High Resolution X-Ray Diffraction of III-Nitride Wide Bandgap Semiconductors

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Group III-nitride semiconductors, AlN, GaN, InN, and their alloys, have energy band gaps spanning from deep UV to near IR spectra range. III-nitride thin films are widely used to fabricate UV, blue, green, and white light-emitting diodes (LEDs), as well as high power and high frequency transistors. Due to the lack of GaN bulk substrates, however, GaN heteroepitaxy on foreign substrates (normally with a large lattice mismatch) generates a high density of structural defects, and the as-grown film is often defective and strained. The defects and residual strain greatly affect the material property and the device performance. X-ray diffraction (XRD), as a rapid and non-destructive technique, is commonly utilized to characterize the material quality and device structures, offering a quick yet crucial feedback.

This talk reviews the major applications of XRD in III-nitride material and device R&D. First we will show a few fundamental roles of XRD in determining the epitaxial relationship between III-nitride epilayer and substrates, the thickness and lattice parameters of AlGaN/GaN heterostructure and InGaN/GaN multiple quantum wells, followed by a reciprocal space mapping (RSM) study of the strain status and the alloy composition of III-nitride heterostructures. Then we will present a comprehensive XRD study of extended structural defects in III-nitride films, including line defects (dislocations) and planar defects (stacking faults). By measuring x-ray rocking curves (XRCs) on a series of planes ($10\underline{1}n$) with various angles from the surface, we can study the effect of growth conditions on the mosaic tilt and twist in Ga-polar (0001) and N-polar ($000\underline{1}$) GaN thin films, which are accommodated by screw and edge type threading dislocations (TDs), respectively. For nonpolar ($11\underline{2}0$) GaN and semipolar ($11\underline{2}2$) GaN, an emerging area in III-nitride community, to obtain a complete picture of their mosaic microstructure (often with a strong anisotropy), we implement detailed XRC measurements on both on-axis and off-axis planes at various azimuths, together with a modified Williamson-Hall analysis for the basal plane stacking faults. The above studies have not only offered us an in-depth understanding of GaN microstructure, but also furthered the improvement of material quality and device performance.

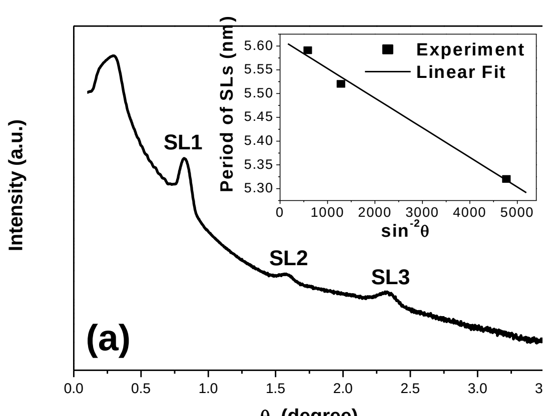

Fig. 1 Grazing incident x-ray reflectivity of AlGaN/GaN superlattice (SL).

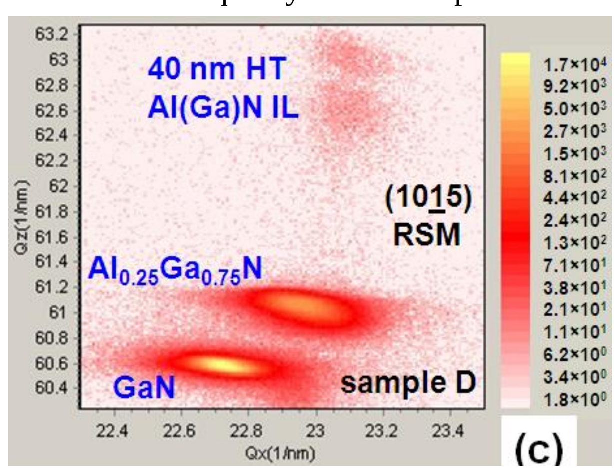

Fig. 2 Grazing incident ($10\underline{1}5$) x-ray reciprocal space mapping of AlGaN/AlN interlayer/GaN.