OMVPE growth of carbon doped bases for advanced HBT applications

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Advanced compound semiconductor Heterojunction Bipolar Transistor (HBT) structures rely on a thin, heavily-doped base region with good minority carrier characteristics to obtain high-speed, high-gain performance. In recent years, carbon has become the predominant base dopant, due to its low solid-phase diffusion properties. It is also relatively easy to obtain high doping levels. In addition to commercially available InGaP/GaAs devices, C-doped bases show promise for future InGaAs/InP and InGaP/InGaAsN devices.

In this paper, we will discuss and compare the OMVPE growth techniques and characteristics of C-doping in GaAs, InGaAs, and InGaAsN for HBT devices. Intrinsic doping has been shown to be the method of choice for GaAs devices [1], however as both In and N are added, it becomes necessary to use extrinsic doping with either CCl_4 or CBr_4. Either method relies on a constant V/III ratio across the deposition surface to obtain uniform doping levels. In the case of intrinsic doping, this can be tricky, as it utilizes the properties of kinetically-limited growth.

For the case of InGaAs and InGaAsN materials, as the composition strays from GaAs, it also becomes increasingly difficult to obtain high electrically-active C doping levels, while retaining lattice-matching. Doping these materials require either an *ex-situ* or *in-situ* anneal step to remove residual hydrogen from the epi-layers. We will discuss the effect that our own *in-situ* annealing technique has on the physical, electrical and optical quality of the material, as characterized by atomic microscopy, photoluminescence, x-ray diffraction, SIMS, and Hall measurements. By optimizing the growth conditions and anneal step, we have achieved electrically active C-doping levels of > 3E19 cm^{-3} in $In_{0.53}Ga_{0.47}As$, $In_{0.03}Ga_{0.97}As_{0.99}N_{0.01}$, and GaAs with mobilities of 63 cm^2/V-sec, 75 cm^2/Vsec, and 97 cm^2/Vsec, respectively. These films show excellent morphology and atomically smooth surfaces with < 5 Å RMS roughness.

[1] F. Brunner, T. Bergunde, E. Richter, P. Kurpas, M. Achouche, A. Maaßdorf, J. Würfl, and M. Weyers, *J. Crystal Growth*, v. 221, pp. 53-58, 2000.