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Elemental Quantification and Visualization of GaN Structures using APT and SIMS

A. D. Giddings[1], T. J. Prosa[1], A. Merkulov[2], F. A. Stevie[3], H. G. Francois-Saint-Cyr[1], N. G. Young[4], J. S. Speck[4] and D. J. Larson[1]

1. CAMECA Instruments Inc., 5500 Nobel Drive, Madison, WI 53711, USA.
2. CAMECA SAS, 29 Quai des Grésillons, 92622 Gennevilliers Cedex, France.
3. North Carolina State University, 2410 Campus Shore Drive, Raleigh, NC 27695, USA.
4. Department of Materials, University of California, Santa Barbara, CA 93106, USA.

The in-depth knowledge of focused ion beam (FIB) specimen preparation combined with the sustained development of laser-pulsed atom probe tomography (APT) in the past decade has led to a rapid expansion of applications [1, 2]. However, apart from in a limited number of structures, for example dopants of B, P, and As in Si [3], standard protocols for quantification for a broad range of materials have not yet been defined [4, 5].

GaN devices are of importance to many microelectronic and photovoltaic applications, particularly light-emitting diode (LED) production. The goal of the current work is obtain quantitative data for a GaN laser structure which typically has Mg and Si as p- and n- dopants, respectively, in addition to other elements at a matrix level, such as Al. Comparisons are made to secondary ion mass spectrometry (SIMS), which is a well-known method for quantifying ion implanted standards in various matrices.

Ion implanted standards in GaN were obtained for the dopant, ^{24}Mg, in GaAs as well as two other impurity elements, ^{27}Al and ^{23}Na. With the aid of implant depth simulations [6], the GaN wafer was designed to have two InGaN quantum wells (QWs) situated below the peak implant position. Figure 1a shows a schematic of the structure. Figure 1b is a bright field transmission electron microscopy (TEM) micrograph of the grown material with an inset showing a close up of the two InGaN QWs. These layers provided a scale marker to understand and to calibrate the APT depth scaling, which was then compared to SIMS. Moreover, in order to help obtain quantitative matrix species information, a high-dose implant of Al in GaAs with peak concentration of about 2% atomic was also prepared.

All specimens for APT analysis were prepared by FIB techniques [2]. An additional low-temperature GaN film was deposited on the post-implant specimen prior to lift-out to act as a protective cap, allowing the full volume of the implanted region to be measured by APT. The implanted isotopes were chosen to have distinct mass-to-charge ratios without overlaps in the mass-spectrum. Figure 2a shows atom maps of the target wafer and the three implanted species. The peak implant depth was in concordance with the expectation from the simulations.

SIMS analysis on the samples showed expected depth profiles and provided an accurate measurement for comparison with the atom probe data. In figure 2b, the SIMS data is overlaid on the APT 1D profile (which has been adjusted for background and N deficit [7]). After these corrections, the atom probe analysis achieved a quantification level for a volume of 2.5×10^{-17} cm^3 of less than 2×10^{19} atoms/cm^3 (0.02%) for all the implanted species. This cross-correlation not only assists with the understanding of APT quantification of GaN materials, but could also be extended into a methodology to help generate SIMS relative sensitivity factors.

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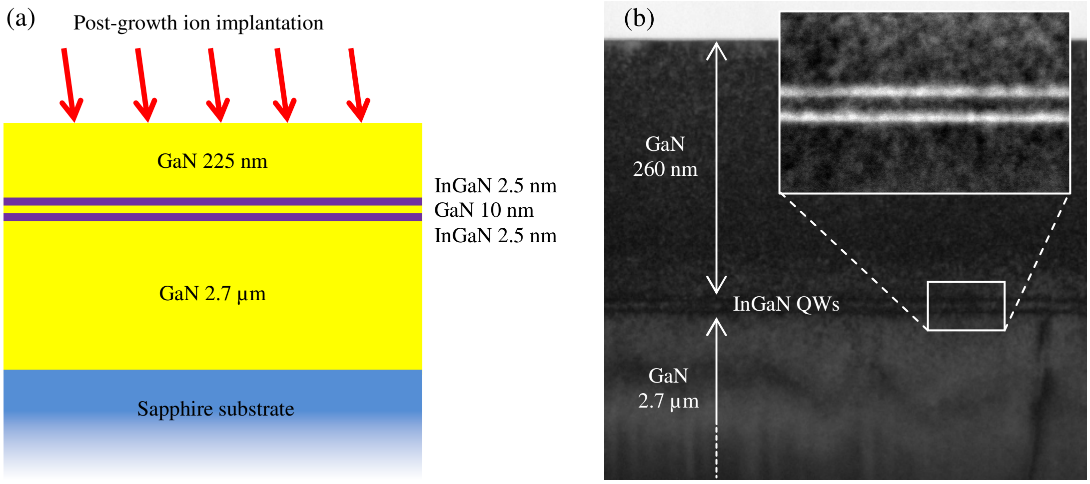

Figure 1. (a) Schematic of GaN sample structure (not to scale). (b) Bright-field (greater atomic number appears darker) TEM micrograph showing the overall structure of the region of interest and the position of QWs inside the GaN layer; inset shows a high-angle annular dark-field (greater atomic number appears lighter) imaging scanning TEM close-up of the two InGaN QWs.

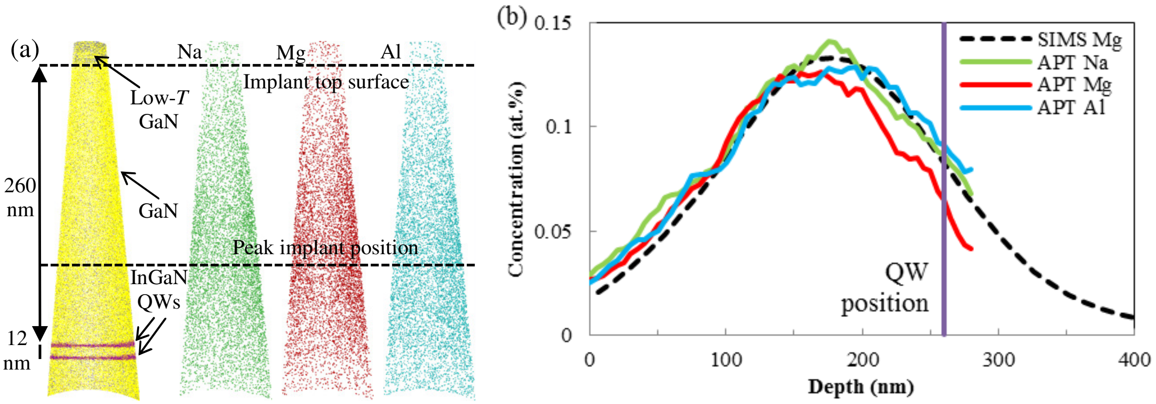

Figure 2. (a) APT atom map showing position of detected Ga and In ions (left-most) and Al, Na and Mg implant ions (right). (b) 1D concentration profile of the implant ions sampled from the 40 nm cylinder, subdivided into 5 nm bins, through the center of the reconstructed volume in (a), with the Mg implant profile measured by SIMS overlaid.