Low-resistance GaN Homojunction Tunnel Diodes and Low Voltage Drop Tunnel Contacts

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The III-nitride material system is promising for optoelectronic and electronic applications. There have been continuing efforts in the development of GaN-based tunnel junctions (TJs) as one of the main remaining challenges in III-nitride materials, which can enable the next generation of III-nitride devices. The TJ can significantly improve the efficiency of visible and ultraviolet emitters as well as solar cells. However, achieving GaN-based TJs are extremely challenging due to the large band gap and the low hole concentration typical in GaN.

In this work, for the first time, we present a high-conductance GaN homojunction tunnel diode with a distinctive negative differential resistance (NDR) at a forward bias of 1.35 V and an intrinsic reverse Zener characteristic grown via metal modulated epitaxy (MME). The most recent achievements in the growth of extremely high doped GaN materials are also presented. In addition, the effect of the Mg doping concentration on the carrier transport of the TJs is studied, showing an increase in the forward and reverse tunneling current densities, the peak-to-valley ratio (PVR), and the NDR peak voltage by increasing the Mg doping concentration. In particular, the TJ using Mg and Si doping concentrations of 5×10^{20} and 7×10^{20} cm^{-3} shows a current density of 400 A/cm^2 at -1.2 V and PVR of ~1.1. Furthermore, the temperature dependent current-voltage (I-V) characteristics of the TJ are discussed to provide insight into the nature of the tunneling behavior in the wide bandgap GaN. We present defect-assisted tunneling as the main carrier transport mechanism rather than interband tunneling. The low-temperature I-V characteristics of the best-performing TJ revealed repeatable NDR features with no hysteresis and PVR of ~1.3, which indicates a minimal carrier freeze-out in the GaN: Mg (see Fig 1).

The highest silicon-doped n++/p++/i/n tunnel-contacted diode demonstrates a turn-on voltage of 3.12 V, only 0.14 V higher than that of the p/i/n control diode, and an improved specific on-resistance of 3.24×10^{-4} Ωcm^2, which is 13% lower than that of the control diode. Finally, recent results on low-resistance TJ contacts to LEDs with minimal voltage drop and the first demonstration of InGaN solar cells with *p-n* GaN homojunction tunnel contacts with an open-circuit voltage of ~2.2 V are presented.

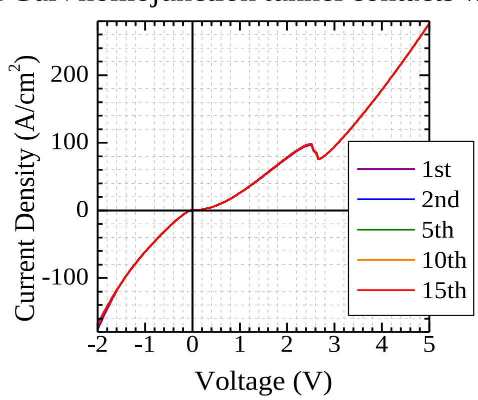

Figure 1. Current-voltage characteristics of a GaN homojunction tunnel diode at 77 k with multiple voltage sweeps.

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Supplementary Pages

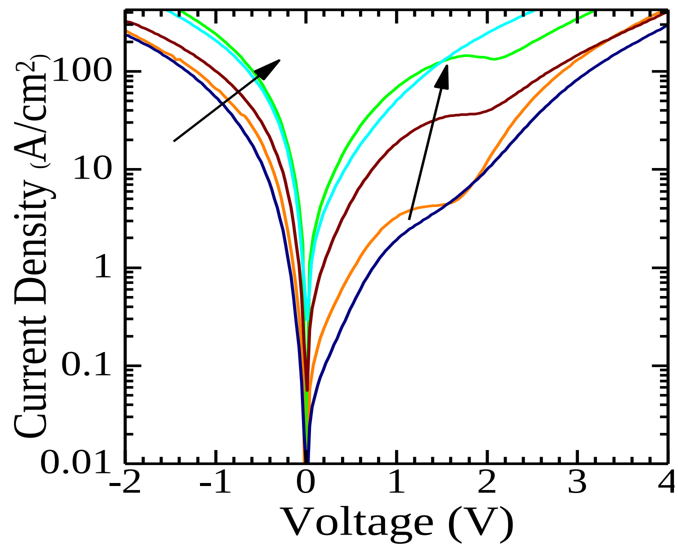

Figure 2. J-V characteristics of p-n homo junction tunnel diodes with different Mg concentrations showing an increase in the current density by increasing the Mg concentration.

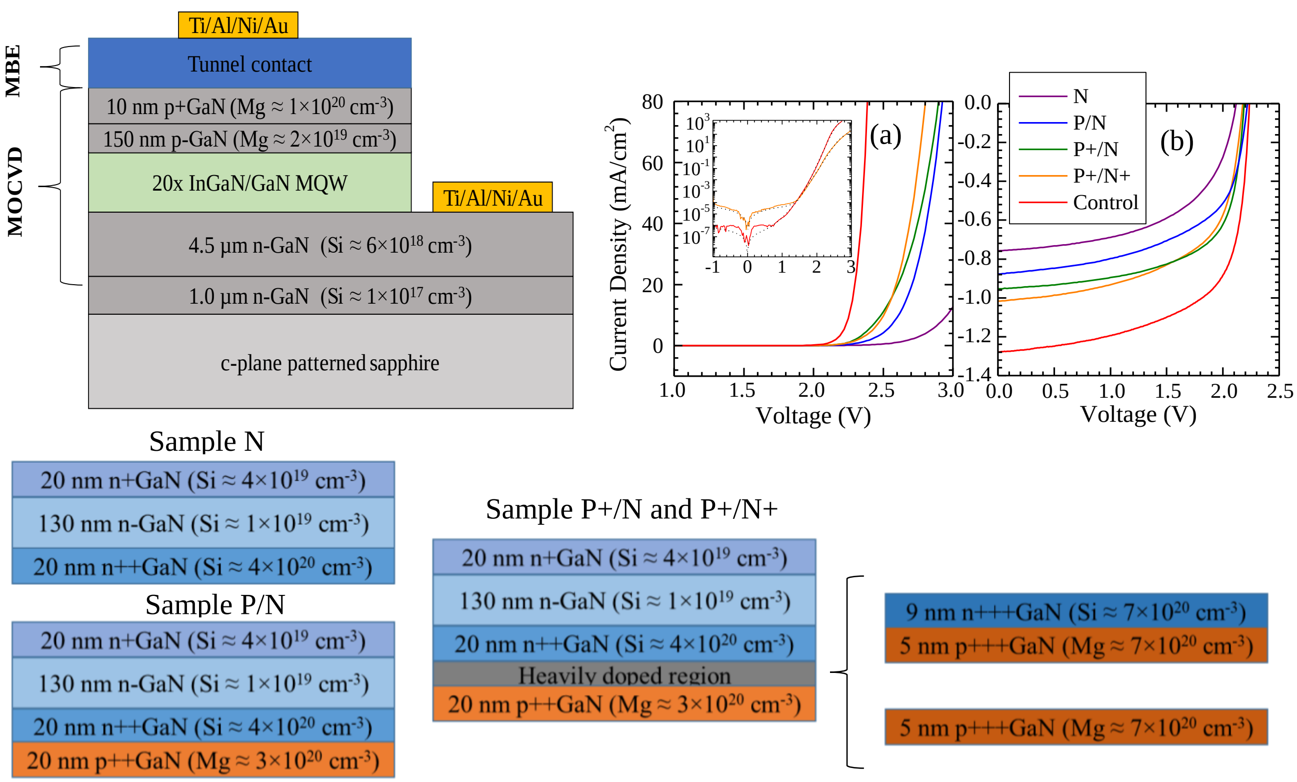

Fig. 3. Left: device structure of an $In_{0.12}GaN$/GaN solar cell with a TJ contact. The TJ contact layer represents four different p-n structures. Right: (a) dark J-V and (b) light J-V characteristics of all the samples. Bottom: the TJ structures used i the InGaN solar cells.