1.1 Nanostructuring

The resarch of the Nanostructuring group is devoted to the fabrication of III-V semiconductor heterostructures, ferromagnet-semiconductor hybrid structures, as well as metastable films by molecular-beam epitaxy (MBE) and to the investigation of their growth-related properties. Synchrotron x-ray diffraction is used to study the growth in situ and in real time, while high-resolution as well as analytical transmission electron microscopy (TEM) are applied to characterize the as-grown structures with high spatial resolution and analyze compositional variations at interfaces.

The in-situ synchrotron x-ray diffraction studies of the growth kinetics of III-V compounds have been continued experimentally and theoretically [V. M. Kaganer *et al.*, Phys. Rev. B **76**, 245425 (2007)]. The nucleation and coarsening behavior of monolayer-high islands on GaSb(001) has been investigated during deposition in real time over a wide temperature range. As a result, the activation energy for island nucleation is deduced indicating a very stable nucleus size [B. Tinkham *et al.*, Surf. Sci. **601**, 814 (2007)]. Ongoing work on the surface reconstructions of GaSb(001) is compared with ab-initio calculations and provides the basis for studying interface formation during the heteroepitaxial growth. The MBE growth of Pr_2O_3 and $PrSi_2$ on Si(001) using high-temperature effusion sources has been investigated by in-plane grazing-incidence x-ray diffraction and reflection high-energy electron diffraction [T. Watahiki *et al.*, J. Gryst. Growth **301–302**, 381 (2007)]. The reduction of an undesired interfacial layer formation is achieved by adding Si during growth.

The MBE growth of low-dimensional heterostructures on GaAs(110) surfaces has focused on the fabrication of high-quality (In,Ga)As/(Al,Ga)As quantum wells [R. Hey **et al.**, J. Cryst. Growth **301–302**, 158 (2007)]. Uncovering the mechanisms of structural degradation in related Bragg reflector and cavity structures by ex-situ electron microscopy has resulted in the growth of defect-free devices. Furthermore, the precise control of the stop bands of distributed Bragg reflectors and of cavity resonances during MBE growth is realized by a customized in-situ characterization method based on the detection of temporal changes in reflectance spectra, thereby enhancing the reliability of the growth of complex structures. For the fabrication of tubular structures with a two-dimensional electron gas sustaining a high mobility, the limits of structural dimensions have been explored as well as the epitaxial strain provided by the stressor layer.

The activities in the area of ferromagnetic films for spin- and magnetoelectronics have concentrated on the investigation of Fe_3Si and the full Heusler alloy Co_2FeSi as promising materials for spin injection into GaAs at room temperature. The studies on Fe_3Si were extended to the determination of the magnetic anisotropy in thin films grown on GaAs(113)A substrates [J. Herfort *et al.*, J. Magn. Magn. Mater. **310**, 2288 (2007)]. In the case of the Heusler alloy, quantitative high-resolution TEM was used to measure the effect of the growth temperature on the atomic ordering and interlayer diffusion of Co_2FeSi films grown on GaAs(001) [M. Hashimoto *et al.*, J. Vac. Sci. Technol. B **25**, 1453 (2007)]. Ferromagnetic Co_2FeSi films grown at 300 °C are successfully applied for spin injection, although at the interface small Co-rich precipitates [M. Hashimoto *et al.*, J. Phys. D **40**, 1631 (2007)] coexist with interfacial regions showing an abrupt transition from GaAs to the ordered $L2_1$ phase of the Heusler alloy.

Dilute magnetic semiconductors are alternative candidates for realizing spintronic devices. Continuing our earlier work on lightly Gd-doped GaN showing ferromagnetism at room temperature, the magnetic behavior at low temperatures has been investigated in detail. Our results are attributed to a coexistence of a spin-glass and a ferromagnetically ordered phase below the spin-glass freezing temperature, which depends weakly on the Gd concentration.

In the area of group-III nitrides, AlN films have been grown by plasma-assisted MBE on M-plane SiC. For particular growth conditions, the epitaxial layer replicates the 6H stacking of the SiC substrate creating a new and metastable AlN polytype [D. Schaadt *et al.*, J. Cryst. Growth **300**, 127 (2007)]. Moreover, the MBE growth of catalyst-free self-assembled GaN nanocolumns on Si(111) substrates has been initiated to offer the potential of a monolithic integration with Si. By using different template materials, epitaxially aligned and defect-free GaN nanocolumns have been realized displaying a narrow size distribution.

In the field of dilute nitrides, a low-substrate-temperature and low-As-pressure growth concept has been introduced for the realization of (In,Ga)(N,As)/GaAs quantum wells emitting at 1.5 μm [F. Ishikawa *et al.*, J. Cryst. Growth **301–302**, 529 (2007)]. With this concept, the incorporation of a high amount of N and the simultaneous suppression of the composition fluctuations has become possible, allowing for the formation of two-dimensional quantum wells with chemically abrupt interfaces. TEM techniques with high spatial resolution have been used to determine the local distribution of the In composition across the quaternary quantum wells indicating segregation behavior. A comparison with In composition profiles in N-free (In,Ga)As layers grown under similar conditions has revealed that the incorporation of N enhances the In segregation [E. Luna *et al.*, New J. Phys. **9**, 405 (2007)]