Advanced electron microscopy of Fe-N precipitates in epitaxial GaN layers

A. Kovács1, T. Kasama1, M. Beleggia1, R.E. Dunin-Borkowski1, A. Navarro-Quezada2, B. Faina3, A. Bonanni3 and T. Dietl1,4

1Center for Electron Nanoscopy, Technical University of Denmark, Kgs.Lynghby 2800, Denmark
2Institute of Semiconductor and Solid State Physics, J. Kepler University, Linz, Austria
3Institute of Physics, Polish Academy of Sciences, Warsaw, Poland and 4Institute of Theoretical Physics, University of Warsaw, Poland

The work was supported by the FunDMS Advanced Grant of the European Research Council within the “Ideas” 7th Framework Programme of the EC.

Introduction

The origin of ferromagnetism in transition metal (TM) doped semiconductor arsenides, oxides and nitrides is highly controversial. Recent studies have underlined the need to understand the incorporation of magnetic ions into the host lattice [1], i.e., to study at the nanoscale whether the material is a dilute magnetic alloy, whether magnetic dopants have aggregated to form coherent TM-rich regions, or there is precipitation of secondary magnetic phases. In this work, we employ advanced transmission electron microscopy (TEM) techniques to study the local structural, chemical and magnetic properties of Fe-doped GaN epitaxial layers.

Fe-doped GaN

Fe-doped GaN layers were grown by metalorganic chemical vapour deposition on (001) plane sapphire at a substrate temperature of 950°C. The growth conditions, the effect of growth parameters and the results of magnetic measurements are described elsewhere [3].

Structure characterisation

Cross-sectional (GaFeN) samples were prepared using mechanical polishing and Ar ion milling with a Fischione 1010 system. Each cross-sectional specimen was finished by low-energy Ar ion milling at 500 eV in order to minimize sample damage.

TEM studies were carried out using FEI Tecnai G2 and FEI Titan microscopes, with the latter equipped with a monochromator, energy dispersive x-ray spectroscopy, electron energy-loss spectroscopy, probe aberration corrector and a biprism for electron holography.

For low-temperature studies, a LN2 cooling TEM specimen holder was used. Fe-N precipitates in the GaN matrix were observed using several TEM techniques. Precipitates larger than 10 nm were associated with voids, while particles without voids typically had sizes of ≈5 nm.

The precipitates were identified as hexagonal ε-Fe3N (space group 182, a=0.474 nm c=0.48 nm). They were in epitaxial with the GaN with GaN[100]||Fe3N[110]||(0001). The ε-Fe3N [210] viewing direction was used to determine the lattice parameters of the particles along the b- and c- directions as 0.458 and 0.430 ± 0.002 nm, respectively. The lattice spacings are smaller than those reported in the literature. However, ε-Fe3N is known to show a strong variation in lattice parameter with nitrogen content [4].

References