Electron microscopy of nano-inclusion formation in (Ga,Mn)As magnetic semiconductors

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The origin of ferromagnetism in transition metal (TM) doped semiconductors is still poorly understood. Recent studies [1] have underlined the need to study the incorporation of magnetic ions into the host lattice at the nanoscale, in order to establish whether the material is truly a diluted magnetic semiconductor, whether magnetic dopants aggregate to form coherent TM-rich regions, or whether nanocrystals that contain secondary magnetic phases are present.

Here, we study the transition from a diluted (Ga,Mn)As magnetic semiconductor (0.5 at.% Mn) to a phase-segregated microstructure upon annealing to 630°C. We use a range of transmission electron microscopy (TEM) techniques to study the local structural, chemical and magnetic properties of epitaxial (Ga,Mn)As layers grown on GaAs by molecular beam epitaxy. Aberration corrected high-resolution TEM images and nano-beam diffraction patterns from individual precipitates are used to show that both cubic (zinc blende) and hexagonal (NiAs-type) crystals form with sizes of 8 to 16 nm. High-angle annular dark-field TEM images and electron energy-loss spectroscopy are used to show that local density fluctuations are present adjacent to the Mn(Ga)As nanoparticles. We propose that these regions are voids. We also use *in situ* annealing to follow the phase transformation directly in the electron microscope.

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[1] A. Bonanni and T. Dietl, *Chem. Soc. Rev.* **39**, 528 (2010)