Quantitative Dislocation Analysis of 2H AlN:Si grown on (0001) Sapphire

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In the last few years aluminium nitride (AlN) has attracted much attention due to its extremely large direct band gap of approximately 6.0 eV and its impressive chemical and thermal stability. Thus AlN and $Al_xGa_{1-x}N$ ternary alloys are promising materials for high-power high temperature electronic applications and optoelectronic devices in UV range. For group-III nitride wafers are still not available in sufficient amount and quality, AlN has to be grown on foreign substrates such as Al_2O_3 (Sapphire). Due to the lattice mismatch between the AlN/Al_2O_3 interface of about -11.7%, compressive stress is induced in the crystal system. The strain energy is reduced by the formation of threading dislocations, decreasing the crystal quality [1, 2]. Thus it is still a big challenge to grow AlN directly on foreign substrates with small dislocation density. To make the material suitable for semiconductor devices an efficient doping is necessary to achieve sufficient conductivity. Unfortunately Si doped AlN is still highly resistive mainly due to its large activation energy of several 100meV for the Si dopants. Thus high doping densities of up to 10^{20}cm^{-3} are necessary, however affecting crystal quality.

In this work we analysed the threading dislocations (TDs) quantitatively in highly doped ALN:Si layers by exploiting the 3g weak beam dark field method (WBDF) in cross-sectional transmission electron microscopy. The burgersvectors were determined by using the $|g\cdot b|$ criterion. To investigate the dislocations depending on the doping density, different doped 300nm thick AlN layers were grown on undoped ALN layers under same growth conditions by MOVPE (see [1, 3, 4]). It is shown that most dislocations formed in the undoped AlN layer are pure edge dislocations of type 1/3[2-1-10] along c axis, whereas the number of [0001] pure screw and 1/3[2-1-13] mixed dislocations is very small (Figure 1). Plane-view TEM investigations revealed a dislocation density of $4.1\cdot10^{10}$cm^{-2} for the undoped AlN layer. When growing doped AlN:Si on the undoped layer under same growth conditions the pure edge dislocations penetrate the doped AlN layer without significant changing for low doping densities (doping density $1.5\cdot10^{18}$cm^{-3}). By increasing the doping density to $3.0\cdot10^{19}$cm^{-3} the pure edge dislocations of type 1/3[2-1-10] in the undoped AlN layer change direction at the AlN/AlN:Si interface and band together (Figure 2). This annihilation of the pure edge dislocations is probably promoted by the increasing compressive stress resulting from the lattice mismatch between AlN and AlN:Si. It was also observed for highly doped AlN, that the propagation of the pure screw and mixed dislocations of type [0001] and

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1/3[2-1-13] is blocked at or near the AlN/AlN:Si interface by forming dislocation loops. This effects decrease the dislocation density at the surface. Beside the annihilation effect, the aggregation of the edge dislocations near the surface leads to a degradation of the surface quality (roughness) of the AlN:Si layer.

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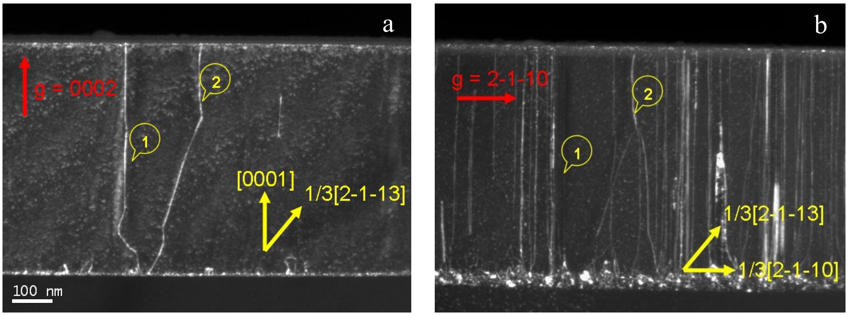

Figure 1: WBDF images of the undoped AlN layer on (0001) sapphire from same sample area by using 0002 and 2-1-10 reflection: (a) Only TDs with b [0001] & 1/3[2-1-13] are visible, whereas the TD “1” is a pure screw and “2” a mixed dislocation. (b) Additional TDs are visible which are all pure edge dislocations of type 1/3[2-1-10].

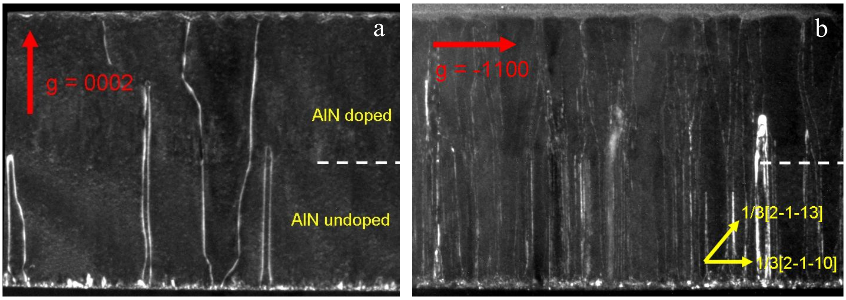

Figure 2: Doped AlN:Si layer on undoped AlN (same growth conditions, doping density $3.0*10^{19}cm^{-3}$): (a) WBDF image with g = (0002) shows pure screw and mixed dislocations forming dislocation loops at the AlN/AlN:Si interface. (b) Annihilation of the pure edge dislocations at the AlN/AlN:Si interface results in a decrease of the dislocation density at the surface.