Generation of misfit dislocations in highly mismatched GaN/AlN layers

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Basic Technology Research Programme

A 1000 micro-emitters per square millimetre

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Motivation: Due to the large lattice mismatch between AlN and sapphire substrates, a very high density of threading dislocations (TDs) exists in AlN films grown directly on sapphire. Recently, a reduction in the dislocation density in the overgrown AlGaN layers on AlN buffers has been observed by inserting a very thin GaN layer, which successfully improved the device operation of 340nm UV-LEDs. The purpose of the present work is to reveal the correlation between strain induced TD movement and the generation of misfit dislocations (MDs) in GaN thin films grown on AlN.

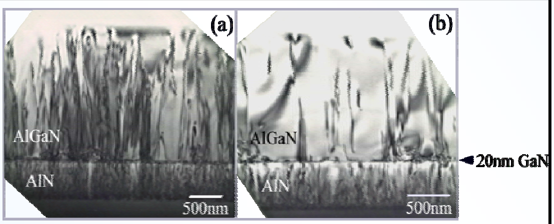

Fig.1 TEM images show that the dislocation density is significantly reduced by inserting an GaN interlayer. (a) $Al_{0.25}Ga_{0.75}N$ grown on AlN without a GaN layer. (b) $Al_{0.25}Ga_{0.75}N$ grown on AlN with a 20nm GaN layer.

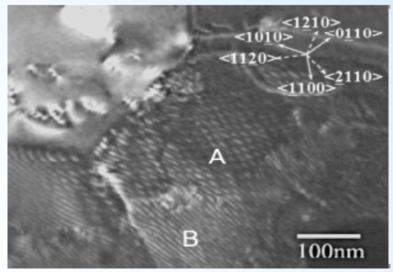

Fig.2 As shown in the plan-view TEM image, a triangular grid of equally spaced MDs is formed in the GaN platelets grown on an AlN layer. The MDs are pure-edge dislocations with $b=1/3\langle 11\bar{2}0\rangle$ and have line directions of $\langle 10\bar{1}0\rangle$ for area A and $\langle 11\bar{2}0\rangle$ for area B.

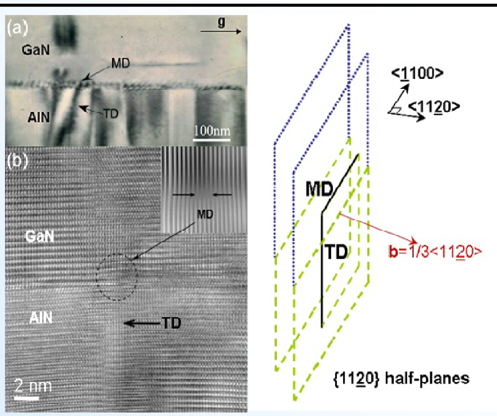

Fig.3 Cross-sectional and high-resolution TEM images demonstrate that, under large misfit strain, most of the TDs in AlN migrated into the interface by *climb* during the GaN growth to become in-plane MDs, which is one key source for origination of the MDs.

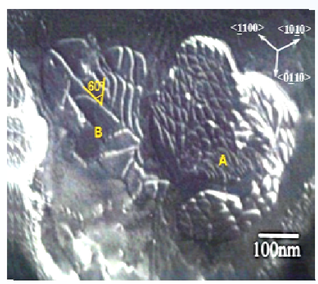

Fig.4 Different MD distributions are observed in different areas. In area B, a few roughly equally-spaced short MDs bordering on a long dislocation suggest that, in addition to the TD migration, some MDs are generated by direct nucleation and originate in order to achieve an isotropic strain relaxation before the final formation of the MD grids.

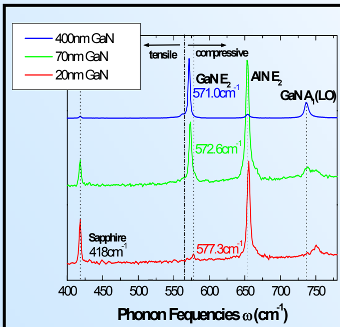

Fig.5 Raman measurement of the GaN films grown on AlN. The residual strain of the GaN films strongly depends on the thickness of GaN films.

We are grateful to Dr. Robin Devonshire and Dr. Richard Jeans for Raman measurement.

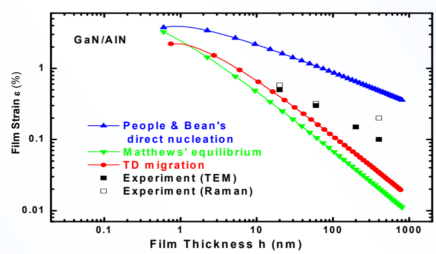

Fig.6 A theoretical prediction based on an energy-balanced model (*red line-Appl. Phys. Lett. 83, 2569)* assuming that MDs are generated by TD migration gives the best agreement with our experimental values of residual strain for smaller thicknesses, indicating that the MDs are first introduced by TD movements at early growth stage. The larger experimental strain values than the theoretical ones at large thicknesses implies a larger MD nucleation energy compared to the TD migration, which can be ascribed to direct nucleation of those MDs. (*Blue line-Appl. Phys. Lett. 47, 322; Green line-J. Vac. Sci. Technol. 12, 126*)

Conclusions: In highly-mismatched GaN/AlN layers, MDs are introduced first by interfacial migration of TDs in AlN at the early stage of GaN growth, which reduces the dislocation density in the overgrown layer and relieves part of strain simultaneously. Then probably by nucleating around the misfit segments of TDs, more MDs are formed gradually to develop into a grid of equally-spaced MDs, leading to nearly complete relaxation of misfit strain.