Strain and lattice tilt mapping of GaN on Si nanowires at early stage of coalescence by synchrotron x-ray nano diffraction

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Gallium nitride (GaN) is a very attractive III-V semiconductor for optoelectronics applications and it is highly relevant for the fabrication of light emitting diodes. Epitaxial growth of GaN is nevertheless expensive due to the substrate cost and size limitations. Thus, growing GaN on low-cost foreign substrates is more common, however, the GaN layer will present many dislocations reducing the emission efficiency. We aim to improve the quality of the epitaxial GaN layer by developing an original method based on growing GaN pyramids on top of GaN/AlN/Si(111)/SiO_2/Si(001) etched nano-pillars [1]. At high growth temperatures, viscoelastic properties of SiO_2 will allow deformation, which should let the pillars undergo a rotation and allow the GaN on top to coalesce into 40x40 µm² platelets with no boundary dislocations. In this work, we combined two x-ray microscopies techniques at the state of the art to gain a deeper comprehension of the GaN coalescence at an early stage.
In a first study we used Dark-Field X-ray Microscopy (DFXM) on beamline ID06 of the European Synchrotron Radiation Facility (ESRF). DFXM is a non-destructive imaging technique that can provide three-dimensional (3D) maps of microstructures in crystalline matter. The whole GaN structure is illuminated with focused monochromatic X-rays and the diffracted beam then passes through a compound refractive lens (CRL) placed after the sample to produce a 10x magnified real (x, y) image on the 2D detector. Combined with a phi (Φ) or omega (ω) rotation of the sample, these scans provide information on the crystallographic mis-orientations in the sample, specifically the tilt and twist of the crystallites. Thanks to DFXM, we show that extremely well oriented lines of GaN (standard deviation of 0.04°) with low dislocation densities [2] as well as highly oriented material for zones up to 10 x 10 µm² in area are achieved with this growth approach. Complementary macroscopic high intensity X-ray diffraction shows that the coalescence of GaN pyramids causes dis-orientation of the silicon layers in the nano-pillars, implying that the growth occurs as intended. Then, to go deeper into the mechanical behaviour of the GaN layers and of the Si pillars, we completed this study by using scanning diffraction x-ray microscopy (SDXM) on beamline ID01 at the ESRF. By performing x-ray diffraction measurements using a two-dimensional detector and a nano x-ray beam (~40 nm), we obtained (Q_x,Q_z) reciprocal space maps around the asymmetrical GaN (105) Bragg reflection at every (x,y) position of the sample and thus obtained the GaN lattice tilt, strain and peak broadening at each position We used SDXM on a reference sample with uncoalesced GaN nanopillars, and on a second sample at the early stage of coalescence (not fully coalesced). The results show that the disoriented GaN pillars have transformed from a large distribution of orientation into bigger well-defined domains of GaN very well-oriented within themselves. In addition, a broadening of the peak along Q_z and a higher strain value were detected at the borders of the same grains identified in the tilt map.
These results will be discussed in terms of mechanisms at work during the early stage of coalescence and optimization of the growth process (pillars pattern, size…). Although it was not possible to achieve highly oriented GaN layers in every case, we show that this growth technique is extremely promising for micro-displays or micro-LEDs, which require small islands of high quality GaN material.

References

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