Carbon in Highly Conductive and Semi-insulating Bulk GaN Crystals

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Halide Vapor Phase Epitaxy (HVPE) is the most common approach for manufacturing gallium nitride (GaN) substrates. The main advantages of this technique are: a relatively high growth rate (>100 μm/h) and the possibility to obtain high-purity material (residual donors and acceptors concentrations are lower than 10^{16} cm^{-3}). Silicon (Si) or iron (Fe), manganese (Mn) and carbon (C) are used as main dopants for crystallizing, respectively, highly conducting (n-type) or semi-insulating (SI) HVPE-GaN crystals [1].

When C substitutes Ga (C_{Ga}) it acts as a deep acceptor and the resistivity of C-doped HVPE-GaN exceeds 10^8 Ωcm at room temperature [2]. A detailed analysis of C in bulk crystals showed that it can be self-compensated [3]. The compensation ratio depends on the C concentration and for its high value (>10^{19} cm^{-3}) the compensation can even reach 1. This means that C, or C-related complexes, can act both as acceptors and donors. Although a lot of research was devoted to C in GaN, a comparison of this dopant in n-type and SI bulk material has not yet been presented. Therefore, in this paper HVPE-GaN crystals co-doped with Si and C as well as Mn and C are studied in detail.

Native ammonothermal seeds of the highest structural quality were used in the HVPE experiments. The morphology, structural quality and growth rate of the co-doped crystals were analyzed applying optical microscopy and X-ray diffraction. Secondary ion mass spectrometry was used to investigate the concentrations of the dopants as well as all the impurities in the crystals. The crystals were also examined in terms of their optical, and electrical properties. For that purpose different characterization methods: Raman spectroscopy, low-temperature photoluminescence and Hall van der Pauw measurements, were applied.

In the HVPE-GaN:Si,C crystals the C concentration was always kept lower than that of Si. The crystallized material was n-type. In the case of HVPE-GaN:Mn,C the concentration of C was higher than that of Mn. The material was semi-insulating at room temperature, but p-type conductivity was revealed in high-temperature measurements.

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