Photoemission spectromicroscopy studies of ELO GaN surface

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ABSTRACT
Photoemission spectromicroscopy is employed to investigate the surface electronic inhomogeneities of epitaxy lateral overgrowth (ELO) GaN material. The surface morphology obtained via photoemission microscopy is in confirmation with AFM. Localized EDCs for Ga 3d-core level obtained on clean GaN demonstrates Fermi level pinning for different growth areas. Hydrogen adsorption destroys this Fermi level pinning. The magnesium deposition on GaN results in Magnesium Island where reactivity of magnesium with nitrogen is higher compared with Ga thus leaving Ga in a metallic form.

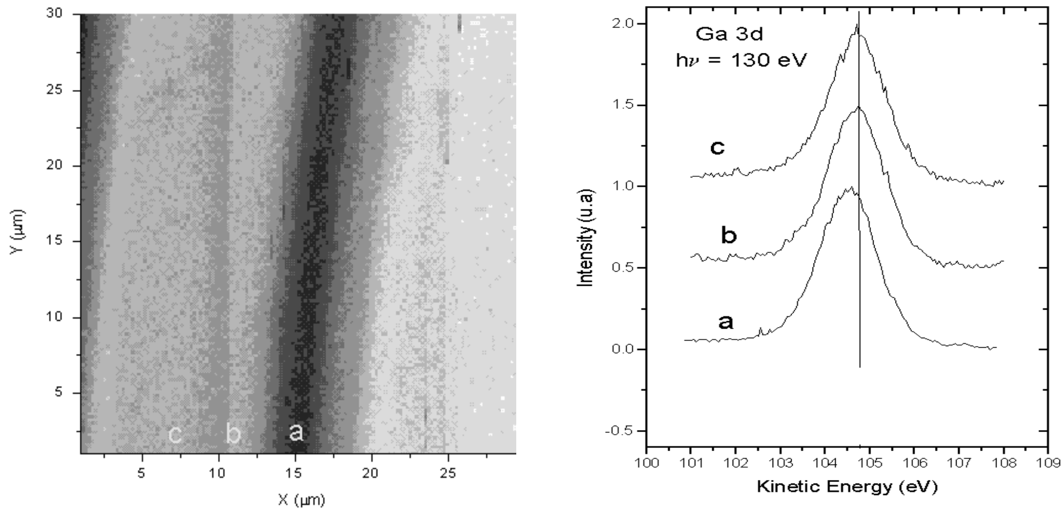
INTRODUCTION
The wide band gap III-V nitrides have attracted much attention because of their great significance in both scientific research and practical applications [1]. Among them GaN is the most interesting materials because of its suitable direct band gap of 3.4 eV at room temperature, notable chemical intertness, and great physical hardness, high temperature stability [2]. However, the development of III-V nitride materials has suffered from the lack of suitable substrate to produce low-dislocation-density using MOVPE or MBE. Currently, the promising technique is the ELO growth of GaN where GaN/sapphire or SiC layer patterned with SiO_2 is used as a substrate to produce stripes of GaN with remarkable reduction in dislocation density [3].

In this work we are investigating surface electronic structure of GaN grown with the above technique. We have investigated electronic surface structure of clean GaN, hydrogen adsorbed GaN, and GaN with an overlayer of Mg. The later two investigation is driven by the fact that hydrogen is one of the precursor used in the growth process while magnesium is used as a p-type dopent.

EXPERIMENT
The ELO GaN used in the experiment was grown on a sapphire basal plane by MOPVE at North Carolina State University. The ELO GaN surface morphology was characterized by atomic force microscopy (AFM). The sample was annealed cleaned at 850^{o}C. The synchrotron radiation-based spectromicroscopy technique has been employed to study the electronic inhomogeneities on the surface. The strength of this technique is its chemical and surface sensitivity. The photoemission spectromicroscopy is thus performed at MAXIMUM at beamline 12.0.1 at the ALS, Berkeley. The microscope has SO optics to focus the beam to less than 0.1 micron. Thus, the microscope is capable of acquiring chemical and electronic information from a localized area.

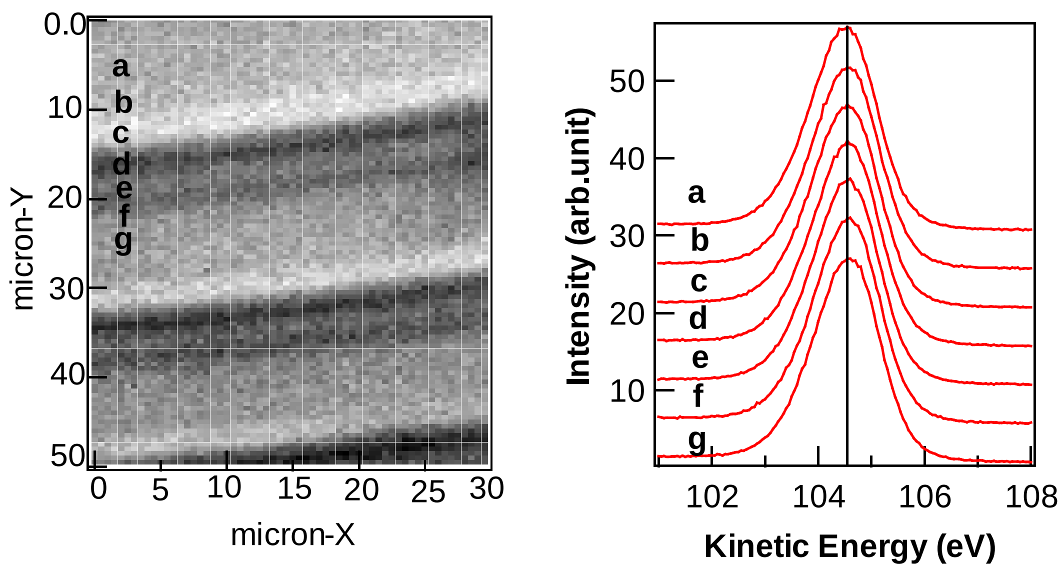
RESULTS AND DISCUSSION
A 30 x 30 μm^2 photoemission microscopy image at step size of 0.3 μm acquired at Ga 3d core level at 104.5 eV using 130 eV photon is shown in fig.1a. The image reveals three distinct areas i.e. (a) meeting fronts where two strips meet each other, (b) an opening areas between masks (homoepitaxial growth), and (c) areas above masks (lateral overgrowth). The fig. 1b shows the series of energy distribution curve acquired at corresponding positions shown in the fig. 1a. The

high resolution EDC's clearly demonstrate the Fermi level pinning. The curve a that is from meeting front area is shifted by 0.15 eV compared to curve b and c. Thus, EDC's suggest the different Fermi level behavior for GaN strip and the meeting front. A 30 x 30 μm^2 of GaN surface exposed to 1000 Langmuir atomic hydrogen acquired at Ga 3d peak shown in fig. 2a. Compared with the image of clean GaN, the hydrogen espouser brings dramatic change in the surface electronic structure. The V-shaped meeting fronts in clean GaN are changed to W shape upon hydrogen exposure. The center of the meeting fronts has less hydrogen adsorption than the other areas hence the core level attenuation is smaller.



(a) (b)

Figure 1. (a) Micrograph of ELO grown clean GaN surface obtained at Ga 3d core level at hv = 130 eV. (b) A set of Ga 3d EDCs obtained at positions marked in (a).



(a) (b)

Figure 2. (a) Micrograph of ELO grown GaN surface exposed to 1000 Langmuir hydrogen obtained at Ga 3d core level at hv = 130 eV. (b) A set of Ga 3d EDCs obtained at positions marked in (a).

The set of EDC obtained at different areas marked in fig. 2a doesn't show any Fermi level pinning. The comparison of fig. 1 and 2 brings forth the fact that the growth fronts in clean GaN have different electronic environment, which gets destroyed upon hydrogen adsorption. A 10 ML Mg deposited on GaN grows with S-K mode and island formation. The core level Ga 3d EDCs in the Mg islands shifts toward higher kinetic energy compared to smooth areas. The bend bending is Ga 3d peak is observed in going from Mg island areas to between-island areas. Also, it is observed that islands are rich in metallic Ga indicating higher reactivity of Mg with GaN leaving behind Ga in metallic form. (Results not shown).

CONCLUSION

The photoemission spectromicroscopy was successfully employed to investigate inhomogeneities of surface electronic structure of ELO GaN material. The set of EDCs obtained at Ga 3d core level demonstrate meeting fronts have different Fermi level pinning behavior compared to opening areas and overgrowth areas. The hydrogen adsorption destroys this Fermi level pinning behavior. We propose that the selective adsorption of hydrogen in meeting fronts may be due to two reasons: (1) the different dislocation density in meeting front area (2) in meeting front regions the GaN surface is oriented {112-2} where as flat regions are oriented along {0001}[5]. This difference in the surface orientation in two regions may lead to difference in the surface free energy, which thus leads to selective hydrogen adsorption. The S-K growth of Mg on GaN leads to islands formation leaving behind metallic Ga. The difference in the Fermi level pinning behavior in Mg reach islands and in between-island area arises from the difference in reactivity of Mg with GaN in two areas.

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REFERENCES

1. S. Srtite and H. Morkoe, J. Vac, Sci. Techn., **B 10**, 1237 (1992).
2. M. A. Khan, J. N. Kuzani, A. R. Bhattarai, and D. T. Olson, Appl. Phys. Lett., **62**, 1786 (19923).
3. S. Nakamura, M. Senoh, S. Nagahuma, N. Iwasa, T. Yamada, T. Matsushita, H. Kiyoku, Y. Sugimoto, T. Kozaki, H. Umemoto, M. Sano, and K. Chocho, Appl. Phys. Lett., **72**, 211 (1998).
4. Y. Yang, S. H. Xu, H. Cruguel, G. J. Lapeyre, J. M. Van Hove, A. M. Wowchak, and P. P. Chow, submitted to Phys. Rev. **B**.
5. Z. Liliental-Weber, M. Bernmara, W. Swider, J. Washburn, J. Park, P. A. Grudowski, C. J. Eiting, and R. D. Dupuis, submitted to Phys. Rev. Lett.

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