Introduction to the Special Issue on GaN and Related Nitride Compound Device Reliability

THE PROPERTIES of III–V nitride heterostructures are attracting increasing attention for a wide range of device applications, including blue, green, and ultraviolet LEDs, short wavelength lasers, and high-power high-temperature high-frequency electronic devices. There are three important binary nitride materials: AlN, GaN, and InN. Among these, GaN shows great promise for microwave applications. The wide energy bandgap of GaN (3.43 eV as compared to 1.4 eV for GaAs) leads to low intrinsic carrier concentration over a wide range of temperatures. This, in turn, allows GaN-based devices to be operable at high temperatures. Moreover, this wide bandgap allows very high electric breakdown fields (1.5×10^7 V/m as compared to 2.5×10^5 V/m for GaAs). As a result, GaN-based devices can be biased at very high drain voltages (breakdown voltage $= 50-500$ V, depending on the application), and because of the large thermal conductivity of GaN ($1.7\ \mathrm{W/cm \cdot K}$ as compared to $0.46\ \mathrm{W/cm \cdot K}$ for GaAs), the channel temperature can reach 300 °C.

Even though the low-field mobility is not high (the best value reported so far for GaN is about $2000\ \mathrm{cm^2/V \cdot s}$ as compared to a value of about $8500\ \mathrm{cm^2/V \cdot s}$ for GaAs), it is not very sensitive to an ionized impurity concentration. Furthermore, a larger peak velocity can be reached (2.7×10^7 cm/s at room temperature as compared to 1.5×10^7 cm/s for GaAs), which permits high currents and high operating frequencies. The energy bandgap difference between AlN and GaN is also quite significant (e.g., 2.57 eV as compared to 0.73 eV for GaAs and AlAs), which permits high concentrations of free carriers to be confined at the AlGaN/GaN heterointerface, paving the way for the high-performance AlGaN/GaN high-electron mobility transistor (HEMT).

GaN-based microwave power HEMTs have defined the state of the art for output power density, and they have the potential to replace GaAs-based transistors for a number of high-power applications. The GaN-based material system, GaN has a breakdown field that is estimated to be 3 MV/cm, which is ten times larger than that of GaAs, and a high peak electron velocity of 2.7×10^7 cm/s. As a result of these properties, excellent high-frequency high-power performance has been achieved with GaN-based HEMTs. Although significant progress has been made in the past few years, reliability and degradation remain as significant obstacles to further device development. One area of active reliability research deals with the reduction of trap effects in GaN-based devices. Historically, a variety of trap effects have been observed. These include transconductance frequency dispersion, current collapse of the drain characteristics, light sensitivity, gate- and drain-lag transients, and restricted microwave power output. In AlGaN/GaN HEMTs, the parasitic charge moving in and out of the traps on the surface and/or in the bulk of the heterostructure affects the density of the 2DEG in the channel, causing effects such as current collapse, and transconductance frequency dispersion. The characteristic time of the recharging process in GaN ranges between nanoseconds and seconds. As a result, the trapping effects can limit device performance even at relatively low frequencies.

In addition, the thermally activated traps contribute significantly to the device low-frequency noise. Understanding the origin of the traps in GaN-based transistors, their locations, and the physical mechanisms involved in the trapping is important for the optimization of device reliability. The inconsistency existing in the field is largely related to the diversity of the trapping effects in GaN and its varying material quality. GaN contains high densities of defects and dislocations formed during the growth due to the large difference in lattice constants and thermal expansion coefficients of the substrate and the epilayers. The defects and dislocations can potentially act as the charge carrier traps, creating localized levels inside the bandgap. In addition, it is believed that the surface of the material contains a large density ($> 10^{13}\ \mathrm{cm^{-2}}$) of donorlike states [3]. Whereas the majority of the trapping effects result in similar degradation of the transistor characteristics at high frequencies, the dominating trapping mechanisms could vary in devices grown by different methods or subjected to different processing procedures. It is essential, therefore, that any characterization method differentiates between various trapping centers.

This Special Issue of T-DMR then becomes a very timely contribution to our attempt to understand the degradation mechanisms of GaN-based devices. The nine articles offer a comprehensive report on the current status of GaN device reliability. The selected articles start with a discussion of the mechanisms of RF current collapse and a review of the reliability of GaN-based LEDs. The editors recognize that additional articles could have been included in this Special Issue, but due to space constraints, the main emphasis has been placed on the reliability of HFETs and LEDs.

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Digital Object Identifier 10.1109/TDMR.2008.925989