X-ray specular reflection study of oxidized 300Å $Al_{0.98}Ga_{0.02}As$ film on a GaAs substrate

S. Cheong, T. Shibata, M. Boyanov, D. Lahiri, B. A. Bunker, D. Hall, G. Snider, C. DeMello
University of Notre Dame, Notre Dame, IN 46556

Introduction

III-V semiconductors have a number of advantages over Si: With a suitable gate oxide, AlGaAs/InGaAs/GaAs-based metal-oxide-semiconductor field-effect transistor (MOSFET) devices could significantly outperform present Si electronics due to the lower effective mass, higher electron mobility, and higher saturated electron velocity. A new wet thermal process for oxidizing AlGaAs [1] is being explored for this purpose. [2-4] Although these insulating layers are crucial to device operation, their properties, including the interface between the as-grown oxide layer and semiconductor substrate, are not yet well understood. Defects at this interface can produce Fermi-level pinning, increase leakage currents, and increase interface recombination. To characterize this interfacial region, x-ray reflectivity and evanescent-wave X-ray absorption fine-structure spectroscopy (XAFS) measurements have been performed. The goal of these studies is to correlate the physical structure to electronic properties and sample preparation methods.

Methods and Materials

A thin 300Å $Al_{0.98}Ga_{0.02}As$ film on a GaAs substrate was surface-oxidized using techniques described previously.[3,4] To investigate the bulk properties such as the density profile as a function of depth, thickness of oxide layer and roughness of both surface and interface, x-ray specular reflectivity was measured at the MRCAT ID-10 line using 8-circle Huber diffractometer. The x-ray energy was tuned at 300 eV below the As K-edge (11567 eV) and the dimension of the incident beam size was defined as approximately 50 μm vertical height by 5 mm horizontal width. We employed two slits after the sample to reduce the background scattering and assure that all the beam reflected off the sample was detected – the slit dimensions were 500 μm × 3 mm for the first slit and 1 mm × 3 mm for the second slit. We used the ion chambers to detect incident and reflected x-ray beams; filled with 90 % He and 10 % N_2 gases for the detection of incident beam, and 100 % N_2 gas for the reflected beam. The MRCAT beamline is equipped with a double-crystal cryogenic Si (111) monochromator and a tunable undulator which allows the x-ray energy to vary over the range of 5 keV to over 30 keV. A harmonic rejection mirror was also used to eliminate the third and higher x-ray harmonics from the monochromator; the contamination of the beam by these higher energies greatly complicates the data interpretation.

Results

X-ray reflectivity is a good probe of x-ray optical constants (and therefore density) as a function of depth from the surface. Fig. 1 shows both the experimental reflectivity as a function of incidence angle, and a fit to the data using a reflectivity fitting routine originally written by H. Chen and S. Heald.[5] The fit to the data is model-dependent: The physical models considered for this included single, double, and triple overlayers on the GaAs buffer layer. In the fitting itself, the layer thickness, density, and interfacial roughness were "floated" in the fitting. The model that gave the best agreement with the data is shown in Fig. 2, and corresponds to a thin oxidized GaAs layer overlying a largely Al_2O_3 oxide layer, which in turn overlies a mixed higher-density layer above the GaAs. The models that do not include the thin GaAs overlayer or the higher density intermediate layer yield a significantly worse fit to the data. The

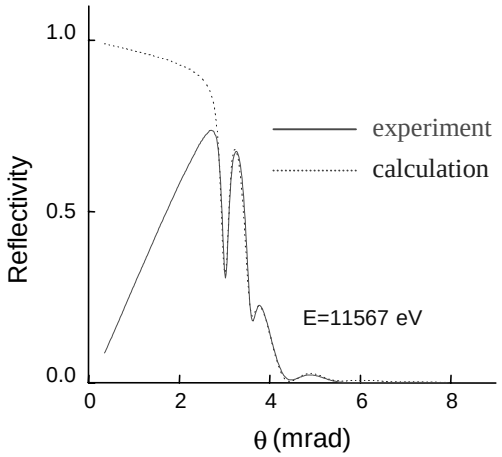

Fig. 1 X-ray reflectivity as function of incidence angle for 300 Å oxidized $Al_{0.98}Ga_{0.02}As$ film on GaAs substrate

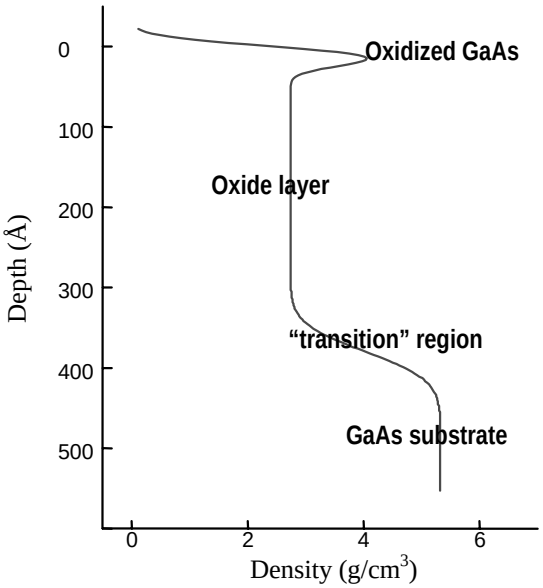

Fig. 2 Density depth profile is obtained by fitting data; best fit for oxide density was obtained by 2.73 g/cm^3 ± 5%

presence of a thin oxidized GaAs surface layer is attributed to a residue of the original 500 Å GaAs protective cap which was not fully removed by a citric acid/hydrogen peroxide selective etch before oxidation. The presence of Ga at the surface was confirmed by both reflection-mode XAFS and X-ray photoelectron spectroscopy (XPS). Recent modifications in sample preparation technique should eliminate the GaAs overlayer and simplify data analysis in future studies.

Discussions and Conclusions

The reflectivity data reported above were limited in angular range because of beam stability problems. These problems have been rectified, and we have been recently obtained much high-quality data, which is lower noise and over a long angular range. The analysis of the longer-range data is currently underway.

Acknowledgments

This work was supported by Air Force Grant F49620-98-1-0120. Portions of this work were performed at the Materials Research Collaborative Access Team at the Advanced Photon Source. MRCAT is supported by the U. S. Department of Energy under Contract DE-FG02-94-ER45525 and the member institutions. Use of the Advanced Photon Source was supported by the U.S. Department of Energy, under Contract No. W-31-102-Eng-38.

References

[1] J. M. Dallesasse, N. Holonyak, Jr., A. R. Sugg, T. A. Richard, and N. El-Zein, Appl. Phys. Lett. **57**, 2844 (1990).

[2] E. I. Chen, N. Holonyak, Jr., and S. A. Maranowski, Appl. Phys. Lett. **66**, 2688 (1995).

[3] C. B. DeMelo, D. C. Hall, G. L. Snider, D. Xu, G. Kramer, and N. El-Zein, Electron. Lett. **36**, 84 (2000).

[4] C. I. H. Ashby, J. P. Sullivan, P. P. Newcomer, N. A. Missert, H. Q. Hou, B. E. Hammons, M. J. Hafich, and A. G. Baca, Appl. Phys. Lett. **70**, 2443 (1997).

[5] S. M. Heald, H. Chen, and J. M. Tranquada, Phys. Rev. B **38,** 1016 (1988)