Scanning Probe Microscopy of $Al_xGa_{1-x}As$/GaAs layers prepared in cross section via Beam Exit Ar Ion Polishing

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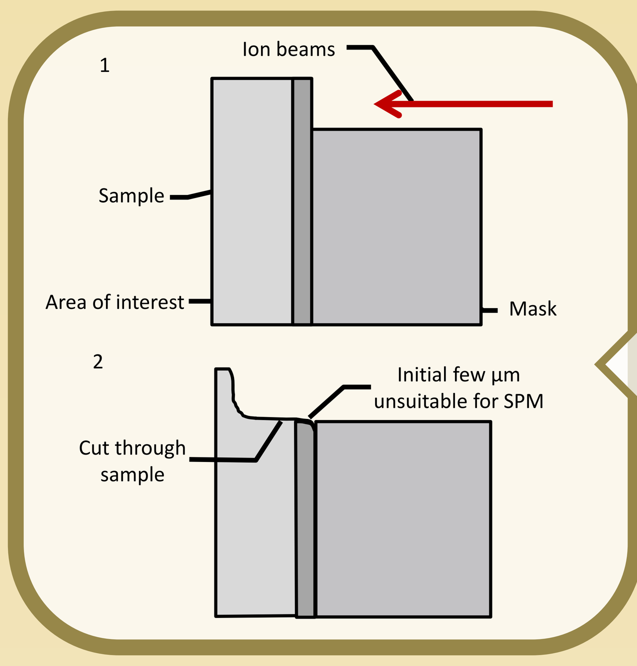
Introduction

Semiconductor nanostructure devices rely on precise dimensions, as small variations can cause extensive changes to device properties. As such, it is often beneficial to obtain cross-sectional analysis of the sample. For III-V semiconductor samples, much of this work is carried out using transmission electron microscopy (TEM). This method requires careful sample preparation; combined with a limited number of available facilities it is inevitably a time-consuming and expensive process. As such, investigating other methods to image buried nanostructures is advantageous.

Here we report the resolution of layers with a thickness as low as 1 nm using a novel method of cross-sectional scanning probe microscopy (SPM).

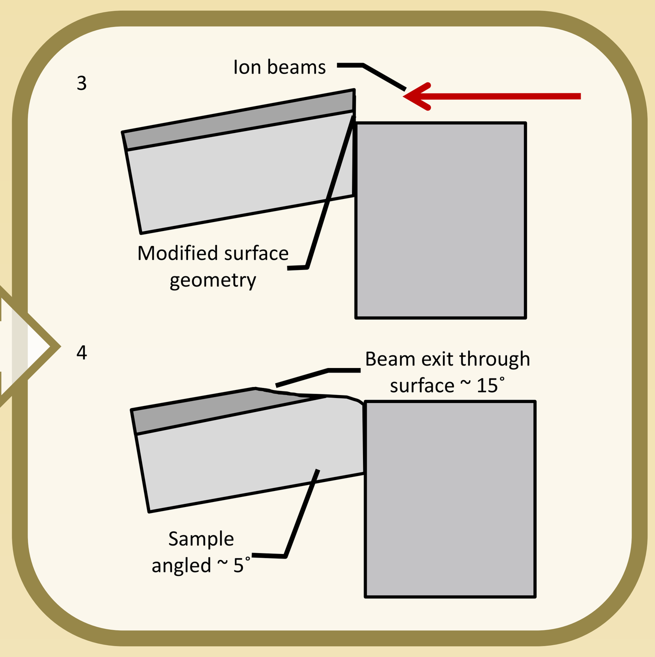


Beam-Exit Ar-Ion Polishing (BEXP)

Conventional ion beam cutting enters the sample through the surface (fig. 1). However, this results in an area of a few micrometres at the beam entry which is unsuitable for scanning (fig. 2). Unfortunately, semiconductor nanostructures are often buried very close to the sample surface, therefore the cut quality through this region is of utmost importance.

Instead of penetrating through the sample surface, the BEXP [1] technique enters through the side of the sample (fig. 3), with the beam exiting through the surface at a glancing angle of approximately 15° (fig. 4). This produces a relatively smooth cut through the area of interest (roughness < 1 nm). Furthermore, the small angle reduces the disruptive effects common when scanning near or over the sample edge.

The cut angle also stretches out the nanostructures buried within the sample over a larger area, allowing easier identification of layers.



Sample creation

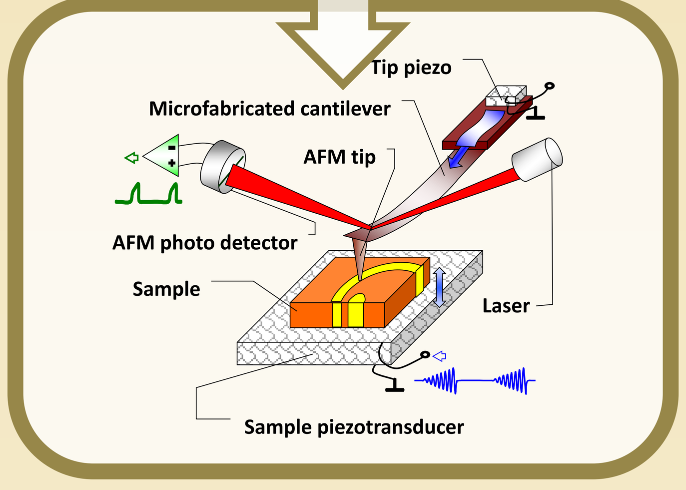
$Al_xGa_{1-x}As$/GaAs samples were grown using solid source molecular beam epitaxy (MBE). $Al_xGa_{1-x}As$ composition x varied between 0.2 and 1.0.
After cross-sectioning using BEXP, the samples were allowed to oxidise before imaging.

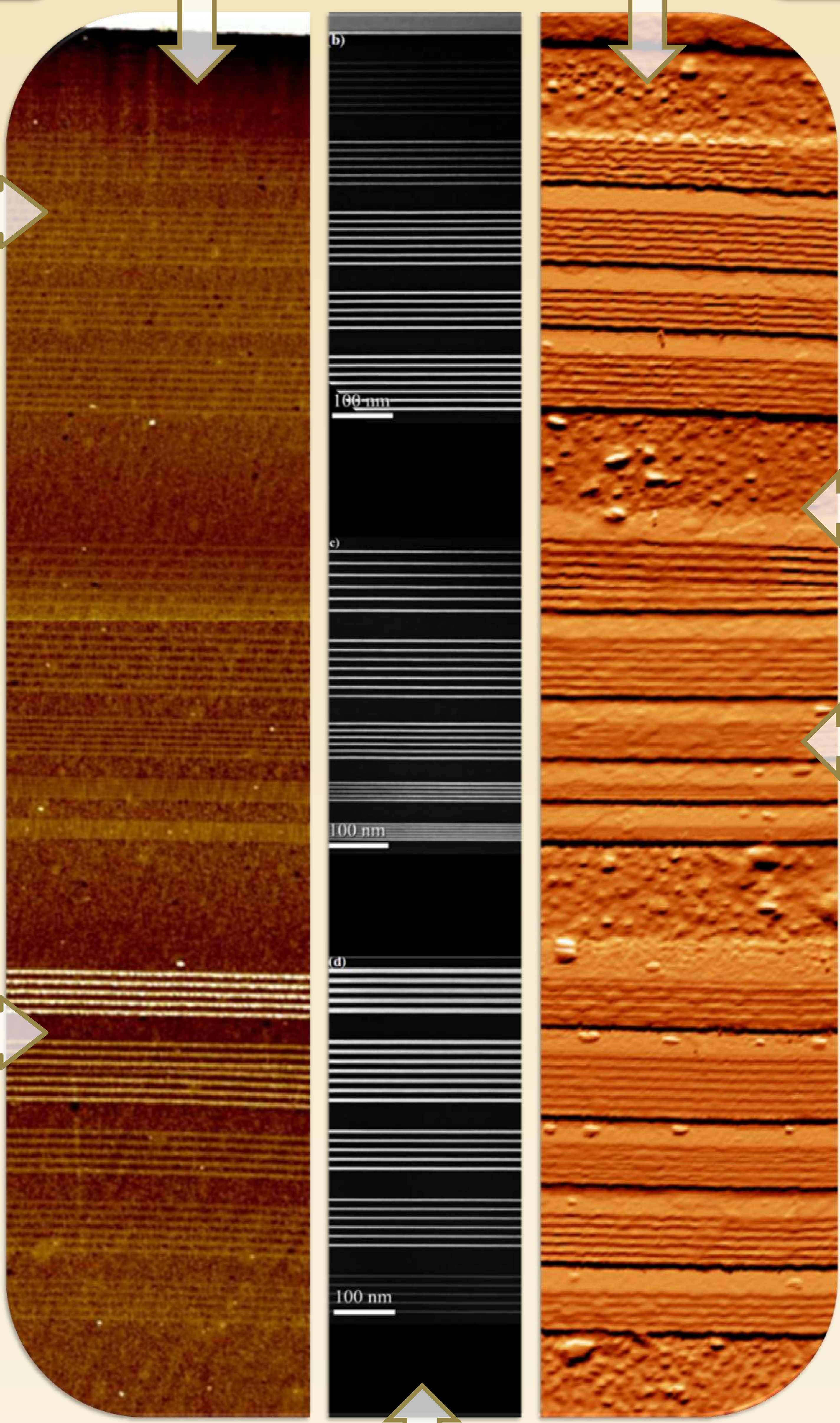
Scanning Probe Microscopy (SPM)

Samples were analysed using a Digital Instruments Multimode SPM in both Tapping Mode AFM and ultrasonic force microscopy (UFM).
Oxidised $Al_xGa_{1-x}As$ layers protrude above GaAs layers by an amount which varies with Al content x [2], allowing identification during imaging.

Ultrasonic force microscopy (UFM)

UFM [3] is a contact mode SPM technique. The sample is vibrated at a high frequency (a few MHz) causing the cantilever to become "infinitely" rigid and the surface to elastically "indent" itself against the cantilever tip. This allows effective elastic mapping of a variety of materials.





Al content variation

3nm $Al_xGa_{1-x}As$ layers with 12nm GaAs layers
From the top, Al content = 0.2, 0.4, 0.6, 0.8, 1.0

Etching

To enhance clarity, a Citric Acid/Hydrogen Peroxide etch has been used. GaAs is etched much faster than AlAs. Ratio and etch time can be altered to allow identification of different layers.

Varying layer thickness

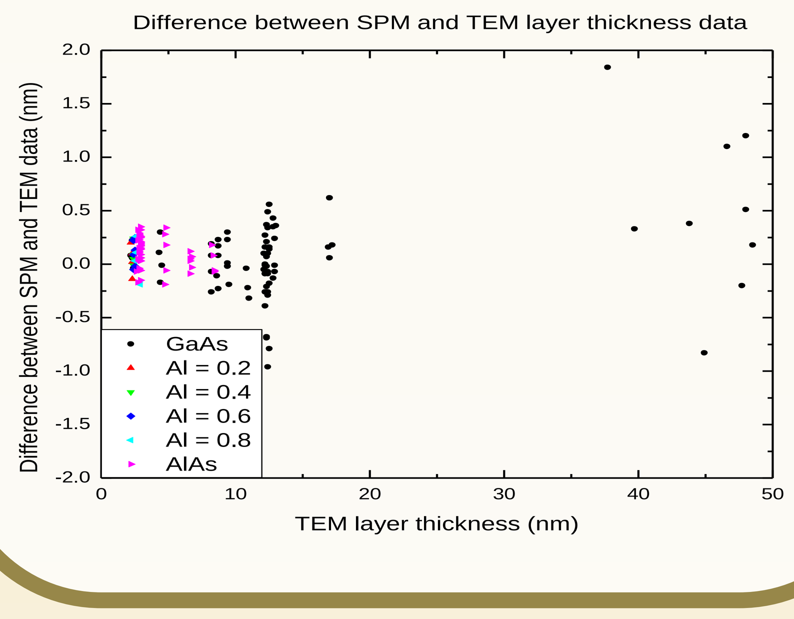
Layer thickness of both types of layer vary.
From top, AlAs/GaAs layer thickness = 8/8 nm, 6.5/9.5 nm, 5/11 nm, 3/12.5 nm, 1/13.5 nm

Varing GaAs spacing

3nm AlAs layers. GaAs layer thickness varies.
From the top, GaAs layer thickness = 17 nm, 13 nm, 9 nm, 4.5 nm, 2 nm

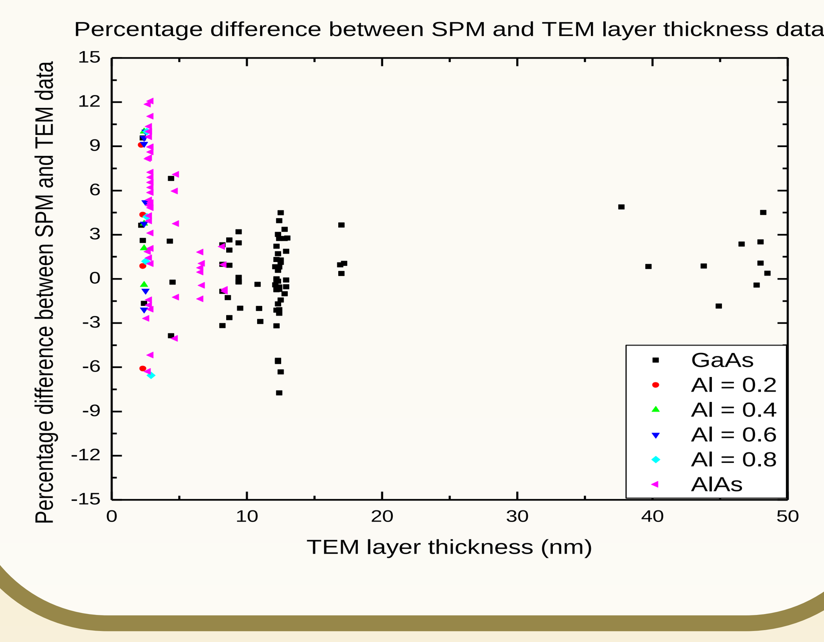
Results

Thin layers (< 10 nm) are accurate to within 0.5nm. Larger layers (> 35 nm) are accurate to within 2 nm, due to a larger scan size required to measure the distance.



Percentage results

SPM results agree to within 12% of TEM data for small layers. Agreement rapidly improves as layer thickness increases.



Conclusions

$Al_xGa_{1-x}As$/GaAs layers were grown via MBE and cross sectioned using BEXP. SPM data for over 180 layers was compared with TEM results. SPM values agreed to within 10% for thin layers under 10 nm. Agreement rapidly improved as layer thickness increased.
We conclude that this method could be used to study $Al_xGa_{1-x}As$/GaAs devices such as vertical cavity surface emitting lasers (VCSELs) and quantum cascade lasers (QCLs), and should be applicable to other III-V semiconductor samples containing quantum wells and superlattices.

Transmission electron microscopy (TEM)

TEM analysis was obtained using a Jeol 2000FX system. Layer thicknesses were measured to within 0.2 nm.

References & Acknowledgements

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