

## 1.2 Semiconductor Spectroscopy

The research activities of the Semiconductor Spectroscopy group focus on controlling elementary excitations (photons, electrons, and spins) using surface acoustic waves (SAWs), the magnetotransport and magneto-optical properties of ferromagnet-semiconductor hybrid structures, the electrical and optical properties of quantum-cascade structures and lasers, the optical polarization properties of wide-gap group-III nitride films, carrier diffusion in (In,Ga)(As,N) films, and the quantum transport theory for carriers and spins.

In the area of SAW modulation, a compact optical waveguide modulator based on a Mach-Zehnder interferometer driven by surface acoustic waves has been demonstrated [M. M. de Lima, Jr., *et al.*, *Appl. Phys. Lett.* **89**, 121104 (2006)]. The modulator was monolithically fabricated on GaAs with an active-region length of approximately 15  $\mu\text{m}$ . It yields peak-to-peak modulation exceeding 90% of the average transmission and operation in the gigahertz frequency range. A coherent interaction of microcavity polaritons and externally stimulated acoustic phonons has been found to form a tunable polariton superlattice with a folded energy dispersion determined by the phonon population and wavelength [M. M. de Lima, Jr., *et al.*, *Phys. Rev. Lett.* **97**, 045501 (2006)]. Under high phonon concentration, the strong confinement of the optical and excitonic polariton components in the phonon potential can create weakly coupled polariton wires with a virtually flat energy dispersion.

With regard to magnetic materials, the antisymmetric planar Hall effect in Fe and Fe<sub>3</sub>Si layers grown on GaAs(113)A substrates and the symmetric intrinsic planar Hall effect in Fe<sub>3</sub>Si on GaAs(001) have been shown to be closely related to each other [K.-J. Friedland *et al.*, *J. Phys.: Condens. Matter* **18**, 2641 (2006)]. These effects appear in conjunction with additional contributions to the anomalous Hall effect, which reflect the magnetic-field-induced crystalline anisotropy upon atomic ordering of the crystal. The role of the symmetry of the spin fluctuation coherence on the magnetotransport properties of Fe<sub>3</sub>Si films has also been investigated [M. Bowen *et al.*, *Europhys. Lett.* **74**, 163 (2006)].

Size effects on a first-order phase transition in submicron MnAs disks on GaAs(001) have been demonstrated using a high-resolution imaging method [Y. Takagaki *et al.*, *Phys. Rev. B* **73**, 125324 (2006)]. For MnAs disks with sizes smaller than twice the film thickness, an individual disk consists of either entirely  $\alpha$ -MnAs or entirely  $\beta$ -MnAs as a consequence of the nucleation initiation of the first-order phase transition. Slow relaxation of the magnetization in MnAs nanoparticles fabricated from epitaxially grown films has been demonstrated [Y. Takagaki *et al.*, *Appl. Phys. Lett.* **88**, 032504 (2006)]. In disks with a diameter as small as 100 nm and a thickness of 50 nm, the decay of the magnetization at 27 °C, which is only 10 °C below the Curie temperature  $T_C$ , is less than 1% over a period of one day. The relaxation of the magnetization in the MnAs nanomagnets consists of three exponential decays that are associated with the first-order phase transition between the ferromagnetic and nonmagnetic phases of MnAs and fast

and slow flipping processes of magnetic moments [Y. Takagaki *et al.*, Phys. Rev. B **74**, 224417 (2006)].

In the area of quantum-cascade lasers (QCLs), the gain coefficient of GaAs/(Al,Ga)As QCLs with a nominal Al content of 0.45 has been calculated as a function of transition energy and electric field strength by solving the Schrödinger and Poisson equations self-consistently in the framework of a linear scattering-rate model with periodic boundary conditions [L. Schrottke *et al.*, J. Appl. Phys. **100**, 053102 (2006)]. The calculated gain characteristics exhibit a large range of transition energies and a corresponding range of possible operating field strengths. These results may provide an explanation for the observation of a rather large range of the lasing energies for QCLs with nominally identical cascade structures. Applying this model to undoped GaAs/Al<sub>0.45</sub>Ga<sub>0.55</sub>As quantum-cascade structures (QCSs), the mechanisms for negative differential conductance (NDC) and bistable behavior observed in the current-density-electric-field  $j$ - $F$  characteristics of have been investigated [S. L. Lu *et al.*, J. Appl. Phys. **100**, 023701 (2006)]. While the  $j$ - $F$  characteristic of a QCS with a single period exhibits NDC without bistability, NDC and a bistable behavior are observed for a QCS with 20 periods of the same design. For GaAs/Al <sub>$x$</sub> Ga<sub>1- $x$</sub> As quantum-cascade laser structures (QCLS), in which part of the cascade is always doped, the current-voltage  $I$ - $V$  characteristics exhibits current plateaus with discontinuities for voltages below lasing threshold [S. L. Lu *et al.*, Phys. Rev. B **73**, 033311 (2006)]. The number of current discontinuities is correlated with the number of periods of the QCLS, suggesting the formation of electric-field domains that span the entire structure. For dilute (In,Ga)(As,N)/(Al,Ga)As multiple quantum well structure, intersubband transitions have been analyzed within a three-band  $\mathbf{k}\cdot\mathbf{p}$  model [M. Giehler *et al.*, Phys. Rev. B **73**, 085322 (2006)]. The intensity and the width of the intersubband absorption spectra are clearly affected by strong scattering of electrons on N-related defects.

Turning to group-III nitrides, the optical polarization anisotropy in GaN films for different nonpolar orientations has been studied by polarized photoreflectance (PR) spectroscopy [P. Misra *et al.*, Appl. Phys. Lett. **88**, 161920 (2006)]. The exciton transition energies of an unstrained, high-quality  $C$ -plane GaN film have been used to accurately determine the crystal-field and spin-orbit splitting energies. For films with a nonpolar orientation, the resonant features observed in the PR spectra exhibit a strong in-plane polarization anisotropy and transition energies different from the ones measured in the  $C$ -plane GaN film. The ultrafast behavior of the polarization filtering in anisotropically strained  $M$ -plane GaN films has been investigated by time-resolved pump-probe spectroscopy [T. Flissikowski *et al.*, Phys. Rev. B **74**, 085323 (2006)]. The reduced in-plane crystal symmetry and the anisotropic in-plane strain in  $M$ -plane GaN films lead to different absorption coefficients along the two principle in-plane axes. On an ultrafast time scale, the resulting pump-and-probe transients are governed by two different processes, namely the relaxation dynamics of holes in the two uppermost valence bands and a coherent coupling artifact.