Functional Materials

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Aberration corrected TEM and Super-X STEM-EDXS characterization of high electron mobility transistor structures

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GaN based high electron mobility transistor (HEMT) devices provide an outstanding performance for high frequency and high power applications as used in radar and next generation mobile telecommunication systems. The devices are based on GaN/AlGaN heterostructures with high mobility of charge carriers. The electron channel is contacted by ohmic source and drain metal structures. The channel switching is realized by a metal gate structure forming a Schottky contact to the upper AlGaN layer. The performance of the devices is strongly related to crystal defects and impurities within the epitaxial grown heterostructure, the interface perfection of the AlGaN/GaN electron channel and the metal/semiconductor interfaces of the gate. Furthermore structural and chemical changes during accelerated aging tests lead to a degradation of the electrical performance of such devices. Knowledge of reactions especially at the metallic gate is essential to understand the degradation mechanisms. In order to characterize the relevant hetero layer and interfaces, high resolution techniques for atomic level imaging and chemical analysis are required.

New developed TEM techniques allow aberration corrected imaging and superior sensitivity for STEM-EDXS analysis by new Super-X detectors with high acceptance angles. The new Super-X detector has been evaluated and applied to characterizing GaN-HEMT test structures before and after defined electrical treatment. Aged samples were selected by their electrical behavior after testing and potential defect sites under the gate were localized by emission microscopy. Electron transparent TEM cross sections were extracted from defect and reference positions by using focused ion beam (FIB) milling techniques. The lamellas were transferred in situ within a crossbeam system into self-made TEM grids with adapted clip holders for fixing the lamella (Figure 1a) [1]. To minimize sidewall defects and to further reduce lamella thickness all lamellas were finally polished by low energy FIB milling. Sample thicknesses lower than 80nm are regularly achieved using dedicated SEM based thickness mappings [2]. TEM investigations were performed at 300kV with an aberration corrected microscope (Titan G2 60-300, FEI) equipped with a high sensitive EDXS system (Super-X, FEI).

The gates are produced by depositing metal layer stacks onto the semiconductor surface where the SiN dielectric has been opened beforehand. The gate structure consists of layers of Nickel, Platinum and Gold. In the studied structures, metals grow with their (111) planes parallel to the flat GaN substrate surface. It was found that during the accelerated aging test a rough interface evolves (Figure 2), often starting at the edges of the gate semiconductor interface where pores are formed during the degradation. Thanks to the aberration correction imaging structures can be imaged without delocalization at the interfaces. Due to the sample thickness the superposition of lattice structures stays visible (Figure 2b). As a consequence of the electrical stress, interdiffusion of the metals can be identified. The gold tends to diffuse to the surfaces of the gate next to the GaN and SiN (Figure 3b). With the sensitivity of the new Super-X EDXS system in combination with the lateral resolution of the STEM it is possible to detect monolayers of impurities at the interfaces.

It is shown that the improved performance of the imaging and analytical TEM techniques gives a better insight into the microstructure of the GaN-HEMT transistor structures. It offers new possibilities to visualize load and aging related defects. These results can help to improve the performance, lifetime and reliability of GaN-HEMT devices by optimization of the manufacturing processes.

1. Altmann et al., Microscopy Microanalysis, 2011, 17 (Suppl 2), 626-627
2. Salzer et al., Microscopy Microanalysis, 2010, 16 (Suppl 2), 172-173

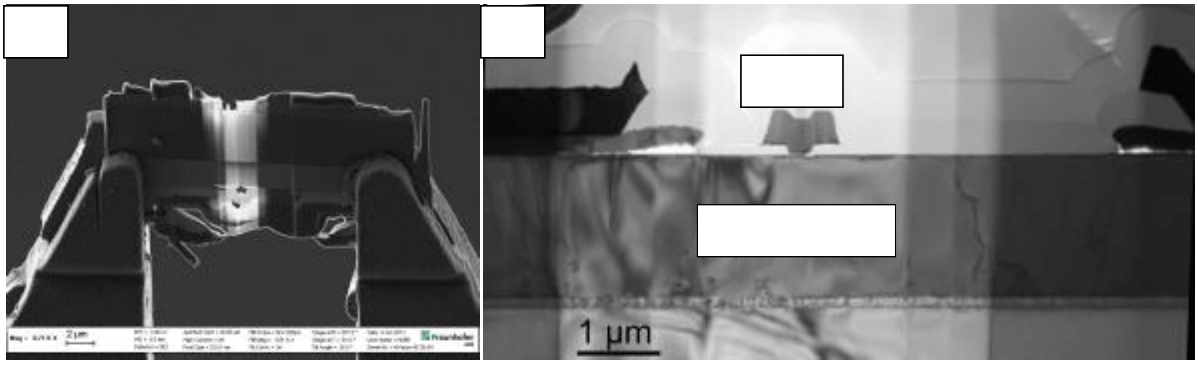

Figure 1. TEM cross section of a GaN transistor. a) FIB prepared sample in a special TEM magazine holder; b) TEM overview of the sample

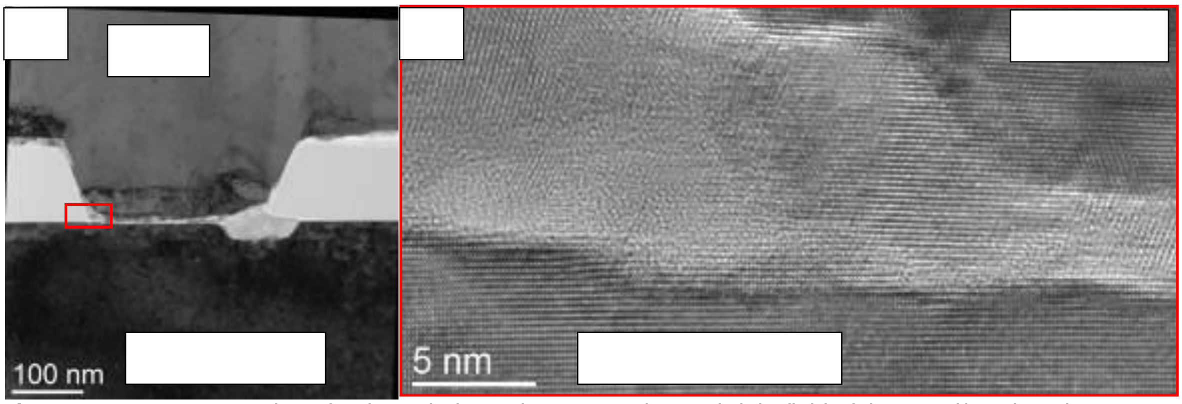

Figure 2. TEM cross section of a degraded transistor gate. a) TEM bright field of the metal/semiconductor interface; b) HRTEM detail of the left edge

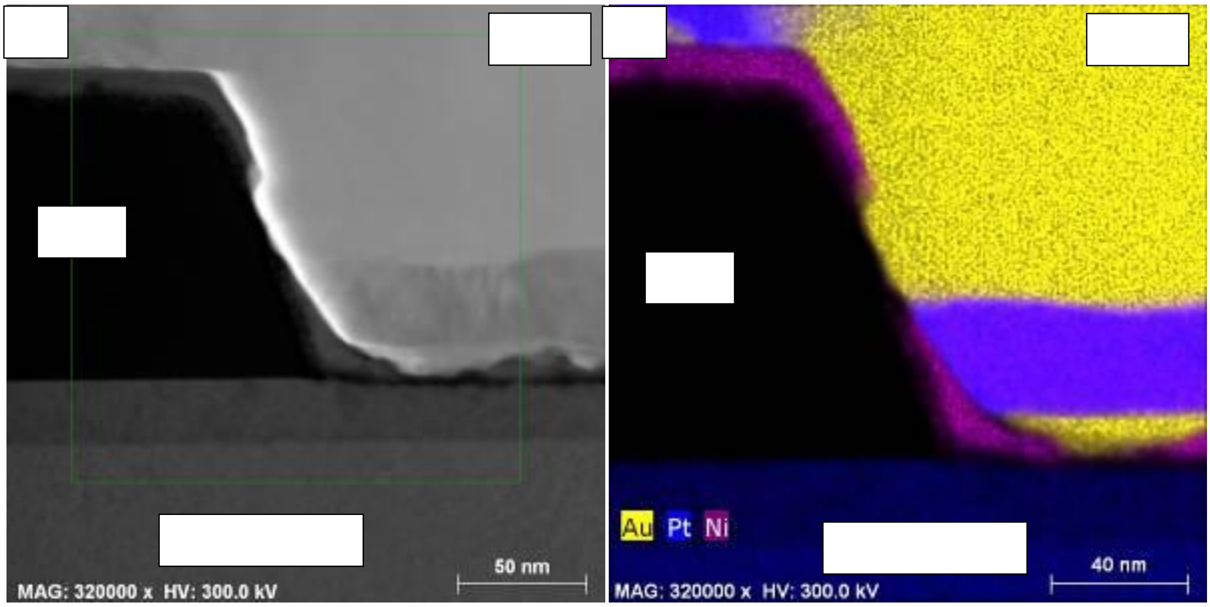

Figure 3. TEM cross section of a degraded transistor gate. a) STEM image of the left part of the gate; b) EDXS intensity map of characteristic X-rays of selected elements.