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Electrical and Structural Characterization of GaN p-n Heterostuctures by Scanning Probe Microscopy

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III-Nitride based devices have been of great interest in the last few years, notably due to their success is optoelectronics, where semiconductor lasers and light emitting diodes (LED's) have been demonstrated and successfully commercialized [1]. Structural and electrical characterization at the microscopic and nanoscopic level is of great importance for the understanding and development of new devices. In this work, electrical and structural characterizations of GaN p-n heterostructures using cross-sectional Scanning Probe Microscopy (SPM) are presented. SPM techniques are most valuable in allowing the local variations of structural and electrical properties of the surface of the samples to be mapped on the micrometer or nanometer scale, simultaneously. Atomic Force Microscopy (AFM) and Friction Force Microscopy (FFM) were used to study structural properties of the cross section of a GaN/AlGaN p-n heterostructure, as shown in Figure 1. Using these techniques, the thicknesses of the five layers present in the heterostructure were measured within 5% agreement when compared to the values obtained by Field Emission Scanning Electron Microscopy. The electrical properties of this sample were studied using Electrical Force Gradient Microscopy (EFM) and Surface Potential Microscopy (SP). In these experiments a harmonically oscillating Platinum coated Atomic Force Microscope probe is scanned over the cross-sectional surface of the sample at a constant separation. The contact potential between the surface of the sample and the metallic probe creates an electrostatic force on the metallic probe changing the oscillating frequency and amplitude of the probe. Recording the change on the oscillating frequency of the probe a map of the gradient of the electrostatic interaction between the metallic probe and the sample is acquired (Figure 2b). The contact potential between the metallic probe and the surface of the sample is acquired in the SP experiments using a lock-in technique to determine the change in the oscillating amplitude of the probe, as shown in Figure 2c). The electrical conductivity type of the different layers as well as the location of the p-n junction was determined using EFM and SP.

EFM was also used to study the p-n junction location with respect to the InGaN quantum well in the cross-sectional surface of an InGaN quantum well (QW) p-n heterostructure. Figure 3 shows the topographic and EFM images of the cross-sectional surface of the sample, where the light area in the left side is n-type, the central dark stripe is p-type, and the light area in the right is the Au contact. The inflection point between the n-type and p-type regions correspond to the maximum in electric field of the p-n junction, i.e. the p-n junction location. The lighter thin stripe between the n-type and p-type regions corresponds to the QW. In this particular sample the distance between the QW and the p-n junction was found to be approximately 20 nm, in good agreement with STEM-EBIC results for a similar heterostructure.

[1] S. Nakamura, et al., Appl. Phys. Lett. **70**, 1417 (1997).

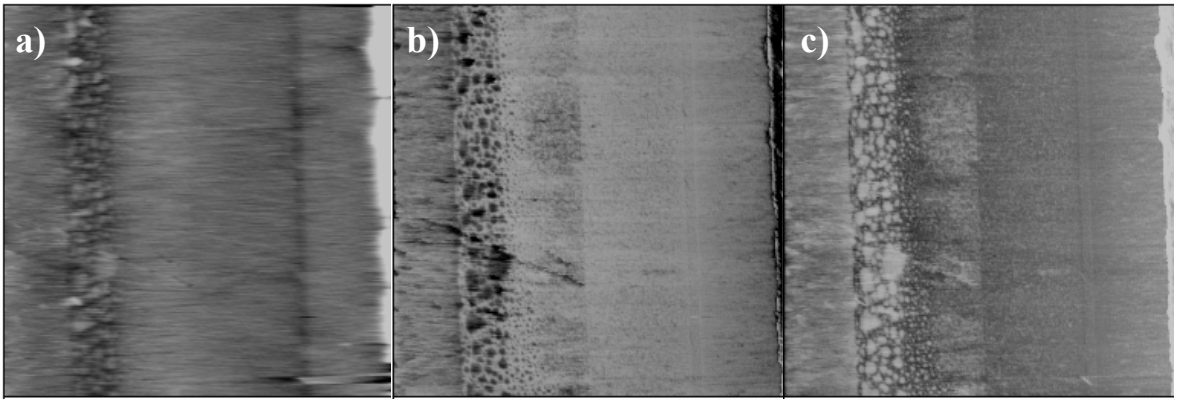

Figure 1. SPM images in contact mode of a field of 3.6x3.6 μm of the cross-sectional surface of the GaN/AlGaN p-n heterostructure: a) topographic image, b) friction image acquired in the trace direction, c) friction image acquire in the retrace direction.

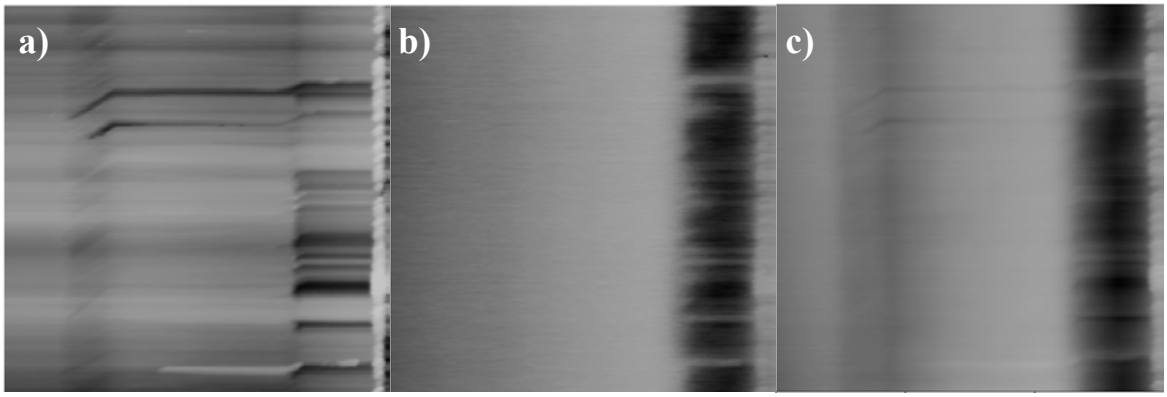

Figure 2. SPM images in tapping mode of a field of 3.0x3.0 μm of the cross-sectional surface of the GaN/AlGaN p-n heterostructure: a) topographic image, b) EFM image, c) SP image. The dark areas in images b) and c) correspond to p-type layers, the light areas at the left of the images correspond to n-type layers, and the thin light area at the right of the images is the Au contact.

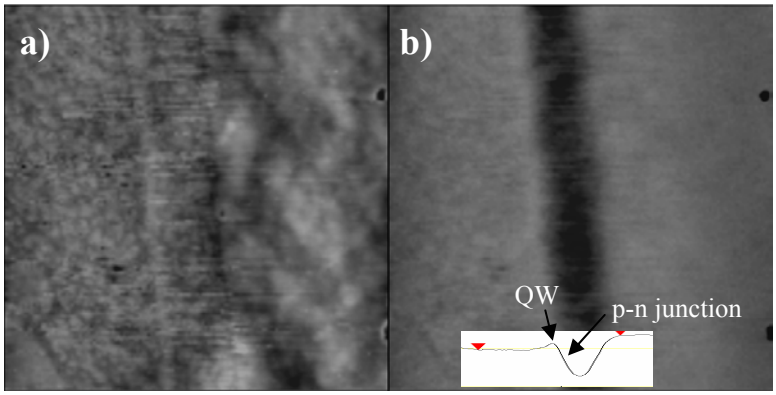

Figure 3: Topographic a) and EFM b) images of the cross-sectional surface of the InGaN QW p-n heterostructure. In image b) the light area in the left side is n-type, the central dark stripe is p-type, and the light area in the right is Au contact. The insert in the EFM image is a cross section profile of the central part of the image showing the QW and the p-n junction locations.

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