Effect of growth temperature on the GaN/AlN in N-polar AlN-based HEMT

Itsuki Furuhashi[1], Xu Yang[2], Yoann Robin[2], Yoshio Honda[2], Hiroshi Amano[2], Markus Pristovsek[2]
[1]Graduate School of Engineering, Nagoya University
[2]Institute of Materials and Systems for Sustainability (IMaSS), Nagoya University
Furuhashi.itsuki.r2@s.mail.nagoya-u.ac.jp

Due to its great properties, III-nitride semiconductors have become the material of choice for a high power and high frequency High Electron Mobility Transistors (HEMTs). However, the inner structure of the current GaN-based III-polar HEMTs has inherent physical limitation, like carrier confinement and limited polarization charge. N-polar AlN-based HEMTs can overcome this. We have demonstrated the first N-polar AlN-based enhancement-mode HEMT [1]. Since the performance was limited by the sheet resistance (R_S), we focused on the crystal's surface morphology and changed the growth condition especially the GaN channel layer.

Our N-polar AlN based HEMTs have a N-polar GaN channel layer (GaN CL) on the top and N-polar AlN transition layer (AlN TL) below the channel. The structures are based on the step-bunched N-polar AlN buffer layer grown on the sapphire. Based on earlier work, we focused on the impact of the growth temperature relating the surface morphology by AFM, strain relaxation and GaN CL thickness by XRD, R_s by non-contact type resistance measurement, and carbon and oxygen concentration by SIMS.

In the GaN CL, we changed the growth temperature from 650˚C to 1080˚C using a V/III ratio of ~1000 using trimethylgallium (TMGa) and NH_3 as a precursor. The GaN surfaces show, step-bunching after growth above 850˚C and dots are generating below 750 ˚C. This is consistent with a shortening of the surface diffusion length of the Ga adatoms. At high temperature, Ga adatoms have too long diffusion length so step-bunching is enhanced while at low temperatures, 3D growth occurs. For the electrical properties, also impurities like carbon and oxygen are important. We grew a thick relaxed N-polar GaN layer stack on N-polar AlN while we changed the growth temperature from 750˚C to 1000˚C with V/III ratio at ~7500 using TMGa and triethylgallium (TEGa) as a Ga precursor. Figure 1 shows the result. The carbon incorporation with TMGa exponentially increases with lower temperature, similar to other groups' result for metal-polar GaN. However, the carbon incorporation is much lower on N-polar GaN as also reported before. This exponential increase is due to the reduced decomposition of NH_3 and thus, supplying less atomic hydrogen to the surface to desorb the CH_3 radicals. A similar effect was seen also for N-polar AlN, although at much higher temperatures because it has to grow at much lower V/III ratio. The carbon incorporation changes with TEGa. Above 850 ˚C with TEGa, carbon concentrations are exponentially decreasing. However, carbon incorporation also decreases to lower temperatures, because TEGa decomposes into C_2H_4 or C_2H_5 radicals that cannot incorporate until they decompose to CH_3.

No difference can be seen between TMGa and TEGa in the oxygen incorporation. The trend with growth temperature is the same for both, the lowest point is 850˚C and it forms a U-shaped curve.

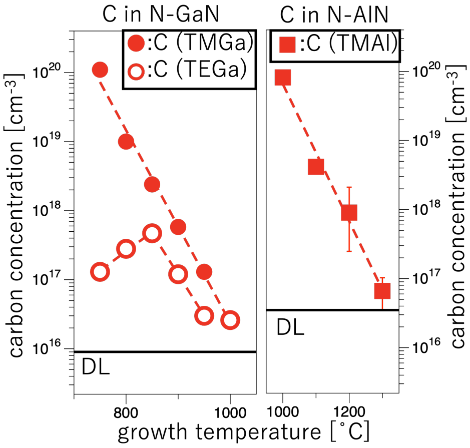

Figure 1 carbon concentration at N-polar GaN and AlN

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References

[1] Chengzhi Zhang, Yidi Yin, Peng Huang, Itsuki Furuhashi, Markus Pristovsek, Martin Kuball, and Matthew D Smith, (under revision)