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# GaN, AlGaN, GaNAs and Related Heterostructures Grown by Molecular Beam Epitaxy

**Hyonju Kim**

Applied Semiconductor Physics
Department of Microelectronics and Nanoscience
Chalmers University of Technology and Göteborg University
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# ABSTRACT

This work deals with growth and characterization of III-nitrides and related heterostructures as well as GaNAs alloys grown by plasma assisted molecular beam epitaxy (MBE). The III-nitrides belong to the *wide bandgap semiconductors* due to their large energy bandgap spanning from 1.9 to 6.2 eV. Owing to their large and direct bandgap, therefore, III-nitrides can be used for violet, blue, and green light emitting diodes (LEDs) as well as for high temperature and high speed-high power transistors. The GaNAs alloys have attracted much attention due to their large and composition-dependent bowing parameter and the corresponding broad span in the bandgap. In addition, this material system can be grown lattice matched to Si, and GaAs when In is incorporated together with N. The subjects of this work consist of three main parts, as described briefly below.

Since doping is a critical issue for semiconductor devices, unintentional impurities are also important because they may have detrimental effects on optical and electrical properties. Therefore, we have investigated correlations between growth parameters and residual impurities, especially, B, As and O, incorporated in the GaN layers to identify their possible origins. The B impurity was found to originate from the *p*BN crucible used in the N plasma source. The relatively high As impurity background level (~$3\times10^{18}$ atoms/cm$^3$) observed in the unintentionally doped GaN is ascribed to the previous growth of arsenides in the same system. By improving the layer crystalline qualities, we could observe a significant reduction of the O impurity levels in the GaN layers.

The AlGaN/GaN heterostructure is an important element in electronic devices due to their excellent electrical properties such as electron carrier concentration and mobility, which are ascribed to the existence of a two-dimensional electron gas (2DEG) at the heterointerface. We report about the growth and characterization of the $Al_xGa_{1-x}N$/GaN ($x \leq 30\%$) heterostructures.

Due to the large miscibility gap in the GaNAs ternary alloy, it was found to be difficult to incorporate high concentration of As in GaN, or N in GaAs. Alternative ways may be to grow thin As-rich layers embedded in GaN, or short period superlattices, $(GaN)_m(GaAs)_n$. In this respect, we have studied the growth of a thin As-rich layer buried in wurtzite GaN, and thick GaAs grown on wurtzite GaN. The SIMS analysis demonstrates that an *in situ annealing/interruption process* at optimized temperature is essential to obtain a well-confined thin As-rich layer embedded in the GaN. A strong evidence of As surface segregation was observed, and analyzed using an one-dimensional empirical segregation model. In addition, the presence of As in wurtzite GaN is found to be responsible for the formation of basal plane stacking faults. The thick GaAs layers grown on GaN (0001) are found to have two preferential growth orientations, i.e., GaAs (111) and (220).

The characterization techniques used for this work are summarized as: Secondary Ion Mass Spectrometry (SIMS), High-resolution X-ray Diffraction (HRXRD), Atomic Force Microscopy (AFM) and Transmission Electron Microscopy (TEM).

Key words: plasma-assisted MBE, III-nitrides, unintentional impurities, AlGaN/GaN, GaNAs, surface segregation, stacking fault, heterointerface