Magnetization of Multi-Component Two-Dimensional Quantum-Hall Systems

M.R. Schaapman[1], **U. Zeitler**[1], **P.C.M. Christianen**[1], **J.C.Maan**[1], **D. Reuter**[2], **A.D. Wieck**[2]

[1]*Nijmegen Science Research Institute of Matter, High Field Magnet Laboratory, University of Nijmegen, Toernooiveld 1, 6525 ED Nijmegen, The Netherlands*
[2]*Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstrasse 150, D-44780 Bochum, Germany*

Using a recently developed, sensitive torque magnetometer[1] we have measured the magnetization of the multi-component two-dimensional electron systems (2DES) in a dual-subband 2DES and in electron bilayers. The oscillatory dual-subband 2DES magnetization reflects the energy-level structure of crossing Landau-levels originating from both bands. An additional reduction of the total energy shows up at the crossings, which may be related to the exchange interaction between energetically coinciding levels with opposite spin and different subband index.

The magnetization of the bilayer 2DES shows sharp steps related to the symmetric-anti-symmetric energy gap (Δ_{SAS}) while, surprisingly, the amplitude of steps at Landau-level transitions is significantly reduced.

As the magnetization of a 2DES is proportional to its chemical potential, magnetometry provides direct access to this thermodynamic property. By using optical readout, our technique is free of electronic interference and the high sensitivity of 10^{-3} μ_B^* per electron allows to resolve the typically small signals of a 2DES, enabling the investigation of single-electron as well as interaction effects.

In the first system we study two coupled, spatially coincident 2DESs, realized by populating the second electronic subband. The dual-subband 2DES is an MBE-grown GaAs/AlGaAs heterojunction with a density of $8.0 \cdot 10^{11}$ cm^{-2}. Where the magnetization of a single 2DES is characterized by sawtooth-like de Haas-van Alphen oscillations, we observe triangularly shaped, non-$1/B$-periodic oscillations of the magnetization with a reduced amplitude. These effects are explained by a field dependent self-consistent calculation, demonstrating that the changes in the magnetization of the dual-subband 2DES are determined by oscillations in the confining potential due to redistribution of electrons between the subbands. At 1 K we observe additional magnetization minima at Landau-level crossings. We speculate this enhancement of the exchange interaction is caused by mixing of spin-split Landau levels from both subbands, leading to a reduction of the 2DES total energy.

The second system is the bilayer 2DES, where the 2DESs are not spatially coincident and their coupling is determined by the thickness of the interwell-barrier. The bilayer 2DESs are MBE-grown GaAs/AlGaAs double quantum-wells with a total density similar to the dual-subband system. Interwell-barriers are tailored to give a Δ_{SAS} in the range of 1 meV: smaller than the Landau-level splitting, but much larger than the spin-splitting. We present measurements showing Δ_{SAS}, although its origin is spatial and neither spin nor orbital angular moment of the electrons changes, gives rise to sharp steps in the magnetization. Surprisingly we also find the Landau-level splitting in such systems is significantly reduced.

[1] M.R. Schaapman et al., Appl. Phys. Lett. **81**, 1041 (2002).

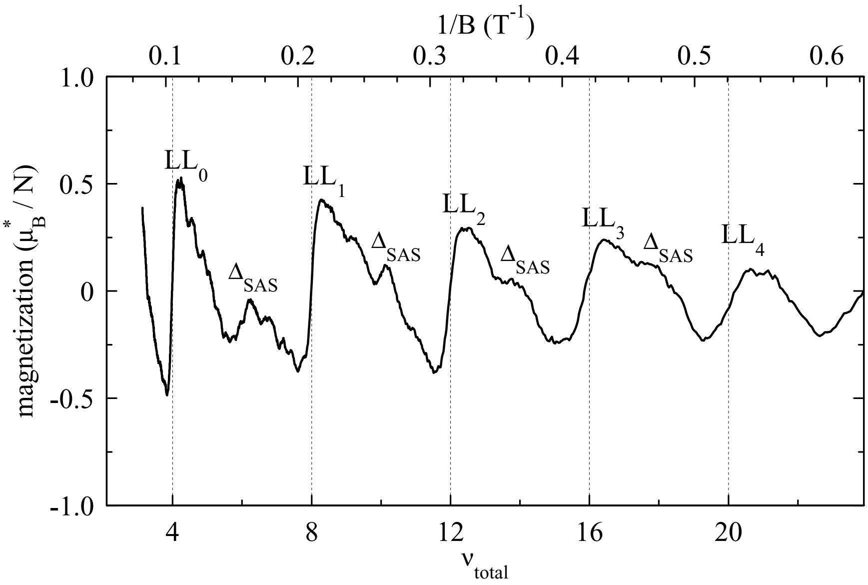

Figure 1: Magnetization of a bilayer 2DES with a 4.0 nm barrier and $n_{\text{total}} = 9.2 \cdot 10^{11}$ cm^{-2} at 1.3 K. The sharp, periodic, Landau-levels transitions (LL) can be seen at $\nu_{\text{total}} = 4$N, the size is much reduced compared to the 1 μ_{B}^{*}/N typical for a single 2DES. The changes in magnetic moment at $\nu_{\text{total}} = 4$N+2 are related to Δ_{SAS}, they are clearly observed although there is neither a change in spin nor in angular momentum.

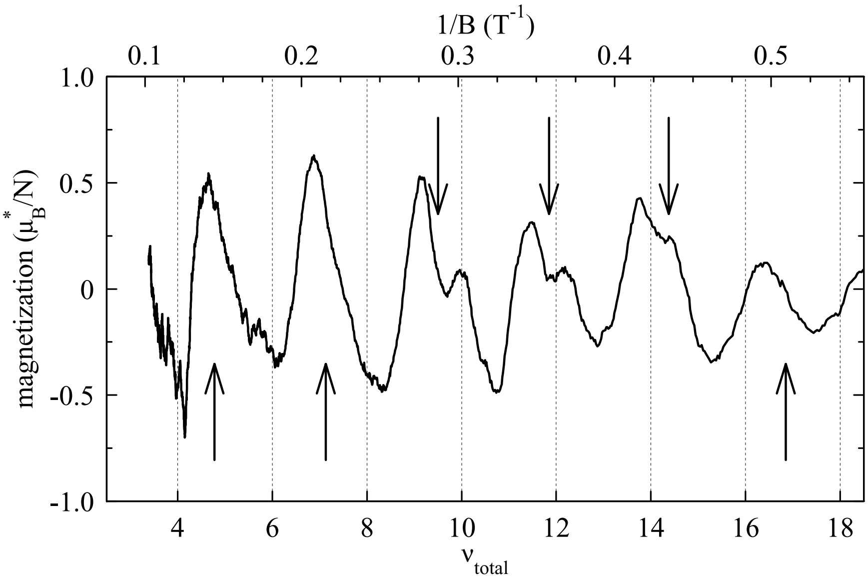

Figure 2: Magnetization of the dual-subband 2DES ($n_{\text{total}} = 8.0 \cdot 10^{11}$ cm^{-2}) at 1 K. Oscillations are triangular in shape with a reduced amplitude and non-$1/B$-periodic behavior. Additionally small oscillations can be seen at Landau-level crossings (indicated by arrows) in intermediate magnetic fields, suggestive of energy-gap enhancement due to level-mixing.