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High-Resolution Electron Backscatter Diffraction in III-Nitride Semiconductors.

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The large and increasing interest in III-nitrides semiconductors lies in the wide range of useful applications that can be achieved, from high electron mobility transistors (HEMTs) to light emitting LEDs and lasers. However, the III-nitride materials are usually epitaxially grown on foreign substrates, which lead to the formation of a large number of dislocations and significant strain variations in the epitaxial layers that seriously affect the performance of devices based upon them.

The acquisition of high resolution electron backscatter diffraction (EBSD) patterns in the scanning electron microscope (SEM) is a very powerful method for the microstructural characterization of crystalline materials. EBSD is well established as a technique capable of measuring elastic strains, lattice rotations, and defect density in metallic materials, but until recently, it has not had much uptake for characterization of semiconducting materials [1]. This is largely as a result of the angular resolution limit of ~0.5° (~10^{-2} rads) of the conventional Hough-transformed analysis. The introduction of cross-correlation based analysis of EBSD patterns has seen a step change in the angular resolution to ~10^{-4} rads which is sufficient to enable analysis of the much smaller misorientations and even local elastic strain fields that are more typical in semiconducting materials [2].

For EBSD measurements samples are tilted by 70° towards the EBSD detector (in our case Bruker e^- Flash HR with forescatter diodes FSDs). When the electron beam strikes the specimen, the electrons backscattered from the sample produce a diffraction pattern on the phosphor screen (Figure 1b). Changes in elastic strain and lattice rotations cause small shifts in the positions of zones axes and other features in the EBSD patterns. Cross-correlation is used to measure the shifts between each test pattern and a reference pattern on at least 35 sub-regions distributed across the pattern. The dispersion of shifts across the pattern is used to determine the change in lattice strain and rotation relative to the reference point.

We have used the method on different III-Nitride semiconductor specimens. The EBSD measurements were made from linescan and 2D maps on the plan view of samples. We have measured the tilt, twist and elastic strain on different specimens. Histograms were constructed of the rotations about the surface normal (ω_{12} twist mosaic) and two orthogonal axes in the surface plane (ω_{13} and ω_{23} tilt mosaics). Example histograms from a 900 nm thick GaN layer on sapphire are shown in figure 2.The width of the twist mosaic was found to be larger than the tilt mosaic. The twists within the layer are due to the edge components of threading dislocations (TDs), while tilts result from screw components. The EBSD results indicate that the edge type TDs are present in greater density than the screw type.

Finally, we have also combined EBSD strain mapping with electron channeling contrast imaging (ECCI) observations of TDs [3]. Figure 3a shows an ECCI image from the top surface of 15 µm thick layer grown from a complex nano-dash template. The red circles indicate the positions of TDs found automatically by image analysis procedures. The TDs are highly clustered at the coalescence junctions between growth regions from different nucleation sites within the nano-dash template. Figure 3b is the ε_{11} elastic strain variation measured by EBSD within the same field. As expected there is clear correlation between the positions of dislocation clusters identified by ECCI and locations at which the strain field changes most significantly.

References:

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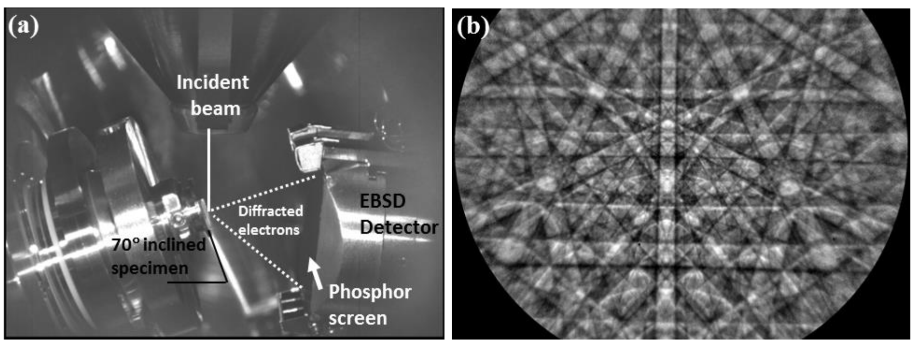

Figure 1. (a) Schematic EBSD geometry and (b) example EBSD pattern obtained from GaN on sapphire.

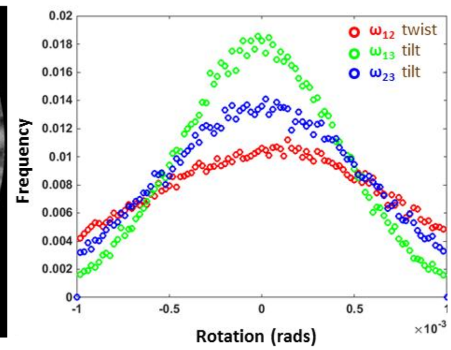

Figure 2. Histograms showing tilt and twist distributions in 900 nm GaN on sapphire.

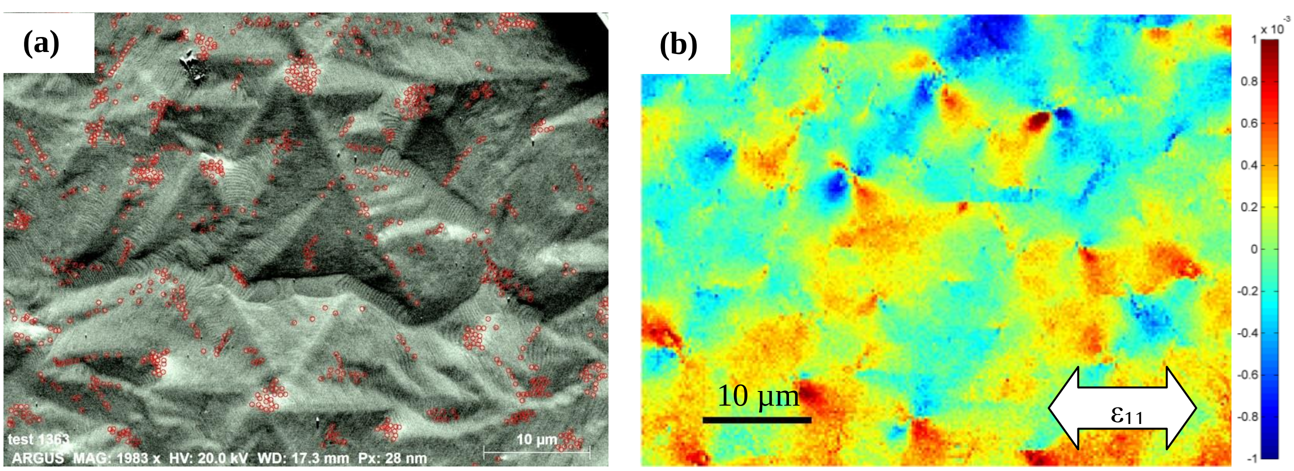

Figure 3. (a) ECCI showing TDs (marked with red circles) and atomic terraces and (b) one component (ε_{11}) of the corresponding elastic strain field obtained by EBSD.