Te co−doping and room temperature ferromagnetism in (MnGa)As−cluster layers by MOVPE

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Diluted−magnetic semiconductor (DMS) materials are an important basis for progress of magneto−optics and spin−(opto−)electronics. Up to now, molecular beam epitaxy (MBE) has been mainly applied to grow III/V−DMS layer structures. Here we present the results of the successful epitaxial growth of magnetic (GaMn)As layers using metal organic vapour phase epitaxy (MOVPE). Ferromagnetism, in particular at room temperature, and n−type carrier transport characteristics are important properties for spinpolarized−electrons injection−structures. In the present paper, our results of the successful n−type co−doping with Te are discussed. The samples have been grown in a standard commercial horizontal MOVPE reactor system (AIX 200, Aixtron Corp.) by using triethylgallium (TEGa) and tertiarybutylarsine (TBAs). As Mn−source the compound bis(methylcyclopentadienyl)manganese $(MeCp)_2Mn$ has been used. To investigate the growth regimes of the material system (GaMn)As the deposition temperature, the Mn/Ga ratio, the growth rate and the V/III−ratio have been varied.

The combination of high Mn/Ga ratios with deposition temperatures in excess of 500 °C allows the growth and defect−free embedded of (MnGa)As−clusters (verified by transmission electron microscopy (TEM)) in the surrounding GaAs matrix. Investigations by SQUID−magnetometer show ferromagnetism in these clusters with Curie temperatures above 300 K. One difficulty of the transport or the alignment of electron spins in such a material is the obvious p−doping of the (GaMn)As material. The advantage in these cluster containing structures is, that Mn−atoms are only incorporated in the surrounding GaAs:Mn−matrix up to the solubility limit. Under the chosen MOVPE growth conditions, this limit is at $2*10^{19}$ Mn−atoms/cm^3, even for samples with ferromagnetism at room temperature. Due to the relatively high Mn−acceptor binding energy of ~ 110 meV, the typical hole densities in the matrix (investigated by room temperature Hall measurement) are in the middle range of 10^{18} cm^{-3}. Increasing the Te co−doping level we observe the change in the majority carrier transport from p−type to n−type for a series of samples grown at 500 °C and 600 °C. Temperature dependent Hall studies, and structural investigations by AFM will be presented and discussed. Characterization by secondary ion mass spectrometry (SIMS) shows a clear correlation of the Te incorporation on the Mn−supply at 600 °C, but not at 500 °C.

The formation of defect−free embedded ferromagnetic (MnGa)As−clusters and the successful co−doping form a promising basis for the future development of magnetic III/V structures grown by MOVPE for spin−(opto−)electronics applications.