we can separate the exponential decay of the interaction volume from the exponential decay of the diffusion length. This allows accurate measurement of diffusion lengths in a convenient planar geometry while avoiding the pitfalls of planar geometry in SEM EBIC.

Our sample consists of a high purity single crystal n-type GaN substrate (275 µm thick) grown by HVPE with a threading dislocation density of $\sim 10^6/cm^2$ and patterned with a nickel Schottky contact as well as an indium ohmic contact. As can be seen in Fig. 1b, the GaN sample is patterned with a Ni contact and wired with Ag epoxy to an Au wire. Since the EBIC image only shows areas where charge carriers are measurably excited and separated, only the Ni pad and some of the Ag epoxy is visible. Fig. 2a shows the line profile EBIC signal as a function of distance, which was taken from the inset of 2a. As can be seen, is a short, fast decay and a long, slow decay. These two exponential decays can be fit and two different decay lengths can be solved for, shown in Fig. 2b. Initial measurements show the minority carrier length for n-type GaN to be 265 ± 27 nm, which is consistent with reported values for these samples [4]. We will present further measurements of *in situ* reverse biasing and subsequent changes in EBIC signals.

This research was performed at the University of Maryland NanoCenter Advanced Imaging and Microscopy Laboratory. The data was taken on a JEOL 2100F S/TEM operating at 100kV and 200 kV in STEM mode using a Nanofactory STM-TEM holder.

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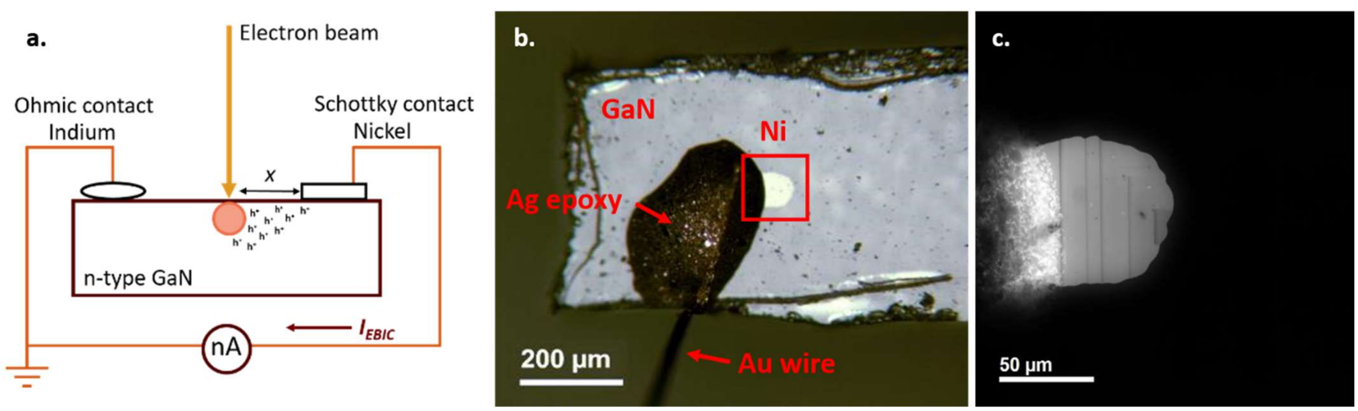

Figure 1. a) Schematic showing STEM EBIC setup, b) Optical micrograph of sample after wiring to TEM holder, c) EBIC image at 100 kV.

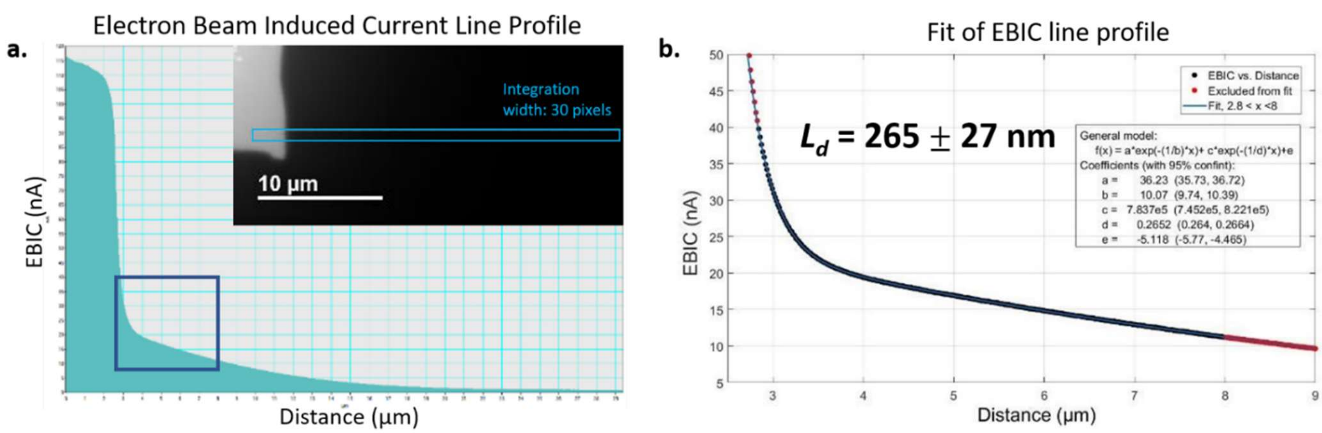

Figure 2. a) Line profile of EBIC data, taken from the inset, with an integration width of 30 pixels b) Fit of EBIC line profile, illustrating the two exponential decay fit and the calculated diffusion length.

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