Room temperature electrically detected magnetic resonance of performance limiting defects in GaN pn junction diodes

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In order to utilize any semiconductor material, it is important to understand the physical and chemical nature of its most important electrically active defects. Multiple studies have been reported on defects in GaN but direct experiment evidence linking specific defect structures to their properties is very limited. Electrically detected magnetic resonance (EDMR) along with conventional electron paramagnetic resonance (EPR) has unrivaled analytical power for identifying point defects. However, EDMR has many orders of magnitude greater sensitivity than conventional EPR [1-2]. In this work, we report on the EDMR detection of an important defect in GaN devices with detailed observation of hyperfine structure. These observations involve room temperature EDMR measurements of GaN pn diodes. The measurements involved device active region of $<10^{-7}$ cm^3. There have been longstanding sensitivity barriers which have limited the application of magnetic resonance techniques on III-V materials. This work may have cleared a path to identifying point defects in a variety of III-V devices. The first and second derivative EDMR signal shown in figure 1 was obtained on a GaN pn junction diode at room temperature with 3.05 V forward bias (**B** ⊥ c). The EDMR signal has a $g \approx 2.005$, and a rich, partially resolved hyperfine structure consisting of 10 lines. These are the first reported room temperature EDMR or EPR results reported on GaN devices. In figure 1, we show a model calculation involving an unpaired electron shared with three equivalent Ga nuclei with 60% ^{69}Ga and 40% ^{71}Ga and a hyperfine coupling constant of 32.1 G and 44.4 G, respectively. The hyperfine structure is similar to the previously observed L1 center in undoped GaN irradiated by 2.5 MeV electrons reported by Watkins et al. [3].

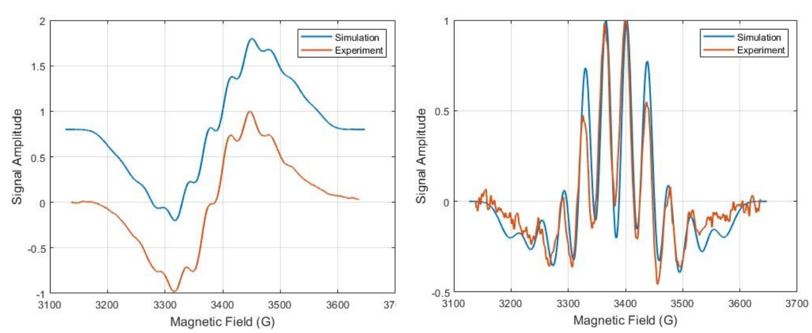

Figure 1. (left) Experimental EDMR spectrum (orange) and the simulation (blue). (right) Second derivative EDMR spectrum and simulation

[1] N. J. Harmon et al., IEEE Trans. Nuc. Sci., **67**, 1669, (2020).

[2] E. B. Frantz et al, J. Appl. Phys., **130**, (2021).

[3] G. D. Watkins et al., Phys. B: Condens. Matter, 308-310, **62**, (2001).

Supplementary Information:

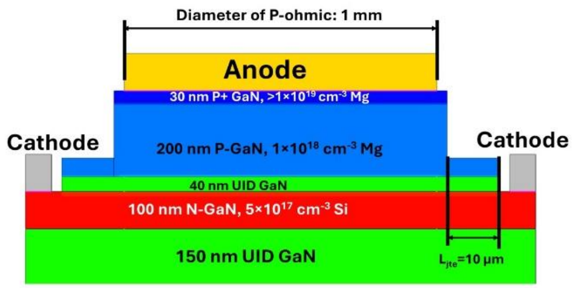

Figure 2. Schematic diagram of the GaN pn junction diode utilized.

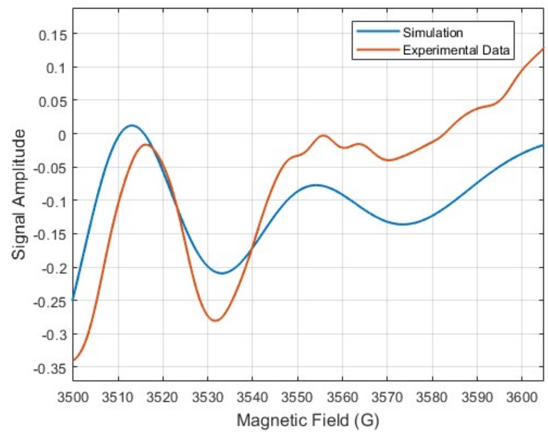

Figure 3. Second derivative EDMR of the two outer peaks on the right side for the GaN pn junction diode at 3.05V forward bias and room temperature.

The GaN pn junction diode utilized in this study has a doping concentration is $>10^{19}$ cm^{-3} Mg for the p-side and $5x10^{17}$ cm^{-3} Si for the n-side. The device has a 40 nm unintentionally doped (UID) GaN spacer between the n and p-doped regions. The EDMR spectrum was obtained with 1.6 kHz modulation frequency and 15 G modulation amplitude. In GaN, there are two Ga isotopes with nuclear spin I = 3/2 and natural abundance of ^{69}Ga = 60% and ^{71}Ga = 40%, and ^{14}N isotope with nuclear spin I = 1 and 100% natural abundance. Additional hyperfine contribution may arise from the Mg doping as ^{25}Mg has a nuclear spin I = 5/2 and natural abundance of 10% or impurities such as C and H which may account for differences between our model and experiment. In our pn junction diode, the EDMR phenomena detected is spin-dependent recombination.