Oscillatory Magnetization of GaAs Quantum Wires

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The magnetization is a fundamental thermodynamic quantity and monitors the change of the ground state energy of an electron system in a magnetic field B. It thus gives direct access to the energy spectrum including the many-body interaction (direct Coulomb, exchange interaction, correlation). In particular interesting are low-dimensional electron systems, i.e., quantum wires and quantum dots, where, in addition, the lateral confinement potential alters the interaction strength and the energy spectrum. We have developed highly sensitive micromechanical cantilever magnetometers to monitor the magnetization of low-dimensional electron systems [1] [Fig.1(a)].

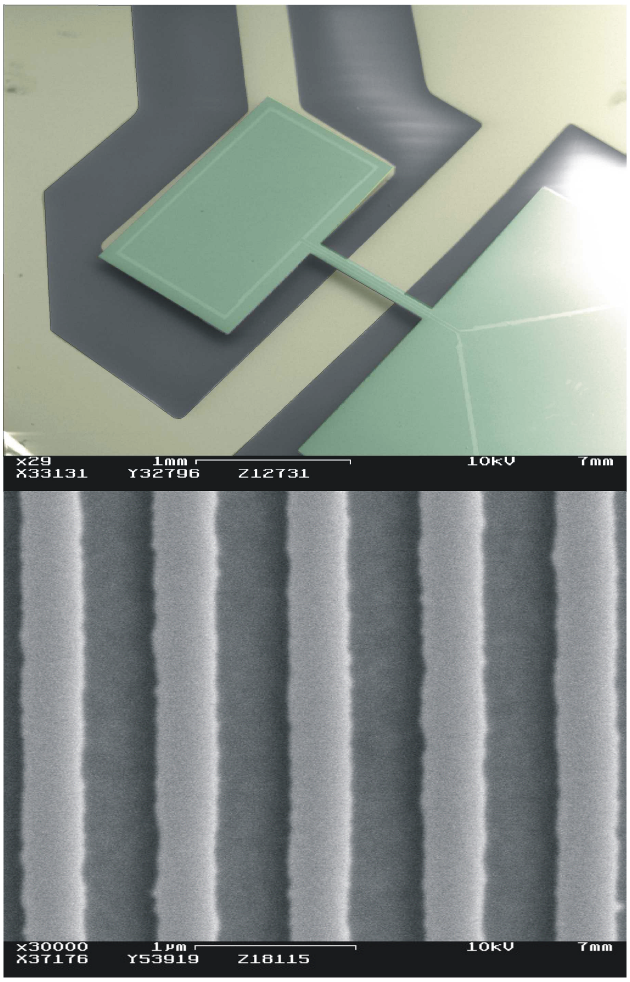

Fig. 1:
(a) Scanning-electron micrograph of the micromechanical sensor. The rectangular area, which is suspended in air by means of the smaller beam, contains the quantum wire array. The cantilever is metallized from the backside and forms a plate capacitor with a metallic counterelectrode (bright-gray area) on the substrate (dark area). Using a capacitive readout scheme the magnetic-moment-induced deflection of the thin and flexible cantilever beam is detected.
(b) Scanning-electron micrograph of an integrated quantum wire array prepared by laser-interference lithography and reactive ion etching. The period of the array is 800 nm. The one-dimensional electron system (1DES) resides in the bright-gray areas.

Here we report on cantilevers which incorporate arrays of quantum wires patterned by means of laser-interference lithography and reactive ion etching in a AlGaAs/GaAs heterojunction [Fig.1(b)]. Magnetization data are obtained at low temperatures down to 300 mK and in magnetic fields up to 16 T.

We observe oscillations of the magnetic moment of the quantum wire array. They evolve systematically as a function of carrier density n_s [Fig.2(a)]. At low carrier density the shape of the oscillations significantly deviates from the sawtooth like behaviour observed for the unstructured two-dimensional electron system (2DES) [Fig.2(b)]. Moreover the positions of the integer filling factors $\nu = n_s/(eB/h)$ are no longer in the center of the negative slope of the oscillations as they are in a 2DES. The periodicity deviates from the 1/B behaviour in the low field regime. When we increase the carrier density via the persistent photo effect the shape of the oscillations develops towards the sawtooth-like shape expected from the 2D de Haas-van Alphen effect. The 1/B periodicity is restored.

In order to evaluate the data in greater detail we have performed calculations based on a single particle model assuming a parabolic lateral confinement potential. The comparison with the experimental traces suggests that the latter are strongly influenced by the electron-electron interaction. We attribute the 2D-like magnetic behaviour at high n_s to effective screening of the external potential.

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[1] M.P. Schwarz, D. Grundler, I. Meinel, Ch. Heyn, and D. Heitmann, Appl. Phys. Lett. **76**, 3564 (2000).

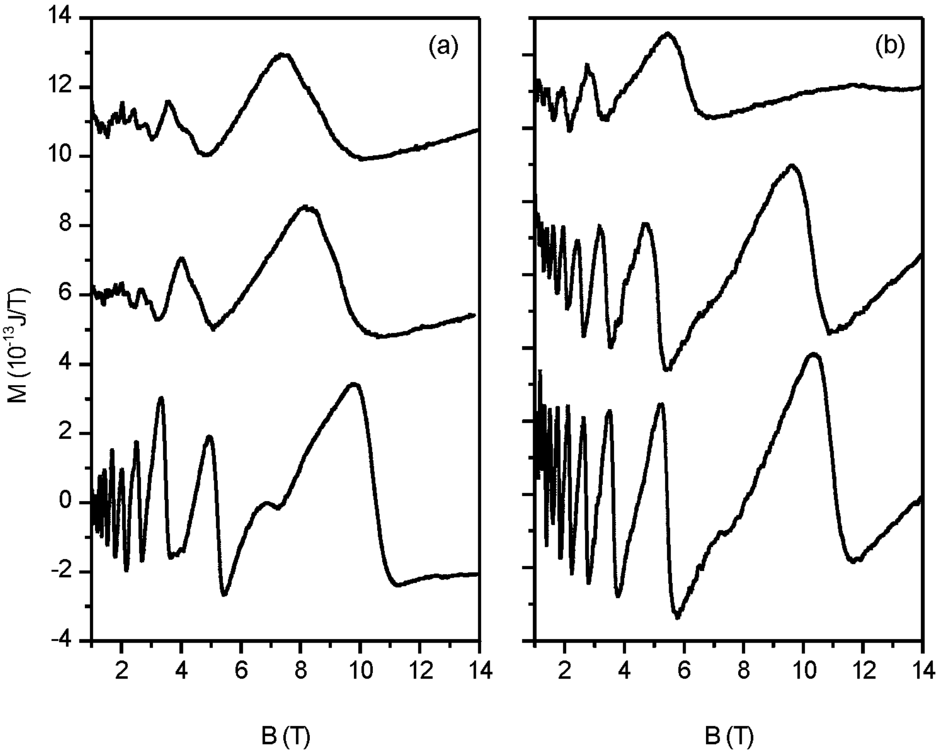

Fig. 2: (a) Magnetization of the array of quantum wires.
(b) Magnetization curves for the 2DES reference sample fabricated from the same wafer.
The data were taken at a temperature of 300 mK. From top to bottom the electron density is increased successively. The curves are offset for clarity.