Correlation of polarity and crystal structure with optoelectronic and transport properties of GaN/AlN/GaN nanowire sensors

[1]**M. DEN HERTOG***, [2]F. GONZALEZ-POSADA, [1]R. SONGMUANG, [2]J.L. ROUVIERE AND [2]E. MONROY

[1] *INSTITUT NEEL-CNRS, 25 rue des Martyrs, 38042 Grenoble cedex 9, France*

[2] *CEA-GRENOBLE, INAC / SP2M, 17 rue des Martyrs, 38054 Grenoble cedex 9, France*

e-mail: martien.den-hertog@grenoble.cnrs.fr

Semiconductor nanowires (NWs) are promising candidates for many device applications ranging from electronics and optoelectronics to energy conversion and spintronics. Their large surface-to-volume ratio can be used advantageously in sensor applications where especially the chemical inertness and robustness of GaN are highly desirable characteristics, enabling device operation in extreme environments such as high temperature, radiation and extreme pH levels.

In this work, we correlate the crystal structure and heterostructure measured by scanning transmission electron microscopy (STEM) and the photodetector performance of defect-free GaN-AlN NW heterostructures on the level of a single NW, paying particular attention to the impact of the measuring environment on the electronic transport and photocurrent dynamics. The effects of GaN/AlN heterostructure engineering and surface states are discussed.

GaN NWs are grown by plasma-assisted MBE on Si(111) [1]. They have a length of 1.2–1.5 μm and a diameter of 30−80 nm. Individual NWs were dispersed on electron transparent Si_3N_4 membranes and contacted using e-beam lithography.

Using aberration-corrected annular bright field (ABF) and high angle annular dark field (HAADF) STEM, we identify the NW growth axis to be the N-polar [000−1] direction (Fig. 1). The electrical transport characteristics of the NWs are explained by the polarization-induced asymmetric potential profile and by the presence of an AlN/GaN shell around the GaN base of the wire. The AlN insertion blocks the electron flow through the GaN core, confining the current to the radial GaN outer shell, close to the NW sidewalls, which increases the sensitivity of the photocurrent to the environment and in particular to the presence of oxygen. The desorption of oxygen adatoms in vacuum leads to a reduction of the nonradiative surface trap density, increasing both dark current and photocurrent [2].

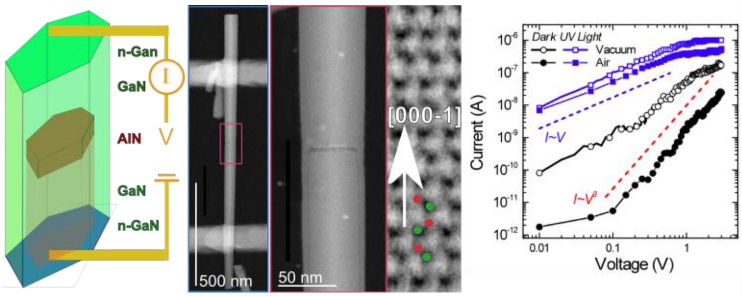

Fig. 1. From left to right: schematic of the NW structure, HAADF STEM image of a contacted GaN NW with an AlN insertion. Zoom of the boxed region viewed along the [11-20] direction. Atomic structure of GaN viewed along [11-20] overlaid on an ABF STEM image. $I-V$ characteristic from ***the same*** NW device measured in the air and in vacuum, in the dark and under UV illumination.

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