Workshop on Electronic Material Nanostructures, Sept. 20-23, 2001, Warsaw, Poland.

Tunnel junctions and high power, high frequency transistors based on pyroelectric AlGaN/GaN heterostructures

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Bound sheet charges with high concentrations are induced by gradients of pyro- and piezoelectric polarization at surfaces and interfaces of pseudomorphic $Al_xGa_{1-x}N$/GaN hetero- and quantum well structures. Free carriers tend to compensate positive and negative bound sheet charges causing a *self-organized* formation of two dimensional electron or hole gases, respectively. Gradients in polarization and corresponding sheet charges influence the carrier concentration and the band edge profiles in GaN based heterostructures significantly and have to be considered for optimum device design and performance of high frequency and high power transistors (HEMTs) as well as for tunnel junctions.

The pyro- as well as the piezoelectric polarization in wurtzite group III nitride alloys are predicted to vary non linear with changing alloy composition, mainly due to different electronegativity of the cations and internal strain effects (varying bond length and angle). As a consequence a linear interpolation of spontaneous polarization and piezoelectric coefficients between binary compounds in order to determine the polarization of alloys and sheet charges at $Al_xGa_{1-x}N$/GaN interfaces and surfaces is inaccurate.

To measure polarization gradients in $Al_xIn_yGa_zN$/GaN heterostructures we have used the formation of two dimensional carrier gases which tend to compensate positive polarization induced bound sheet charges. We have determined the carrier concentration profiles and electrical transport properties of undoped, silicon and magnesium doped $Al_xGa_{1-x}N$/GaN heterostructures by a combination of high resolution X-ray diffraction, atomic force microscopy, Hall effect, C-V profiling and Shubnikov-de Haas measurements. The investigated samples with N- and Ga-face polarity were grown by metalorganic vapor phase deposition (MOCVD) or plasma induced molecular beam epitaxy (PIMBE) covering a broad range of alloy compositions, barrier and quantum well thicknesses.

The calculated polarization induced sheet charges based on improved sets of pyroelectric and piezoelectric constants and the sheet carrier concentration for 2DEGs and 2DHGs determined self-consistently from a coupled Schrödinger and Poisson equation will be presented and compared to the experimental values. The influence and relevance of the determined carrier distributions on the performance of AlGaN/GaN based polarization induced HEMTs and tunneling diodes will be discussed. The patterning and etching processes used to realize these electronic devices and their influence on the physical properties of polar GaN and AlGaN surfaces will be presented. The outstanding performance PI-HEMTs with transit velocity values of 1.32×10^7 cm/s, cut off frequencies of up to $f_T = 76$ GHz for 150 nm gate length and an output power of 4 W/mm at X-band will be demonstrated. In addition the first microwave amplifier build by a combination of 4x4 AlGaN/GaN PI-HEMTs will be compared with AlGaN/GaN large periphery devices as presented in the literature reaching total output powers of 21 W at 8-12 GHz under continuous wave operation.