Nanowire-specific electrical doping regime

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Introduction of electrical dopant species in semiconductors generally results in increasing built-up strain for increasing dopant densities, till reaching the solubility limit and/or a strain relaxation stage associated with extended defect formation. By contrast doping in nanowires (NWs) obeys a specific regime, associated with their unique morphology. In the case of GaN NWs grown on Si (111) by molecular beam epitaxy, the eased strain relaxation due to the large amount of free surface favors the incorporation of Si dopant at concentrations higher than in layers [1]. Also, specific adatom surface diffusion and reconstruction-stabilized sidewall stoichiometry are affecting dopant incorporation. Hence, atom probe tomography [2] and energy-dispersive X-rays spectroscopy (EDX) [3] experiments at the nanoscale demonstrate that preferential Mg incorporation through the m-plane side walls of GaN NWs leads to a higher Mg density in the NW periphery, about ten times larger than in the NW core. Scanning spreading resistance microscopy (SSRM) experiments were performed to investigate the effect of inhomogeneous dopant distribution on the electrical transport properties of n-type and p-type GaN NWs at the nanoscale. In Si-doped GaN NWs a conductive core surrounded by a more resistive shell was put in evidence, which is assigned to the depletion resulting from Fermi level pinning on m-plane surface states. By contrast, in the case of Mg-doped GaN NWs, the SSRM is one order of magnitude smaller at the periphery than at the centre of the Mg-doped GaN. This experimentally demonstrates that peripheral Mg incorporation in GaN NWs indeed counterbalances the depletion resulting from Fermi level pinning on m-plane surface states, which results in preferential current flow in the highly doped shell. For the same samples as measured by SSRM, EDX reveals a Mg concentration of about 2-4 $\times$ 10^{20} /cm^3 in periphery, higher by more than one order of magnitude compared to the NW centre where the Mg content is below the experimental detection limit of 10^{19}/cm^3. The coexistence of these different electrical conduction channels, specific to NWs, opens new prospects on the full understanding of the opto-electrical properties of NW-based devices such as visible or UV light emitting diodes.

[1] Z. Fang et al, Nano Lett. 15, 6794 (2015)

[2] A.M. Siladie et al, Nanotechnology, 29, 255706 (2018)

[3] E. Aybeke et al, submitted