X-ray Probes of the Layer and Interface Structure of Nanoscale Films for Electronics and Spintronics

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Very high resolution x-ray diffraction techniques developed in the 1980s, driven by the need to measure composition and lattice strain in thin compound semiconductor films for optoelectronic devices. Since then, as the scale of electronic components has shrunk, the thickness of films has also decreased, placing greater and greater challenges to the x-ray analysts and their instrumentation. We illustrate how this challenge has been met with examples of high resolution diffraction profiles taken both from the early pioneering days and much more recently. The rapid acquisition of data from areas as small as individual scribe lines will be demonstrated from an x-ray tool designed for use in a FAB cleanroom.

In the 21st Century is has been realised that in-plane diffraction measurements, previously almost exclusively within the remit of synchrotron radiation sources, could be done in the laboratory by exploiting recent developments in x-ray optics. We illustrate the application of laboratory-based grazing incidence in-plane diffraction to obtain independent twist and tilt data from GaN films grown on thin $Al_xGa_{1-x}N$ buffers on sapphire [1].

Grazing incidence x-ray reflectivity has now become a standard tool for the measurement of layer thickness and interface width in nanoscale thickness metal films for spintronic devices and data storage. Measurement of the off-specular scatter enables topological roughness to be distinguished from chemical intermixing across interfaces. Although much work has been done at synchrotron radiation facilities, laboratory sources can be used with great effect. We illustrate the application of laboratory sources in the accurate measurement of ultra-thin epitaxial layers of Co, Cu and Ni on silicon. As the structural layer parameters were fixed independently, an improved precision in measurement of layer magnetisation was obtained in analysis of polarised neutron reflectivity profiles [2].

Grazing incidence scattering becomes particularly powerful when combined with grazing incidence fluorescence measurements. We show that laboratory diffractometers can be used to collect high quality grazing incidence fluorescence data from nanoscale metal films in a very short time. The application is illustrated in a study of the effect of Bi as a surfactant in the sputtering of smooth $Fe_{50}Mn_{50}$ exchange bias films. Both from a simple consideration of the Bi fluorescence signal as a function of depth of penetration of the X-ray wave [3] and more sophisticated modelling [4], as a function of grazing incidence angle of the fluorescence signals from all the elements present, we show that Bi does act as a surfactant under conditions of one or two monolayer coverage.

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