Hydrogen role in GaN based semiconductors: ToF SIMS profiles and resistance study.

S. Vangelista[a*], M. Perego[b], G. Seguini[b], A. Pulici[b], C. Wiemer[b], S. Spadoni[a], L. Livellara[a], R. Pezzuto[a], F. Iucolano[a], C. Tringali[a], P. Colpani[a]

[a]STMicroelectronics, Technology R&D, Via C. Olivetti 2, 20864 Agrate Brianza (MB), Italy
[b]IMM-CNR, Unit of Agrate Brianza, Via C. Olivetti 2, 20864 Agrate Brianza (MB), Italy

In recent years, the demand for electric power has been on the rise, leading to a shift in focus towards wide band semiconductors (WBG), such as gallium nitride (GaN) and its related alloys. One of the most interesting aspects of GaN materials is the ability to grow AlGaN/GaN heterostructures, which form a two-dimensional electron gas (2DEG) and allow for the design of AlGaN/GaN high electron mobility transistors (HEMT) structures. However, a major challenge with this technology is its normally-ON nature, which limits its applications. To improve system reliability, normally OFF HEMTs are highly desirable. One method to achieve this goal is to grow a p-type cap layer (pGaN) using magnesium (Mg) as the most used acceptor [1]. Mg-doped GaN is grown using metalorganic vapor deposition (MOCVD), with metalorganics and organic compounds and hydrides as precursors (ammonia NH_3, Trimethylgallium - TMGa, and biscyclopentadienyl-magnesium - Cp_2Mg), and the growth usually occurs in H_2 ambient. This results in the presence of Mg-H and atomic H, which significantly increase the resistance of Mg-doped GaN due to the deactivation of Mg [2]. To activate Mg impurities, thermal annealing is required, which induces hydrogen dissociation from the Mg-H complex in the Mg-doped GaN layers.

Despite the known mechanism, there have been only a few quantitative experimental investigations on the relationship between the amount of hydrogen dissociated from Mg-doped GaN and the electronic properties of the p-GaN. This study aims to address this gap by correlating the role of hydrogen in the thermal activation process of Mg-doped GaN and the resistivity variation of p-GaN, as a function of temperature up to 800°C. Time-of-flight secondary ion mass spectrometry (ToF-SIMS) was used to evaluate the Mg and H depth profiles, and Hall measurements were adopted to investigate the conductive properties of the annealed samples. Through the optimization of ToF-SIMS acquisition protocols (Fig.1), we were able to improve the detection limit of hydrogen and correlate its concentration values with the GaN electronic properties. Specifically, our study utilized Hall measurements and sheet resistance measurements in a Van Der Pauw configuration (Fig. 2) to investigate the activation rate of dopant impurities and their correlation with hydrogen content. Our findings suggest that the activation rate of dopant impurities is not strictly correlated with the concentration of hydrogen present.

These findings have important implications for the development of normally OFF HEMTs and the wider field of WBG semiconductors.

References

1. Nardo et al J. Phys. D: Appl. Phys. **55** 185104 (2022)
2. S. J. Pearton, A. Y. Polyakov, Chem. Vap. Deposition, **16**: 266-274 (2010)
3. Y. Nakagawa et al., Japanese Journal of Applied Physics, **43(1R)** 23 (2004)

* *corresponding author e-mail: silvia.vangelista@st.com*

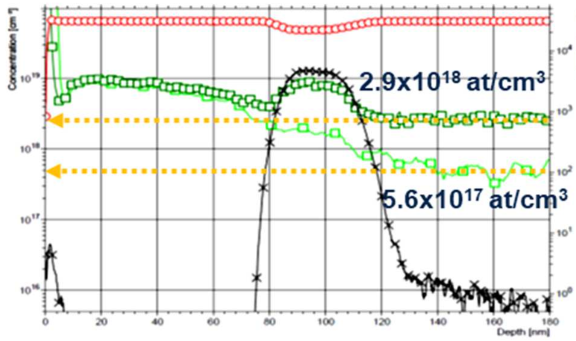

Fig. 1: *H^- concentration profile in the as grown sample obtained by TOF-SIMS analysis operating in interlace mode (light green open symbols) and not interlace-mode (dark green open symbols).*

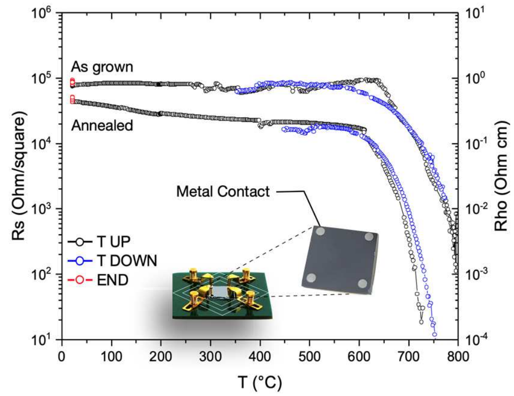

Fig. 2: *Evolution of sheet resistance (Rs) as a function of temperature for the as grown and annealed samples. Measurements were performed in Van der Pauw configuration as shown in the inset.*