Crystallite phase and orientation determinations of (Mn,Ga)As/GaAs-crystallites using analyzed (precession) electron diffraction patterns

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Magnetic semiconductor materials have attracted widespread attention in recent years because of their potential for the transport of information on the basis of the intrinsic spin of electrons. One promising approach towards the realization of spintronic devices is, therefore, the combination of semiconducting materials with magnetic materials, e.g. self-assembled “surface contactable quasi-embedded” MnAs crystallites in a [001]-oriented GaAs matrix as grown by metal-organic chemical vapor deposition, see Figure 1. One peculiarity of unstrained bulk-MnAs is a temperature-dependent phase transition from ferromagnetic $\alpha$-MnAs (P63/mmc) to paramagnetic $\beta$-MnAs (Pnma) at 40°C and subsequently to paramagnetic $\gamma$-MnAs (P63/mmc) above 125°C. These phase transitions are also expected to occur in the individual MnAs crystallites in GaAs matrix.

This crystallite/matrix system was analyzed by transmission electron microscopy (TEM) using a JEOL JEM 2200 FS (200 kV, FEG). To identify the crystallite phase of MnAs and to determine the orientations of the crystallites with respect to the GaAs matrix, electron diffraction spot patterns were recorded and analysed automatically. The primary electron beam possessed a diameter of a few nm and was controlled by a dedicated external scanning/precession device (ASTAR by NanoMEGAS, ref. [1]), which is capable of providing the scanning of the primary electron beam in both the classical nano-beam diffraction mode and in a combined nano-beam/hollow cone illumination (precession) diffraction mode.

Precession electron diffraction patterns were used for the crystallographic refinement of the rough initial structure models to superlattice structures. The precession of the primary electron beam reduces dynamical scattering effects so that one may obtain “quasi-kinematic” electron diffraction patterns for sufficiently thin crystals [2], especially at large precession angles [3].

Our analyses on the same sample area, as shown in a virtual bright field image (Figure 2a), provide a phase map (Figure 2b) and three crystallite/matrix orientation maps (Figures 3a-c). The virtual bright field image was calculated from the recorded electron diffraction spot patterns of each scanning increment. Conventional TEM bright field images are shown for comparison in Figure 1. It is clear from Figure 2b that all observed MnAs crystallites possess the orthorhombic $\beta$-MnAs. Note, that we did not deliberately decrease or increase the temperature of the sample during our TEM investigation. The three orientation maps indicate that the MnAs crystallites are well ordered in all three dimensions, i.e. in two perpendicular directions that are parallel to the thin sample film and the direction parallel to the optical axis of the TEM.

Figure 1. Conventional TEM bright field image of MnAs crystallites in a [001]-oriented GaAs matrix in (a) cross-section, (b) plan-view.

Figure 2. Results of ASTAR analysis of the precession electron diffraction spot patterns: (a) virtual bright field as calculated from the electron diffraction patterns at each scanning increment, (b) two-dimensional crystallite phase map.

Figure 3. Two-dimensional orientation maps of MnAs crystallites in a GaAs matrix (a-c) Orientations of MnAs crystallites along the x, y and z axes with respect to the scanned area.