Flow modulation epitaxy of InN/GaN heterostructures; towards InN based HEMTs

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InN and GaN thin films were grown by metal-organic chemical vapor deposition at temperatures between 400 and 620 ºC using the precursors trimethylindium (TMIn), trimethylgallium (TMGa), triethylgallium (TEGa) and ammonia. Step flow growth of GaN and InN was achieved through optimization of the injection sequences for pulsed growth and alternate group-III and –V precursor supply. For layers grown in the conventional growth mode, a residual background carrier concentration as low as 4 x 10^{18} cm^{-3} was obtained. The influence of the growth temperature (T_{gr}), ammonia flow, and growth rate on the structural and electrical properties and the surface morphology of the InN layers will be discussed in detail. For the fabrication of GaN/InN/GaN heterostructures, a GaN growth process compatible to that for InN was developed. First results on GaN/InN/GaN heterostructures will be presented.

While GaN films are typically deposited at temperatures above 1000 ºC, InN is known to decompose already at temperatures around 550 ºC. The low thermal stability of InN is illustrated in Fig.1 (conventional growth: simultaneous injection of TMIn and NH_3). At T_{gr} > 620 ºC, the growth rate of InN, r_{InN}, drastically decreased with increasing temperature and In droplet formation dominated. For T_{gr}< 620 ºC, r_{InN} increased with increasing T_{gr} due to the enhanced decomposition of TMIn. The growth rate of InN was independent of the ammonia partial pressure, p_{NH3}, for p_{NH3} > 0.16 bar at T_{gr} = 480 ºC. The residual background carrier concentration in the InN films steadily decreased from 2.2 x 10^{20} cm^{-3} to 4 x 10^{18} cm^{-3} when the deposition temperature was increased from 400 to 620 ºC, most likely related to a more efficient NH_3 decomposition at higher temperatures. In contrast, the crystalline quality of the 35 nm thick InN layers degraded with increasing growth temperature. The full width at half maximum of the (002) rocking curves increased from 560 (T_{gr}= 400 ºC) to 920 arcsec (T_{gr}= 620 ºC), originating from

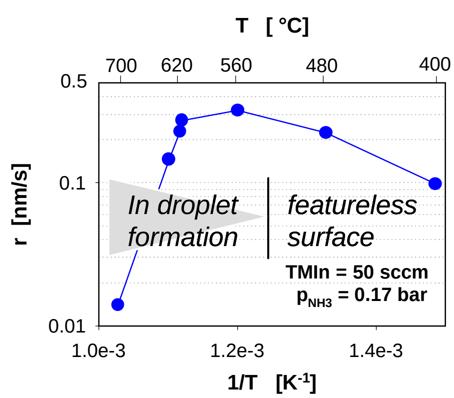

Fig.1. Dependence of the InN growth rate on the growth temperature for films grown in the conventional growth mode.

the higher misorientation of the InN grains, omnipresent in the case of conventional growth of InN in our reactor. To avoid InN grain formation, alternative precursor injection schemes were investigated. At T > 600 ºC, step flow growth of InN was observed when TMIn and NH_3 were injected alternately, in an atomic layer epitaxy (ALE) like growth mode (Fig.2a). In addition, the formation of metal droplets on the surface could be largely suppressed. Pulsed injection of TMIn, but continuous flow of NH_3 resulted in step flow growth of InN as well (Fig. 2b), but did not suppress the formation of metal droplets.

The fabrication of InN/GaN heterostructures requires the development of a GaN growth process compatible to that for InN. To expand the deposition regime of GaN towards lower temperatures, TEGa was investigated as an alternative precursor. Using TEGa instead of TMGa, the transition temperature between diffusion and kinetically controlled growth was reduced from 580 to 480 ºC. But, similar to InN, grain growth of GaN was observed at 400 ºC < T < 620 ºC for conventionally grown films, even at growth rates as low as 0.005 nm/s. By injecting TEGa and NH_3 alternately (ALE, T = 620 ºC), the grain formation could be suppressed, but no smooth steps were formed (Fig. 2c). However, step flow growth occurred by pulsed injection of TEGa (Fig. 2d). For comparison, Fig. 2f shows the surface morphology obtained for pulsed injection of TMGa. Surprisingly, a much more regular step structure was observed. Depositing the InN layer by ALE and the low temperature GaN layer in the pulsed growth mode, 3 nm GaN/1.5 nm InN/GaN heterostructures with very smooth surfaces could be obtained. However, AFM images also indicated, that new structural defects were formed during deposition of the InN/GaN layers, resulting from the large lattice mismatch between InN and GaN (~10%). The electrical and structural properties of the GaN/InN/GaN heterostructures will be discussed.

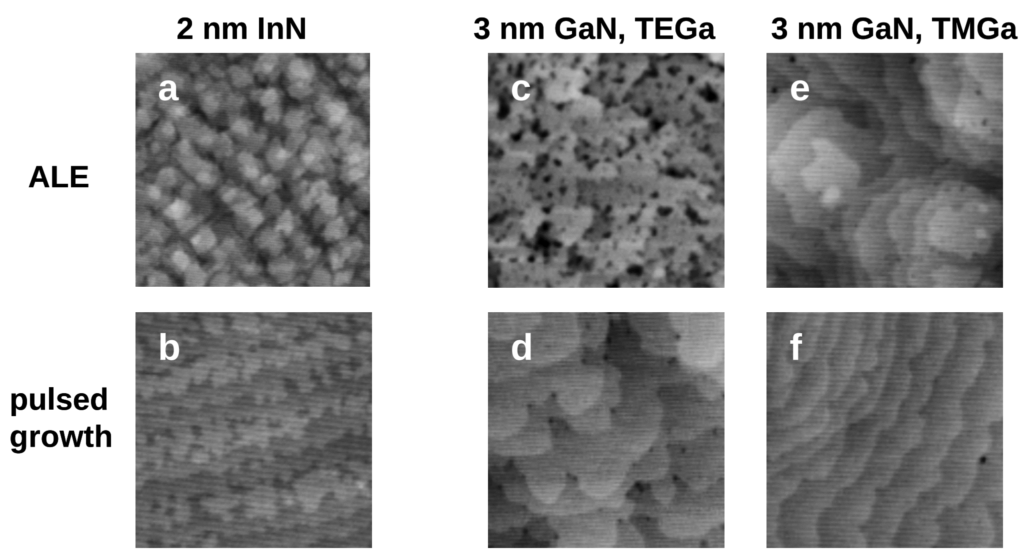

Fig. 2. Atomic force microscopy images (size: 500 x 500 nm, gray scale = 3 nm) of different layers grown on 2 µm thick GaN films at 620 ºC: 2 nm InN (a) grown by ALE, (b) grown by pulsed injection of TMIn; 3 nm GaN (c) grown by ALE with TEGa, (d) grown by pulsed injection of TEGa, (d) grown by ALE with TMGa, (e) grown by pulsed injection of TMGa.