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Citation: *J. Appl. Phys.* **90**, 1058 (2001); doi: 10.1063/1.1379773

View online: <http://dx.doi.org/10.1063/1.1379773>

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Study of growth hillocks in GaN:Si films by electron beam induced current imaging

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(Received 16 February 2001; accepted for publication 25 April 2001)

Remote electron beam induced current (REBIC) measurements have been carried out to investigate electrically active regions in Si doped GaN films. REBIC bright–dark contrast has been observed in the border of growth, round or pyramidal, hillocks, while pyramidal hillocks also show bright contrast at the center. The results are explained by the inhomogeneous distribution of charged point defects and impurities at the hillocks. © 2001 American Institute of Physics.

[DOI: 10.1063/1.1379773]

The application of III–V nitrides in blue light emitting diodes and lasers has generated an increasing interest in the study of recombination properties of defects in these materials. One of the techniques used has been cathodoluminescence (CL) in the scanning electron microscope (SEM) which provides information on the spatial distribution of the different emission bands and their association to extended defects. In the microscopic observations of the surface of GaN epitaxial films the presence of growth hillocks, with different sizes, typically several microns, and shapes, have been often reported. CL observations have revealed that the hillocks present specific recombination properties related to their structural features. Middleton *et al.*¹ found enhanced yellow emission in the center of pyramidal hillocks and related it to defects associated with inversion domain boundaries. Herrera Zaldivar *et al.*² reported a marked CL contrast at the center and at the border of round shaped hillocks that was explained by an inhomogeneous distribution of point defects and impurities. Electron beam induced current (EBIC) is another SEM-based technique which has been often used to study electrically active defects in semiconductors.³ For EBIC measurements the formation of a barrier, like a Schottky barrier or a *p-n* junction, is necessary. In the remote electron beam induced current (REBIC) method which is applicable to high resistivity and semi-insulating materials, junction or barriers are not used⁴ but two ohmic contacts at opposite ends of the sample surface are necessary. Electron–hole pairs generated by the SEM electron beam produce a current in an external circuit which, after amplification, is used to image the spatial distribution of electrically active regions in the sample. This technique has been applied to the study of electronic recombination and electrical conduction in different materials^{5–8} but its capability to characterize the surface features in GaN films has been to our knowledge not previously reported. In this work, RE-

BIC is used to image electrically active regions of growth hillocks in GaN:Si films, whose recombination properties have been previously studied by CL.²

The samples used were GaN films grown on (0001) sapphire. The films consisted of an 8 μm thick GaN buffer layer grown by the hydride vapor phase epitaxy method, and two 2 μm thick epilayers. The upper layer was Si doped with a carrier concentration of about 10^{18} cm^{-3} . The films were observed in the secondary electron and REBIC modes of scanning electron microscopy by using a Hitachi S-2500 or a Leica S-440 scanning electron microscope with an electron beam energy of 15 keV and temperatures between 77 and 300 K. For the REBIC measurements, ohmic contacts separated about 2 mm on the sample surface were provided by silver paste with gold wires and the signal was detected with a Matelect ISM-5 system.

Secondary electron images show a distribution of hillocks of a size of about 5 μm in a smooth background as previously reported.² Most of the hillocks have a rounded shape (Fig. 1) while some of them are pyramidal. The rounded hillocks often reveal an incipient, with rounded corners, hexagonal shape, which does not correspond exactly with the hexagonal features on different GaN films, reported in the literature. A small fraction of the hillocks, however, have sizes of about 50 μm and show a defined hexagonal shape (Fig. 2).

REBIC images show a significant contrast in the hillocks. Figures 1 and 2 show the emissive mode and the REBIC images at room temperature of one small and one large hillock, respectively. A bright–dark contrast at the hillock border is observed in both REBIC images. This contrast is known as peak and trough (PAT) and has been observed in REBIC investigations of grain boundaries in semiconductors.^{5,6,9} The REBIC contrast across the border has been found to depend on the temperature. Figure 2 shows the induced current image recorded at room temperature with a beam current of 10^{-9} A , and the signal profiles at different temperatures along a line, marked in the image, crossing the border. The profiles show that the bright–dark contrast is asymmetric and increases with decreasing temperature. In particular the intensity of the bright side increases with tem-

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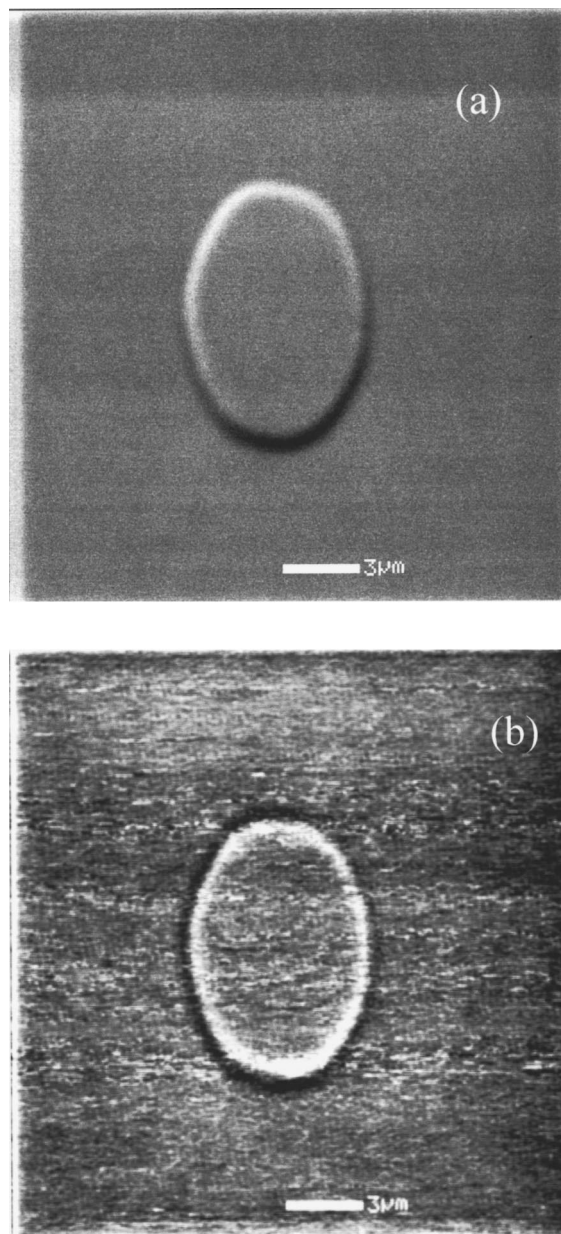


FIG. 1. Emissive mode (a) and REBIC image at room temperature (b) of a small rounded hillock.

perature while in the dark side a clear trend is not observed. Figure 2(c) shows the REBIC intensity profiles across the boundary, obtained with electron beam currents of 10^{-8} A (curve 1) and 10^{-9} A (curve 2), respectively. The variation observed is a reduced signal for the lower current in the dark part of the profile.

The observed REBIC contrast shows that, similar to the grain boundaries of different semiconductors, the border of the hillocks in our GaN samples have associated charges and surrounding space charge volumes. A charged boundary is related to local band bending providing two fields in opposite directions. Electron-hole pairs created by the SEM electron beam are separated by the fields and produce the current in an external circuit. The grain boundary fields are responsible for the bright-dark contrast observed in absence of bias, which is an evidence that the boundary is electrostatically

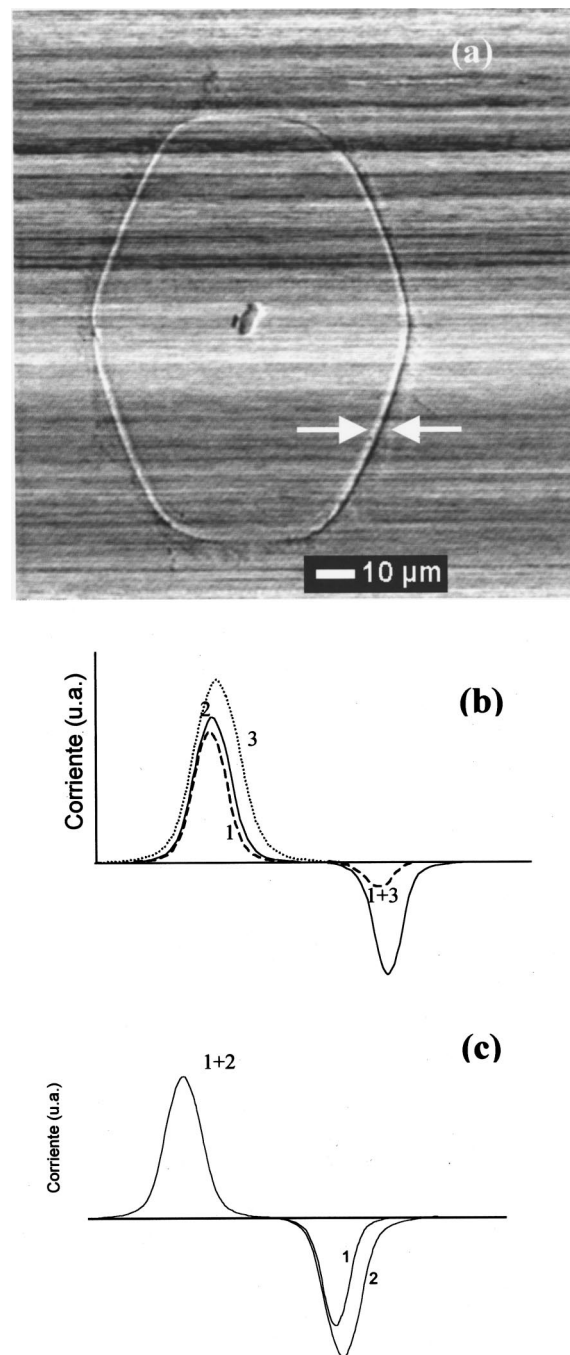


FIG. 2. REBIC image of a big hillock (a) and REBIC intensity profiles obtained across the boundary (as indicated by arrows in the image) (b) with a beam current of 10^{-9} A and different temperatures (curve 1: 298 K; curve 2: 200 K; curve 3: 100 K); (c) at room temperature and different beam currents (curve 1: 10^{-8} A; curve 2: 10^{-9} A).

charged. The electric field causing the PAT contrast is modeled as two Schottky barriers back-to-back.^{9,10} Both temperature and excitation density influence the potential barrier height associated to the hillock border, as Fig. 2 shows. PAT contrast changes towards only bright or only dark contrast by modifying these parameters. The influence of temperature and excitation density on the REBIC contrast has been previously reported for II-VI compounds¹¹ and other materials as diamond⁸ and superconducting ceramics.⁷ The same effect is obtained by the application of a bias or reverse voltage⁶

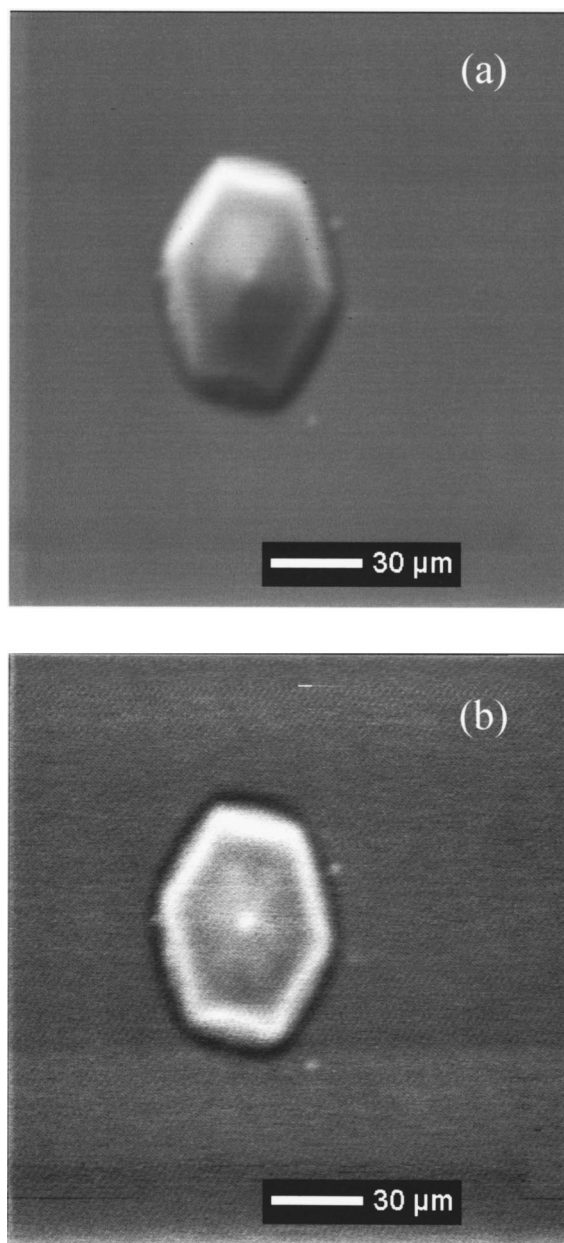


FIG. 3. Emissive mode (a) and REBIC image at room temperature of a pyramidal hillock.

which alters the energy band structure at the boundary and produces flatband conditions.

In the above-mentioned CL work on the same films used here,² the hillocks showed a marked CL contrast at the center

and at the border involving the 360, 430, and 550 nm luminescence bands. The CL contrast at the border is attributed to an inhomogeneous distribution of point defects and impurities taking place during growth. On the other hand, Raman measurements on Si doped GaN films¹² have shown a reduced dopant concentration in the center and in the border of the hillock. In addition to the REBIC contrast of the border of the hillocks, in some cases the center also shows a bright contrast (Fig. 3) which agrees with the CL and Raman observations. Figure 3(c) shows a vaguely visible star-shaped pattern in the central region of the hillock with regions of light contrast along specific, likely $[11\bar{2}0]$, directions. The star-shaped contrast has been reported in the Raman observations of Ref. 12 and related to the distribution of impurities. We suggest that the inhomogeneous distribution of point defects and impurities at the hillocks is responsible of the charge effects detected in the REBIC images.

In summary, REBIC is a suitable technique for the detection of electrically active defects at the surface of GaN films. Round or pyramidal growth hillocks show bright-dark REBIC contrast at the border, which is similar to the contrast observed in the grain boundaries of different semiconductors. In some cases the center appears bright in the images. The distribution of point defects and impurities at the hillocks produces charge effects at the border and center of the hillocks, detected by REBIC.

This work was supported by MCYT-DGI (Project No. MAT2000-2119). M.H.Z. thanks AECI and CoNaCyT for a research grant.

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