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Strain Analysis of $In_xGa_{(1-x)}N/GaN$ Films by CBIM Toward Quantification.

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Strain fields in semiconductors play a decisive role in the physical properties of thin film interface and quantum well structures. The various methods related to convergent-beam electron diffraction (CBED), which have been used to characterize these strain fields are reviewed and compared in reference [1]. Here we consider the possibilities for accurate quantification of energy-filtered CBED strain-field data. The associated techniques, such as convergent beam imaging (CBIM) and large angle convergent beam electron diffraction (LACBED) have the advantage of small probe size, large convergence angle and high spatial resolution. CBED focuses the electron beam to a sub-nanometer area on the specimen so that diffraction information comes from a small crystal region, therefore, it can be used for measuring crystal parameters accurately and mapping strain fields [1,2]. CBIM uses convergent beam illumination with a small objective aperture (figure 1), so that lattice parameter variations or structural distortions are revealed as displacements of high-order laue-zone lines (HOLZ) which are superimposed on the image [3]. LACBED is realized by a relatively large angle convergent beam. It solves the disk-overlap problem by using a small SAD aperture and displacing the sample along the optic axis (figure 1) [4]. For the CBIM and LACBED techniques, a large specimen area is illuminated, but the HOLZ line information comes from a specimen area equal to electron probe size broadened by beam spreading [1,3]. These two methods can map strain fields with coupled images at high spatial resolution using HOLZ lines. Another advantage of the CBIM and LACBED techniques is the energy filtering effect of the objective or SAD apertures. It is known that a majority of high energy-loss electrons (>100 eV) and thermal diffuse scattered electrons (around 25meV) are scattered to high angles [5]. These energy loss electrons can be filtered using the objective or SAD apertures. If combined with an energy filter (Gatan image filter or Ω-filter) to filter plasmon energy loss electrons (several 10eV), the diffraction patterns or CBIM images are free of inelastically scattered electrons. Quantification of these diffraction patterns or images becomes possible. Thus, these versatile techniques can be used for the characterization of novel materials and their strain fields at nanoscale.

Here, we present our recent analysis of $In_xGa_{(1-x)}N/GaN$ thin films grown by the MOCVD method. Two thin films of $In_xGa_{(1-x)}N/GaN$ (x=0.07 and 0.1) with a thickness of 160nm were grown on a GaN substrate (figure 2). The electron probe size was measured to be 10nm. It is seen from CBED patterns that the thin film with x=0.07 has one strained layer near the interface, but the thin film with x=0.1 has two strained layers, with one strained layer on top of the thin film. Three layers are identified from the CBIM image for the thin film with x=0.1; a strained layer near the InGaN/GaN interface (on both sides of GaN and InGaN, total width 55nm), a non-strained InGaN layer (85nm), and a surface-strained InGaN layer (45nm). It is believed that the interface strained layer is related to the cell-constant mismatch and the surface-strained layer, together with In chemical concentration variations. Quantification of these diffraction patterns is in progress. This work is funded by grant DOE DE-FG03-02ER45596. We are grateful to J.P. Morniroli for useful discussions.

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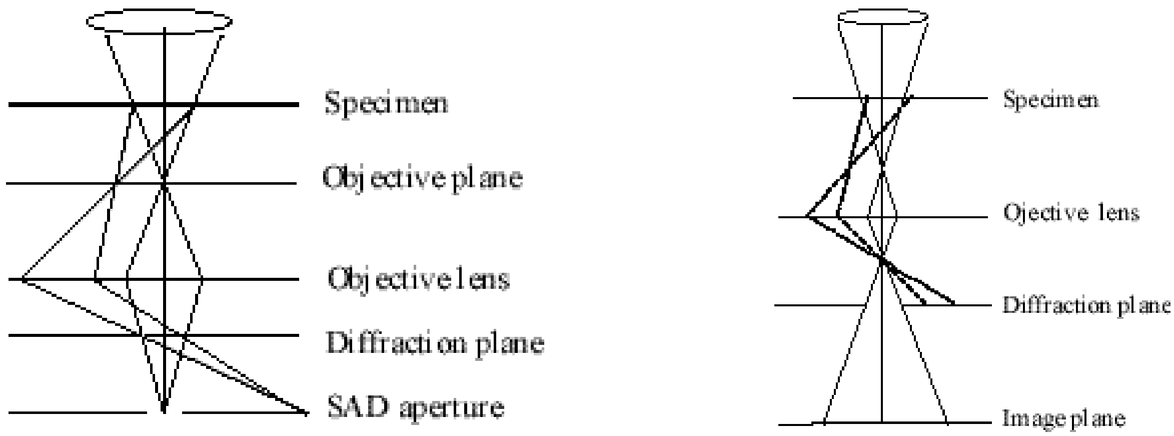


(A) (B)

Figure 1. Schematic ray diagrams of LACBED mode in (A) and CBIM mode in (B). LACBED is image-coupled CBED, showing diffraction HOLZ information and specimen image simultaneous. It solves the disk-overlap problem by using a small SAD aperture and moving the sample along the optic axis. Large angular information can be obtained in one CBED disk. For CBIM mode, a smaller objective aperture is used to select the diffracted beam to form the image. Thermal diffuse scattered electrons are filtered by the objective and SAD apertures.

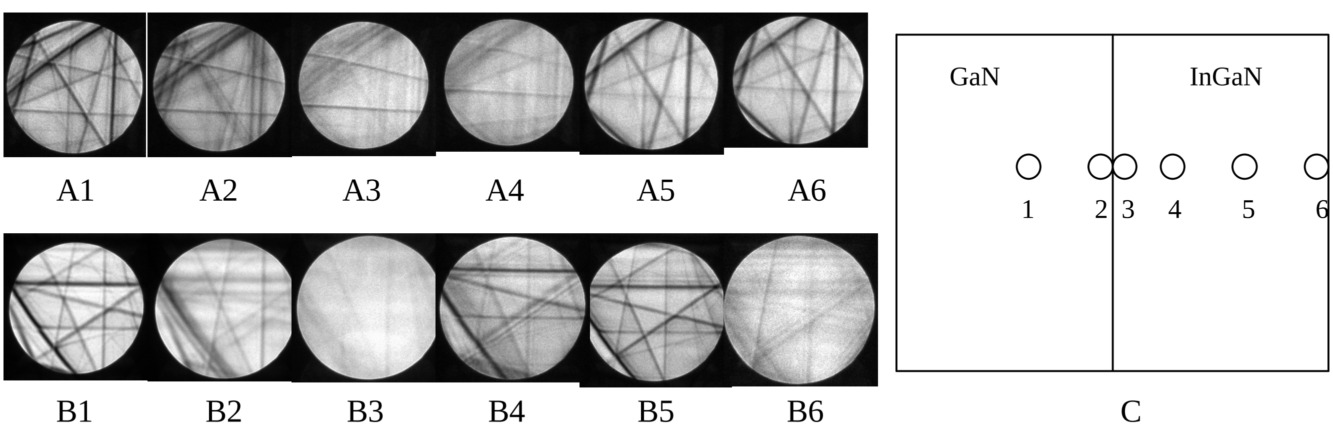
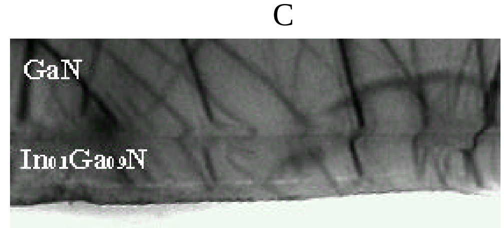


Figure 2 Figure A1-6 and B1-6 are CBED patterns from the specimen area displayed on figure C. A's and B's are for $In_xGa_{(1-x)}N$/GaN thin films with x=0.07 and 0.1 respectively. (D) is the CBIM image of $In_xGa_{(1-x)}N$/GaN (x=0.1) thin film showing three layers from HOLZ lines bending.



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