

First Results on the Spectromicroscopy of AlGaN

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INTRODUCTION

Gallium nitride and related wide band gap semiconductors are an important class of electronic materials because of their potential use in optoelectronic devices operating in the blue range [1]. In the last few years, many efforts have been devoted to investigate the electronic structure of such nitrides, and x-ray photoemission spectroscopy (XPS) has been widely used to study GaN [2]. Among other results, these investigations indicated a substantial band bending due to Fermi level pinning at the sample surface, related to intrinsic localized surface states [3].

XPS has been widely used to study GaN and related compounds, but the technique provides spatially averaged results. Spectromicroscopy [4] can provide spatially resolved information on the chemical composition of the sample surface, as well as standard morphological and chemical analysis. Hence, this technique can provide a deeper insight in the electronic microstructure of these compounds, which is characterized by lateral inhomogeneity and by dislocation densities several order of magnitude above those in other semiconductors.

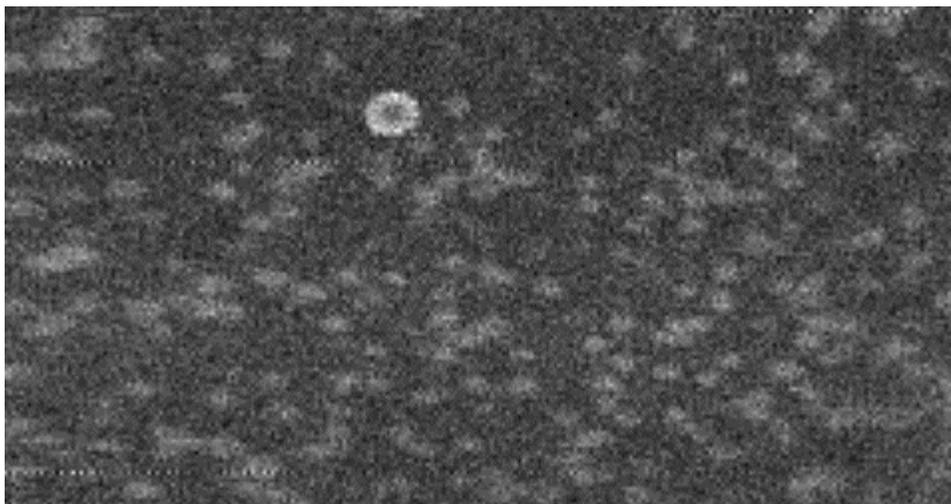


Figure 1: Secondary electron X-ray photoemission micrograph of AlGaN thin film (sample A). The field is 60 μm by 30 μm . The kinetic energy is $E_k=5$ eV. This image clearly shows the surface morphology of the sample, indicating a mean grain size of about 2 μm , in agreement with other atomic force microscopy results.

We report the results of the first investigation of AlGaN films using photoemission spectromicroscopy. The results have been obtained using MAXIMUM [5], a scanning photoemission microscope installed on the 12.0 undulator beamline at the Advanced Light Source (ALS), with a spatial resolution of 100 nm. The AlGaN samples were grown on a sapphire substrate by metal-organic chemical vapor deposition (MOCVD). This preliminary analysis clearly indicates the great potential of spectromicroscopy in investigating chemical inhomogeneity,

impurities and localization in AlGa_xN films, providing detailed information on the chemistry and on the morphology of the investigated systems in the submicron range.

EXPERIMENTALS

In 1987, the University of Wisconsin, in collaboration with the ALS, started the development of an x-ray microscope system of the scanning type with the goal of reaching a spatial resolution better than 0.1 μm , a spectral resolution better than 300 meV, and a base pressure of 10^{-10} torr. All these goals were achieved in 1992, when the photoemission microscope MAXIMUM was originally installed on Aladdin at the Synchrotron Radiation Center (SRC). During the period from 1992 to 1995, the microscope was successfully used to study semiconductor surfaces, interfaces, biological samples and organic particles. However, during the operation of the microscope it became quickly evident that the microscope performance was severely hampered by the relatively low brightness of Aladdin, which limited the available flux at the microscope's focus and, consequently, the achievable spatial resolution. In order to overcome these problems, the microscope was moved to the ALS in April 1995, where it was temporarily installed on the bend magnet beamline 6.3.2. In August 1997, the installation of the microscope in its final location (beamline 12.0) has been completed. The testing of the microscope demonstrated a spectral resolution of 250 meV, a lateral resolution of 0.1 μm in photoemission mode, and a flux on the pinhole of 4×10^{14} ph/sec.

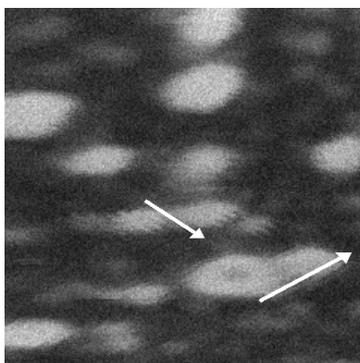


Figure 2: Close-up of the morphological structure of an AlGa_xN film. The field is 12 mm by 12 mm. The kinetic energy is $E_k=5$ eV. The grains show a fine structure, related to their crystalline orientation (arrows).

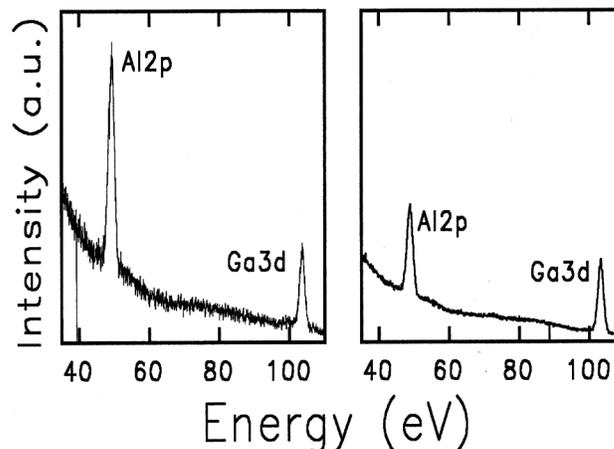


Figure 3: EDCs of the investigated AlGa_xN films. The results evidence the difference in Al concentration between sample A and B ($x=0.23$ and $x=0.51$, respectively).

Radiation from the synchrotron source is monochromatized and then focused by a Kirkpatrick-Baez system to illuminate a pinhole, which serve as spatial filter and source for the microscope optics. A Schwarzschild objective (SO) coated with multilayers for 130 eV produce an image of the pinhole with a 20x demagnification. When a sample is placed at the focus, photoelectrons are collected by a cylindrical mirror analyzer (CMA) electron spectrometer. The sample is mounted on a scanning stage, and by rastering the sample it is possible to produce a 2-d photoemission image.

The MOCVD Al_xGa_{1-x}N thin films had different concentration x of Al and different thickness: sample A (#2922), $x=0.23$ and 4350 \AA thick, and sample B (#2927), $x=0.51$ and 6540 \AA thick.

The chemical composition of the films has been independently analyzed by means of Rutherford backscattering spectrometry (RBS). The results show that both the films have Ga rich surfaces, especially sample A. Sample A shows a top layer (5×10^{17} atoms/cm², 550 Å thick) with $\text{Al}_{0.135}\text{Ga}_{0.44}\text{N}_{0.425}$. In the case of sample B, the top layer (2.5×10^{18} atoms/cm², 2770 Å) shows $\text{Al}_{0.255}\text{Ga}_{0.244}\text{N}_{0.50}$. Standard XPS spectroscopy has also been performed on both the sample.

RESULTS AND DISCUSSION

In Fig. 1 we show a x-ray photoemission micrograph of Sample A. The image evidences the grain structure of the surface morphology. It has been acquired at $E_k=5$ eV (i.e. imaging secondary electrons) and its size is 60 x 30 μm. The grain size deduced from this image (about 2 μm) is in good agreement with the results of AFM analysis. In Fig. 2 a close-up of the surface grain structure is reported. The image size is 12 x 12 μm, at the same kinetic energy of Fig. 1. The image shows in detail the granular structure of the investigated samples, evidencing also the crystalline orientation of some of the grains (arrows in Fig. 2). These results indicate that photoemission microscopy can give high quality morphological information on the surface of the samples.

In Fig. 3 we report the electron distribution curves (EDCs) of the two samples investigated. The relative intensity of the Al2p at $E_k=49.9$ eV ($E_b=75.8$ eV) and the Ga3d at $E_k=103.4$ eV ($E_b=22.4$ eV) indicates a change in the Al concentration. By accounting for the x-ray photoemission cross section, it is possible to have a semi-quantitative evaluation of the Al/Ga ratio in the two samples. The results agree quite well with the ones obtained by means of RBS and standard XPS, thus allowing an evaluation *in situ* of the surface composition.

In Fig. 4, we report three XPS microimages of sample B at different kinetic energy. The energies are 5 eV (secondary electrons), 21 eV (Ga 3p), and 50 eV (Al 2p), respectively. The size is 100 x 100 μm. In Fig 4a, the secondary electron images shows the morphology of the sample surface. A rhombohedral feature (dashed line) is evident in the upper part of Fig. 1a. The diagonal line (arrow) is a crystallographic plane at 60 degree with respect to the feature side. The chemical mapping of Ga and Al (Figs. 4b and 4c, respectively) clearly indicate an Al excess and a Ga deficiency in the crystallographic plane.



Figure 4: XPS microimages of sample B at (a) 5 eV (secondary electrons), (b) 21 eV (Ga3p), and (c) 50 eV (Al2p). A rhombohedral feature (dashed line) and a crystallographic plane (arrow) are evident in (a).

CONCLUSION

We have reported some preliminary results on AlGaN using photoemission spectromicroscopy. The analysis clearly indicates the ability of spectromicroscopy to perform simultaneously morphological and chemical analysis *in situ*, as well as microscopic elemental mapping. Our results

suggest future promising applications of this technique in investigating chemical and morphological inhomogeneity in AlGaN and related materials.

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This work was supported by the U.S. Department of Energy under Contract No. DE-FG02-96ER45569.

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