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Low dislocation density and high mobility GaN based HEMT heterostructures grown by plasma-assisted and high temperature ammonia MBE with Ga as surfactant

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One of the main problems in manufacturing GaN-based devices up to date is the lack of low cost lattice-matched substrates. Growth of III-Nitrides on mismatched substrates using different buffer layers usually yields high dislocation density (10^9-10^{10} cm^{-2} for MBE and 10^7 cm^{-2} for MOCVD using ELOG) which affect the device quality and reliability. Moreover, typical growth temperatures in MBE are much lower as compared with MOCVD. It leads to higher dislocation density which limits carrier mobility. Typical values of room temperature electron mobility in GaN grown on sapphire are in the range 250-350 $cm^2/V{\cdot}s$ for MBE and 500-700 $cm^2/V{\cdot}s$ for MOCVD. On the other hand, MBE has several advantages: in-situ RHEED monitoring, sharper heterojunctions, higher purity etc. At present time, an increasing number of researchers choose plasma-assisted (PA) MBE as it is simpler in service and has its own benefits. However unlike to ammonia MBE, this method does not allow noticeable increase of the growth temperature, which usually improves the material quality.

Earlier we presented the results of employing both types of MBE (plasma-assisted and ammonia), obtained in STE3N MBE System (SemiTEq). It was shown that the use of high-temperature buffer layers AlN/AlGaN grown by NH3-MBE at extremely high temperatures (up to 1150^0C) allows one to improve drastically GaN structural quality. The dislocation density in GaN grown by NH3-MBE or PA-MBE on such buffer layer was reduced down to (9-10)x10^8 cm^{-2} that resulted in substantial increase in electron mobility up to 600-650 cm^2/Vs in a 1.5-µm-thick GaN:Si (n=3-5x10^{16} cm^{-3}). This result is comparable with a good quality MOCVD GaN and several times better than in conventional MBE. Importantly, growth of AlN at 1150^0C is difficult to realize in PA-MBE since Al-rich mode is necessary for 2D-growth, while desorption of Al becomes significant at $T>900^0$C.

In this paper we present the results of further improving of nitride heterostructures quality with use of high-temperature AlN buffer layer grown by ammonia MBE with Ga as surfactant. It is shown that this approach allows to achieve 20-30% electron mobility increase in GaN. 2DEG mobility in GaN/GaAlN up to 2000 $cm^2/V{\cdot}s$ is demonstrated.

Application of this technology for growing on SiC substrates enabled one to manufacture a DHFET with a gate length of 0.5 um and 0.25 um. Up to 50% PAE and delivered power density of 5.5 W/mm at 4 GHz and small signal gain up to 11 dB at 10GHz are achieved.
Besides unlike the NH3-MBE, which is difficult to use at $T<500^0$C (because of low decomposition efficiency of ammonia), PA-MBE growth is very effective at low temperatures, for example for InAlN lattice-matched to GaN. The results of the growth of high quality GaN/InAlN heterostructures (electron sheet density and mobility in the range (2.2-2.4)x10^{13} cm^{-2} and 1200-1300 $cm^2/V{\cdot}s$, respectively) by using both PA-MBE and NH3-MBE with extremely high ammonia flux are shown.