High Si incorporation in MBE-grown GaN nanowires

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This work reports on the structural and electrical properties of Si-doped GaN nanowires (NWs) grown by molecular beam epitaxy (MBE), with a typical length of 2-3 mm and a radius of 20-200 nm. A series of Si-doped GaN NWs were grown with the same growth conditions except for Si cell temperature. There is no visible morphology change with low Si doping. Upon higher Si doping, the radius of the NW is gradually increased while the length is decreased (Figure 1(a)). In the case of the most doped NWs, the radius continues to increase until reaching a certain equilibrium value, and then the wire elongates with a 12-fold symmetry of the top facet. A small but progressive tensile strain with increasing doping has been found by Raman spectroscopy, which has fully relaxed at the most heavily doped sample. With the purpose of mapping the Si content in nanoscale, NWs from two samples with high Si doping (Si cell temperature of 938°C and 950°C) have been analyzed by EDX in a SEM and TEM (Figure 1(b-d)), separately. The measured Si concentrations from two techniques are similar. The NWs grown with the highest Si cell temperature have a core with Si concentration ranging from 2-4 x 10^{20} at/cm^3 with a Si enriched outer part up to 10^{21} at/cm^3. For high Si cell temperature (938°C), both techniques have shown a relatively constant Si concentration throughout the NW with an average value of 10^{20} at/cm^3, as a clue of a larger solubility limit of Si in NWs compared to two-dimensional layers. Furthermore, we have performed electrical transport measurements (four probe resistivity and resistivity temperature dependence) on this series of NWs. Four probe resistivity measurements have shown a controlled doping level with resistivity from 10^2 to 10^{-3} Ý.cm, corresponding to non-intentionally doped (NID) and the highly doped samples, respectively (Figure 1(e)). Resistivity temperature dependence measurements down to 5K reveal a semiconducting behavior for the NID and lowly doped GaN NWs, a metallic behavior for more doped NWs. This implies a carrier concentration from 10^{17} to 10^{20} cm^{-3}, which is consistent with the high doping level previously achieved on microwires[5].

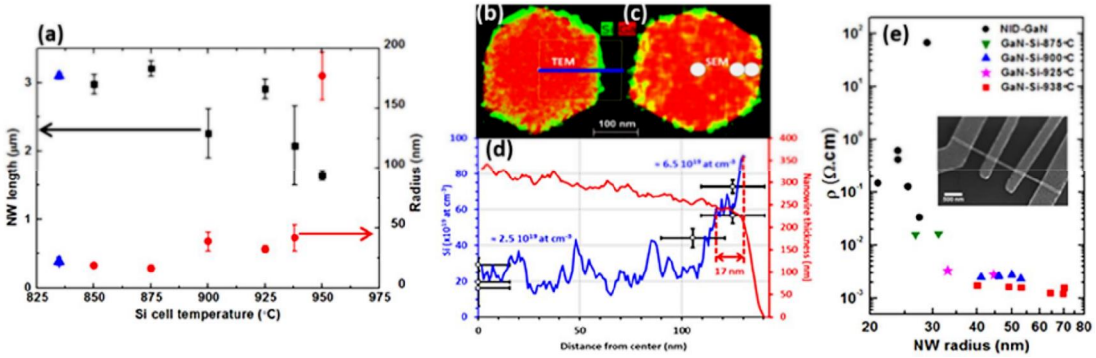

Figure 1: (a) NW length (left axis) and NW radius (right axis) of samples grown upon different Si cell temperatures, the blue data points correspond to the length and radius of the NID NWs. EDX maps of two NWs grown with highest Si cell temperature obtained: (b) at 200 kV using a FEI Osiris TEM and (c) at 4 kV using a ZEISS Ultra 55 SEM. Green and red colors correspond to Si and Ga, respectively. Si concentrations were computed for STEM EDX data (blue line profile in (d)) and for the SEM EDX data (white circles in (d)). The NW thickness of the STEM observation is shown on the red curve in (d). (e) Room temperature four-probe resistivity versus NW radius of samples ranging from NID to the highly doped ones, and a SEM image of one contacted NW is included in the inset.

References

[1]P. Tchoulfian et al. Appl. Phys. Lett. 102, 122116 (2013); Appl. Phys. Lett. 103, 202101 (2013)