Composition and strain measurement in III-V semiconductor using convergent-beam electron diffraction

Guo, Y.[1], Peng, D.[1], Nakashima, P.[1] and Etheridge, J.[1,2]

[1] Department of Materials Science and Engineering, Monash University, Australia, [2] Monash Centre for Electron Microscopy, Monash University, Australia

III-V semiconductors with the zinc-blende crystal structure such as $In_xGa_{1-x}As$, $Al_xGa_{1-x}As$ and $In_xAl_{1-x}As$ have attracted significant interest for use in next generation transistors and other applications. Accurate measurement of local composition and strain is important for correlating structural information with performance of the devices. EDS or (S)TEM imaging can be powerful methods for such investigations. However, the accuracy in these traditional measurements can be limited. Furthermore, it is very difficult, if not impossible, to obtain independent measurements of both composition and strain, that is, the measurements can be made with no interdependence on common parameters.

Here, we develop a method using convergent beam electron diffraction to measure composition, strain and TEM specimen thickness simultaneously and independently from the same specimen volume of a ternary zinc-blende type semiconductor. The method uses a carefully chosen crystal orientation that optimises the influence of scattering from the chemically-sensitive {2 0 0} atomic planes. By virtue of the electron scattering processes involved, three separate parts in one CBED pattern have quite distinctive sensitivity to composition, strain and thickness, and therefore the measurement of composition, strain and thickness are effectively independent of each other. In the chosen crystal orientation, a Bijvoet pair of HOLZ reflections, $\bar{1}$11 1 and 1 11 1, are set to satisfy their Bragg conditions simultaneously. The intensity ratio of these two reflections show a monotonic increase with composition over a wide range of thicknesses. The composition can then be determined from a look-up table that correlates the intensity ratios with composition. The calculation of the look-up table is generated by a Bloch wave program which has included the effect of bonding and static atomic displacements. The strain can be determined from the HOLZ pattern in the central disc or the positions of all the CBED discs while the thickness can be measured from the fringes in 4 0 0 reflections which also exist in the same crystal orientation. We demonstrate the accuracy and feasibility of the method using experimental data on the $In_xGa_{1-x}As$ system.

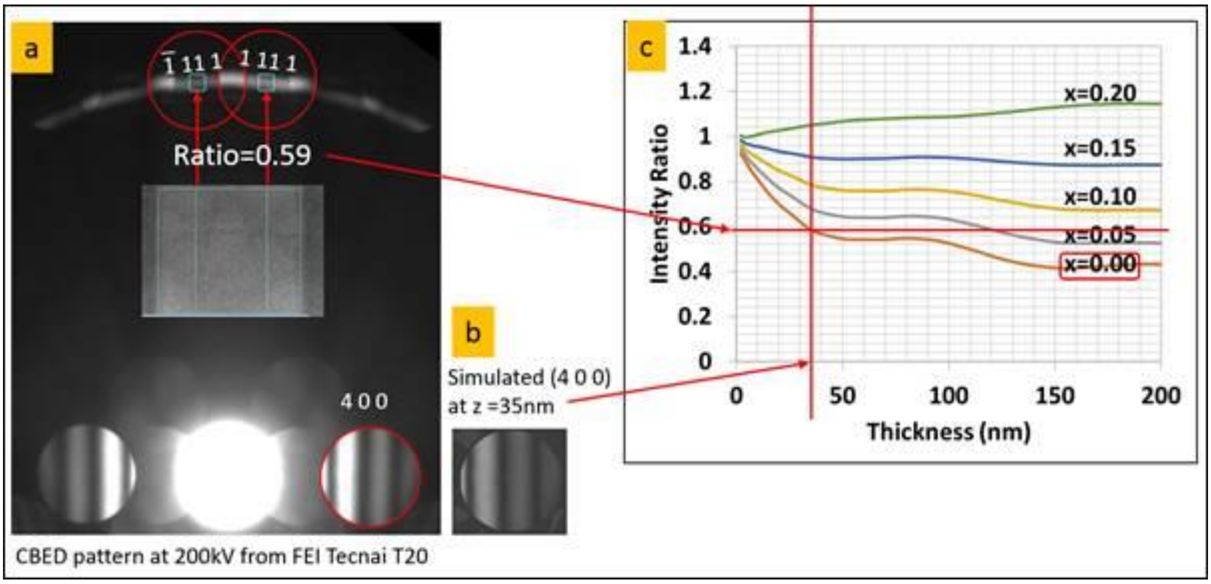

Figure 1. Illustration of composition measurement from an experimental CBED pattern: (a) The ratio of the two integrated intensities is acquired by following a prescribed procedure, and the thickness is measured by comparing the fringes in 4 0 0 with (b) simulations. Then, the measured values of the ratio = 0.59 and the thickness = 35 nm can be found on a ratio-thickness curve in (c), which has been calculated for a composition of x = 0.00. This means composition in the structure which the CBED pattern in (a) is obtained from is x = 0.00 (i.e. pure GaAs).

Acknowledgements The authors thank the Monash Centre for Electron Microscopy for facilities and staff support. This work was supported by the Australian Research Council grant number DP150104483. P.N.H.N. was funded by the Australian Research Council (FT110100427).