Optimization of High Mobility GaN by rf-assisted MBE

Ben Heying[1),3)] , Yulia Schmorchkova[2)] , Chris Elsass[1)] , Christy Poblenz[1)] , Erik Haus[1)] , Lifan Chen[1)], Paul Fini[1)] , Steve DenBaars[1)] , Umesh Mishra[2)] , Jim Speck[1)]

[1)] Materials Dept., University of California, Santa Barbara, CA 93106
[2)] Electrical and Computer Engineering Dept., University of California, Santa Barbara, CA 93106
[3)] benh@mrl.ucsb.edu

The room-temperature Hall mobility for GaN films range broadly in the literature. The highest reported mobility is 950cm^2/Vs with a carrier concentration of 8×10^{16}cm^{-3} for a 60μm thick GaN film grown by HVPE[1]. The record for MOCVD-grown GaN is slightly less at 900 cm^2/Vs for a carrier concentration of 2×10^{16} cm^{-3} [2]. MBE, in contrast, has typically produced films with much lower mobilities. The highest reported mobility, excepting the values presented here, is 580 cm^2/Vs for a carrier concentration of 2×10^{17}cm^{-3} [3] and typical MBE-grown films have much lower mobility values of 100-300 cm^2/Vs [4]. These significantly lower mobility values have led to speculation that MBE-grown material has intrinsic point defects that limit transport properties[5,6]. In addition, GaN films grown by MBE typically have higher dislocation densities than films grown by MOCVD or HVPE, so dislocation scattering could also contribute to the lower mobility values measured for MBE-grown material. Dislocations have been shown to be a dominant source of electron scattering for GaN films having dislocation densities above 1×10^8cm^{-2} [4,7,8]. In this work, we have produced low dislocation density MBE-GaN films by utilizing MOCVD-grown GaN templates as substrates. By optimizing MBE growth parameters used for the growth of GaN films we have been able to achieve mobilities in excess of 1000cm^2/Vs.

The MBE growth parameters were first optimized for surface morphology and structure. Three growth regimes (N-stable, intermediate, and Ga-droplet), having distinct morphologies, are defined on a growth diagram of Ga/N ratio vs. substrate temperature (see Fig. 1). We show, using AFM and cross-sectional TEM, that the N-stable and intermediate regimes are inferior to the Ga-droplet regime. N-stable films exhibit rough, facetted surfaces. Intermediate-regime films have flat surfaces between large pits. In contrast, Ga-droplet regime films have surfaces with no pits that are dominated by step-terrace structures mediated by the threading dislocations. Cross-sectional TEM shows that no additional dislocations are created at the interface between the MOCVD and MBE films.

The effect of dislocation density on the Hall mobility was studied by growing MBE films on templates having different dislocation densities as shown in Fig. 2. The MBE films were grown within the Ga-droplet regime at 750°C and doped to various carrier concentration levels using Si. The increase in mobility with carrier concentration shown in Fig. 2 is similar to what was observed previously by Ng[4] and Weimann[8] and can be explained by a model of dislocation scattering[7]. As the free carrier concentration increases, the dislocation line charges become screened and the mobility increases. Also, the mobility increases at constant carrier concentration for the films grown on the template having the lower dislocation density. For the lower density of dislocations fewer carriers are required to screen the dislocations.

Recently, the effect of the MBE-GaN growth regime on the mobility of the GaNwas studied. A 1μm thick GaN film was grown at the transition line between the Ga-droplet regime and the intermediate regime as shown by point A in Fig. 1. Due to temperature non-uniformities across the substrate the growth regime varied from the Ga-droplet regime on one side to the intermediate regime on the other. Evidence of this variation was clearly visible after growth due to the accumulation of Ga droplets on the surface across only half of the substrate. Small, 30μm square, van der Pauw patterns were etched through the film and the n-p-n barrier between the MBE film the MOCVD films. The room-temperature Hall mobilities were found to change across the substrate as a function of the growth regime. In the Ga-droplet regime the mobility was found to vary between 850-860cm^2/Vs. However in the middle of the sample, outside the area of droplets, the mobility increased to 1020-1060cm^2/Vs and on the edge of the sample, furthest away from the droplets, the mobility increased to the highest value of 1155cm^2/Vs. This sample was re-measured at Lake Shore Cryotronics and the mobility values were confirmed on their Hall measurement system. These mobility values are among the highest reported for GaN films, which demonstrates the suitability of MBE for the growth of high quality GaN

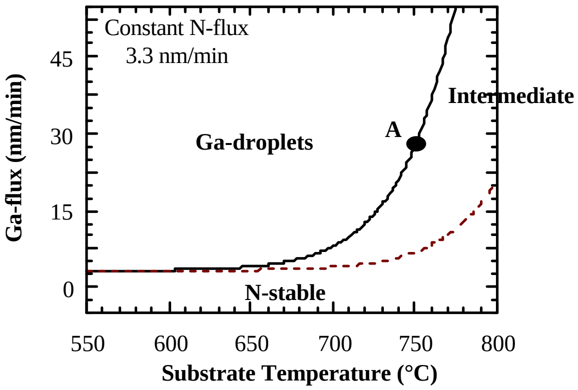

Figure 1 Growth diagram describing the growth conditions used to produce the three different GaN growth regimes. Point A describes the growth conditions used for the high mobility sample.

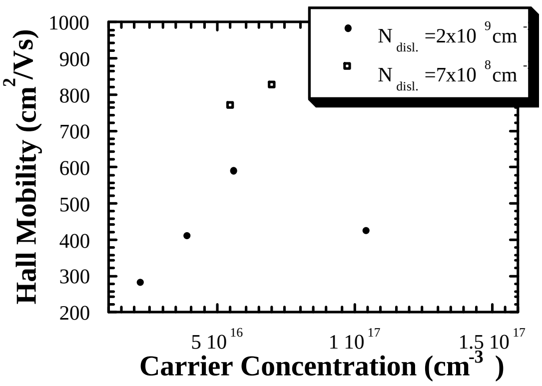

Figure 2 Hall mobility vs. carrier concentration for MBE GaN films grown on GaN templates having different dislocation densities.

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