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Synchrotron White Beam Topography Characterization of Growth Defects in PVT Grown AlN Single Crystals

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Beamline(s): X19C

Introduction: Wide band gap nitride semiconductors are promising materials for a broad range of electronic and opto-electronic devices such as electronic devices capable of operation at elevated temperatures, high power or high frequency, and short-wavelength optoelectronic devices such as solar blind UV light detectors, blue LEDs or UV laser diodes. Currently, some of these applications are being realized by growing heteroepitaxial device structures on SiC or sapphire substrates, but lattice mismatch and incompatibility issues limit their performance. A homoepitaxial relationship between device and substrate should drastically lower dislocation density in the epilayers and thus greatly improve the performance and lifetime of the devices. For this, there is a requirement for large area, low defect density, single crystal AlN or GaN substrates. Defect structures in AlN crystals grown by PVT are characterized by SWBXT [1] and the results are discussed here.

Methods and Materials: AlN crystals were grown by sublimation of AlN source in a BN crucible in N_2 atmosphere [2,3]. SWBXT expts. were carried out at the Stony Brook Synchrotron Topography Station, Beamline X19C.

Results: Transmission x-ray topographs recorded from two spontaneously nucleated AlN crystals obtained from two different crystal runs are shown in Figs.1 & 2(b). In Fig.1, growth sector boundaries that separate regions that grew along different growth fronts and incorporated impurities at different concentrations, and a line of inclusions parallel to the $(\bar{1}100)$ growth front are observed. Gradual reduction in thickness at the top and right edges is indicated by Pendellösung or thickness fringes. Growth dislocations nucleated at impurity inclusions from the bottom edge are seen in the central region. Near the lower edge, where the crystal was detached from the growth chamber, dislocations loops due to plastic deformation are visible. Overall dislocation density is about 10^3 cm^{-2} but most regions are completely devoid of dislocations.

Fig.2(b) shows an x-ray topograph from a thin (0001) platelet that grew in the region of the crucible with a high-temperature gradient. Average growth rate along the fastest growth direction was unusually high, roughly 4mm/h. Compared to the physical shape of the crystal (Fig.2(a)), the x-ray topograph displays considerable distortion due to significant residual stresses in the thin crystal that cause lattice planes to bend. When this crystal's rapid growth conditions are considered this residual stress is not surprising. Other than a few inclusions and strain at left tip where it was attached to the growth chamber, the crystal is essentially dislocation-free.

Conclusions: AlN crystals grown by the sublimation method have plate morphology parallel to $(11\bar{2}0)$ or (0001) planes depending on growth conditions. Dislocation densities of the order of 10^3 cm^{-2} or lower are observed with high degrees of crystalline perfection in most regions as indicated by Pendellösung fringes. Defects such as growth sector boundaries, inclusions and growth dislocations indicate slight concentrations of impurity. Stresses at point of attachment of crystal to growth chamber can lead to plastic deformation and generate dislocations.

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References:

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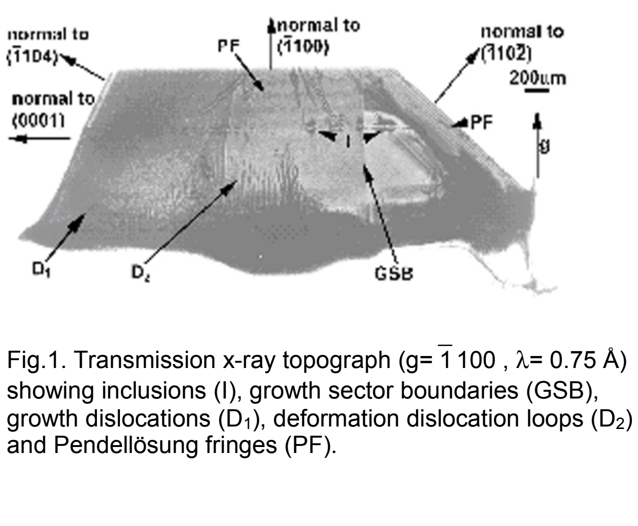

Fig.1. Transmission x-ray topograph (g= $\bar{1}100$, λ= 0.75 Å) showing inclusions (I), growth sector boundaries (GSB), growth dislocations (D_1), deformation dislocation loops (D_2) and Pendellösung fringes (PF).

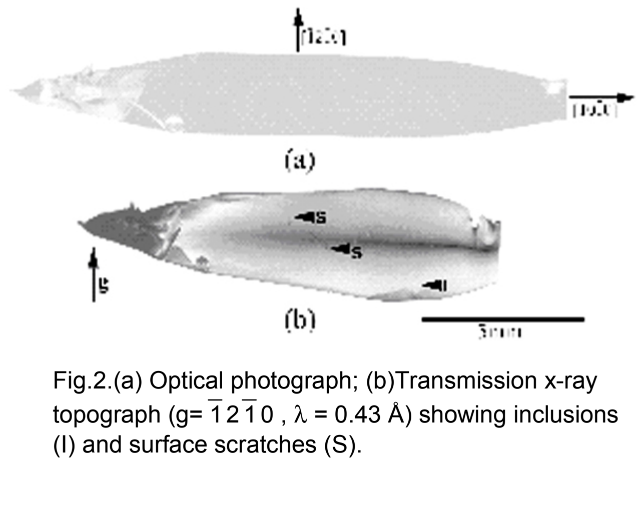

Fig.2.(a) Optical photograph; (b)Transmission x-ray topograph (g= $\bar{1}2\bar{1}0$, λ = 0.43 Å) showing inclusions (I) and surface scratches (S).