Structural and magnetic properties of (MnGa)As clusters in GaAs

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Diluted magnetic semiconductor materials, e.g. (MnGa)As, based on III/V materials attract great interest due to the possibility of combining magnetic properties with existing electronics and optics based on GaAs. In this study, we correlate the structural properties of this novel material system, which have been determined by transmission electron microscopy (TEM), to the magnetic properties as well as the growth conditions. The material has been grown by MOVPE (metal organic vapour phase epitaxy) using triethylgallium and tertiarybutylarsine as more efficient group III and group V precursors. As Mn source bis(methylcyclopentadienyl)manganese has been applied. Under certain growth conditions the formation of (MnGa)As clusters in the GaAs matrix is observed. These (MnGa)As clusters have hexagonal crystal structure and form when the substrate temperature is chosen between 500 and 600°C and the Mn/Ga ratio in the gas phase during growth is high. In the cluster containing samples we observe ferromagnetic coupling up to temperatures exceeding room temperature by SQUID magnetometer measurements. Depending on the growth temperature and the annealing as well as overgrowth conditions, different magnetic characteristics of the (MnGa)As cluster containing films have been found. These magnetic properties can be correlated to the structure, shape and composition of the (MnGa)As clusters and their heteroepitaxial relationship to the GaAs matrix.

High resolution TEM investigations show that clusters, which have been grown at high temperatures have only one distinct heteroepitaxial relationship of the clusters with respect to the matrix – in contrast to those grown at lower temperatures. A high resolution TEM micrograph together with the FFTs of the GaAs as well as the (MnGa)As regions is shown in Figure 1. From these investigations together with the knowledge of the crystal polarity, as determined by convergent beam electron diffraction, one can conclude the heteroepitaxial relationship between the hexagonal clusters and the cubic zinc-blende host matrix.

This structural anisotropy also results in an anisotropy of the in plane ferromagnetic coupling, which might be very important for device applications.

The relaxed lattice mismatch between the (022) GaAs planes and the (11.0) MnGaAs planes amounts to -7.4%. The embedding of the clusters in the GaAs host lattice is however possible without generation of any extended dislocations by forming a coincidence lattice of 13 MnGaAs (11.0) planes with 12 GaAs (022) planes, which reduces the resulting lattice mismatch to +0.9%. The formation of the coincidence lattice is shown in the (filtered) plane view TEM micrograph (Figure 2). The present paper will correlate the structural properties of MnGaAs clusters in GaAs to the MOVPE growth conditions as well as to the ferromagnetic properties of the layers.

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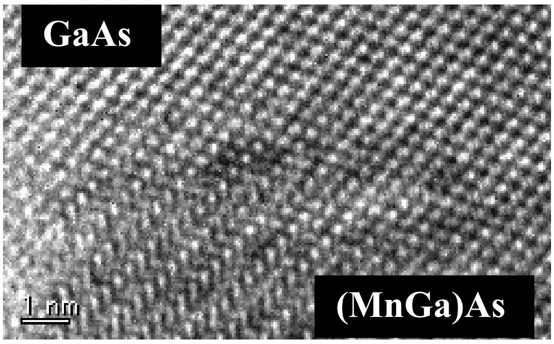

Figure1(a). High resolution image of the interface of a MnGaAs cluster to the

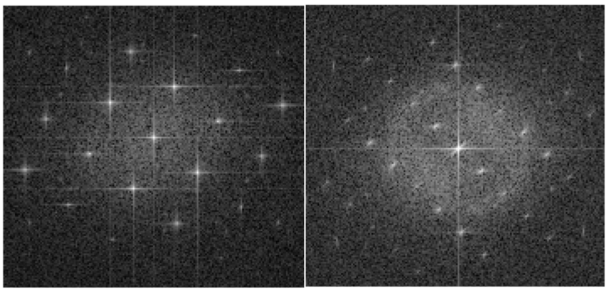

Figure 1(b) & (c). FFTs of the GaAs host (left: b) and the MnGaAs precipitate (right: c).

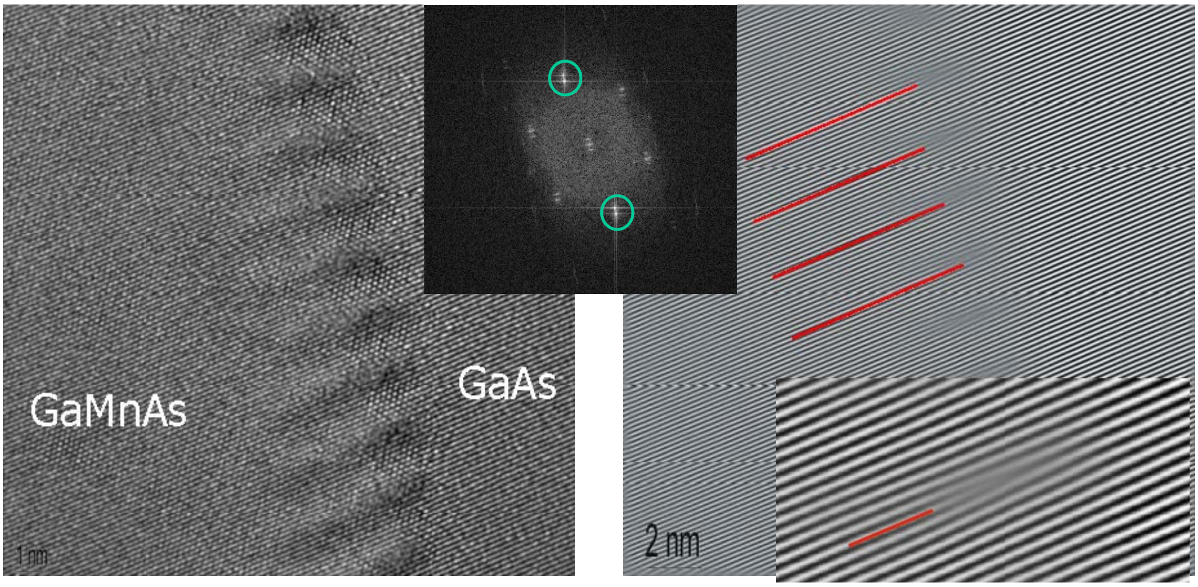

Figure 2. Plan view TEM micrograph (left), showing the MnGaAs/GaAs interface in high resolution and filtered image (right), showing the regular coincidence lattice between (022) GaAs and (11.0) MnGaAs.

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