

1.3 Semiconductor Spectroscopy

The research activities of this research department cover elementary excitations (photons, electrons, and spins) and their control by surface acoustic waves (SAWs) using dedicated spectroscopic techniques, the optical polarization properties of wide-gap group-III nitride films with nonpolar surfaces examined using polarized transmission, reflectance, photorefectance, and photoluminescence spectroscopy, the design and optical as well as transport properties of quantum-cascade lasers using intersubband (mid- and far-infrared) and interband (near-infrared) spectroscopy, the magnetotransport properties of curved two-dimensional electron gases in high magnetic fields at low temperatures, the spin-injection efficiency of ferromagnet-semiconductor hybrid structures, their magneto-optical properties, in particular the degree of circular polarization, using light-emitting diodes with a ferromagnetic layer on top, and the quantum transport theory for carriers and spins.

The existence of spin transport lengths larger than $60 \mu\text{m}$ has been demonstrated in (110) GaAs quantum wells using SAWs for temperatures up to approximately 80 K [O. D. D. Couto *et al.*, Phys. Rev. B **78**, 153305 (2008)]. The investigations of the dynamics of spins aligned along the [110] direction shows that, in addition to the intrinsic absence of the D'yakonov-Perel' spin-relaxation mechanism, the Bir-Aronov-Pikus mechanism is also suppressed due to the type-II carrier confinement imposed by the SAW piezoelectric potential. Experimental evidence is provided for the suppression of the spin relaxation via motional narrowing effects induced by the mesoscopic carrier confinement in narrow stripes along the SAW wave front. A new concept for waveguide acousto-optical devices based on coupled Mach-Zehnder interferometers driven by acoustic waves has been presented [M. Beck *et al.*, J. Appl. Phys. **103**, 014505 (2008)]. These acousto-optical multiple interference devices use the periodic refractive index modulation induced by the acoustic wave to implement functionalities such as ON/OFF switching for an arbitrary time interval as well as for efficient light modulation at high harmonics of the acoustic frequency and pulse shaping for, e. g., integrated Q-switches. Finally, a monolithic acousto-optic light modulator on silicon consisting of a piezoelectric ZnO/SiO₂ microcavity (MC) excited by a SAW has been demonstrated [P. D. Batista *et al.*, Appl. Phys. Lett. **92**, 133502 (2008)]. The modulation of the MC optical resonance by the SAW creates an optical grating on the MC, which efficiently diffracts light beams impinging at the Bragg angle.

The spontaneous emission of *C*- and *M*-plane GaN quantum dots embedded in AlN has been compared [O. Brandt *et al.*, Appl. Phys. Lett. **93**, 081907 (2008)]. *C*-plane dots are characterized by an intense emission with an exceptionally long decay time up to room temperature. In contrast, *M*-plane dots exhibit a much weaker emission with a very short decay time. In addition, the emission of the *C*-plane dots temporally evolves on a timescale of seconds, while the emission of the *M*-plane dots is stable over time. These findings are correlated with the different growth mode and microstructure of *C*- and *M*-plane GaN quantum dots.

The dependence of the optical transition energy E_t of GaN quantum disks (Qdisks) em-

bedded within (Al,Ga)N nanocolumns grown on a (111) Si substrate on disk thickness, disk diameter, barrier thickness, and barrier composition has been investigated experimentally by spatially resolved cathodoluminescence spectroscopy and theoretically [U. Jahn *et al.*, Phys. Status Solidi C **5**, 2164 (2008)]. Results of E_t on the disk and barrier thickness as well as barrier composition resemble those of corresponding quantum wells, whereas results on the disk diameter are essentially determined by the lateral strain distribution of the Qdisks.

The anisotropic in-plane strain in M -plane GaN films on LiAlO₂ has been investigated using photoreflectance, photoluminescence, Raman, and time-resolved pump-and-probe spectroscopy [T. Flissikowski *et al.*, J. Appl. Phys. **104**, 063507 (2008)]. A partial and anisotropic relaxation of these highly strained films under intense optical pumping has been found. The strain relaxation is observed as a redshift of the E_2 -Raman line and as a redshift of the fundamental interband transition energies in the photoreflectance spectra. The photoluminescence intensity in the exposed areas of the sample is significantly reduced compared to the one for unexposed areas. This observation suggests that the strain relaxation is probably due to the introduction of defects, which act as nonradiative recombination centers.

A new type of resistance oscillations in the ballistic transport in a two-dimensional electron gas on cylindrical surfaces with a tangentially directed magnetic field have been observed [K.-J. Friedland *et al.*, Phys. Status Solidi C **5**, 2850 (2008)]. The longitudinal resistance oscillates with a periodicity proportional to the square root of the magnetic field B , which indicates a commensurability of longitudinal distances with a length scale related to the gradient of the magnetic field component B_{\perp} , which is oriented perpendicular to the surface. It is shown that the length of the stripe with energetically free electrons, forming the so-called *snake*-like trajectories around the position where $B_{\perp} = 0$, is the basic length scale for the \sqrt{B} oscillations.

Electrical spin injection from the Heusler alloy Co₂FeSi into (Al,Ga)As has been investigated for different growth temperatures T_G of the injector layer [M. Ramsteiner *et al.*, Phys. Rev. B **78**, 121303(R) (2008)]. Depending on T_G , the spin polarization of injected electrons in the semiconductor is determined by two competing mechanisms: actual spin injection at the Co₂FeSi/(Al,Ga)As interface and ultrafast spin alignment in the (Al,Ga)As layer. This layer is strongly affected by the thermally activated diffusion of Co, Fe, and Si during the growth of the Co₂FeSi layers. Despite the electrical compensation and magnetic transformation in the underlying semiconductor structure, a spin-injection efficiency of at least 50% is achieved as deduced from the analysis of the electroluminescence and time-resolved photoluminescence intensities.

In the plane of a (001) quantum well with both Rashba and Dresselhaus spin-orbit interaction, the application of a constant electric field as well as a SAW have been theoretically investigated [P. Kleinert and V. V. Bryksin, Solid State Commun. **146**, 438 (2008)]. The combined effect of both in-plane electric fields gives rise to a homogeneous out-of-plane spin polarization that exhibits a Hanle-like dependence on the constant electric field. In addition, a spin-mediated charge-current contribution is identified that is driven by the SAW.