Magnetotransport On Evenly Curved Hall-Bars In InGaAs/GaAs-Microtubes

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Abstract. We present transport measurements on evenly curved two dimensional electron systems in Hall-bar geometry. By combining the method of self-rolling strained double-layers with a special lithographic procedure we are able to roll-in and contact AlGaAs/GaAs/AlGaAs quantum well structures into tubes or curved lamellas. Applying a magnetic field to such structures results in a sinusoidal modulation of the magnetic field components perpendicular to the curved 2DES plane. Transport measurements with current direction parallel to the rolling axis exhibit weak oscillations reflecting the superposition of magneto oscillations caused by different perpendicular magnetic field vectors. In contrast to this, magneto transport along the curvature of the tubes shows pronounced Shubnikov-de Haas oscillations which can be associated with the maximum perpendicular magnetic field component between the contacts. Furthermore, a breakdown of magnetic field inversion symmetry depending on the perpendicular field component distribution along the curved Hall-bar is observed.

Non-planar two-dimensional electron systems in magnetic fields have been the subject of many theoretical [1, 2] and experimental works, in recent years. Transport measurements, e.g. on Hall bars containing a tilted facet [3] or on waved 2DESs [4] have been realized using MBE regrowth technology. 2DESs in periodically modulated magnetic fields have also been realized by evaporating and patterning superconducting [5] or ferromagnetic films [6] on top of a heterojunction. However, all the above mentioned systems do not only exhibit a modulation in the perpendicular magnetic field component, but there also exists an intrinsic modulation caused by either strain or surface topography. Preparing evenly curved 2DESs by lifting off the complete electronic structure and transferring it onto glass tube templates results in minimum bending radii of about 1 mm and a 2DESs of decreased quality due to cracks and dislocations [7]. Recently, we demonstrated the realization of evenly curved 2DESs without any change in strain or crystal structure connected to the topographic modulation [8]. Using the method of self-rolling strained semiconductor layers [9, 10] in combination with a special lithographic procedure (independently developed by Vorob’ev [11]) we rolled very thin modulation doped AlGaAs/GaAs heterostructures into microtubes with a predefined radius. Four-point measurements on these structures prove the existence of evenly curved 2DESs in our samples.

In this contribution we show magnetotransport measurements on evenly curved Hall-bars (ECHB) integrated into InGaAs/GaAs-microtubes. In contrast to measurements in Ref. 8 where the current direction was restricted to be parallel to the rolling axis, the improved preparation method used here enables us to also measure transport along the curvature of the tubes, i.e. along the sinusoidal modulation of the perpendicular magnetic field component.

Our samples are grown on GaAs-substrates in a solid source Riber 32P MBE system. On top of a GaAs buffer layer we grow a lattice-matched AlAs sacrificial layer followed by a pseudomorphically strained In$_{20}$Ga$_{80}$As-layer and an In-free layer containing a modulation doped GaAs quantum well (details see Ref. 8). The strained layer system consisting of the In-containing and In-free layers rolls up after the underlying sacrificial AlAs-layer is etched away. The details of the employed lithographic preparation process will be given in an upcoming publication [12]. Figure 1 shows an exemplary InGaAs-microtube containing an ECHB structure.
FIGURE 1. a) micrograph of an InGaAs tube containing a curved Hall bar. The light gray stripes are gold lines supplying the contacts to the Hall-bar. A zoom-in of the curved Hall-bar is shown in b). c) shows the same Hall bar before rolling process, the arrows in b) and c) indicate the same voltage probe.

Figure 2 shows two typical transport curves for an ECHB with current direction along the curvature. The measurements are performed at $T = 4.2\, \text{K}$ with an effective AC-current value of 10 nA fed through source and drain contacts. The electron mobility is $56000 \, \text{cm}^2/\text{Vs}$, the electron carrier density is evaluated by Hall-voltage measurements and amounts to $5.5 \times 10^{11} \, \text{cm}^{-2}$. The distance between the voltage probes is $24 \, \mu\text{m}$, the bending radius accounts to $8 \, \mu\text{m}$. Therefore, roughly half a period of the sinusoidal perpendicular magnetic field vector modulation fits between the voltage probes. By turning the tube around its axis in the magnetic field the phase of the modulation can be tuned in situ. In contrast to the washed out curves measured for transport along the tube axis [8] we here find clear magneto oscillations. Furthermore, a pronounced break of the magnetic field inversion symmetry occurs as soon as the maximum magnetic field vector is shifted from the center of the voltage probes (gray curve in Fig. 2). By using the second pair of voltage probes of the ECHB we achieve the same curves but inverted in $B$. Whereas the background slope of these measurements can be explained in classical terms, e.g. by finite element calculations, the relation between the quantum oscillations and the magnetic field distribution is not well understood, yet. However, investigations of the SdH-minima as a function of the maximum magnetic field position on the ECHB suggest that transport along a magnetic field modulation is dominated by the maximum perpendicular magnetic field component between the voltage probes.

In summary, we successfully prepared evenly curved Hall-bars in InGaAs/GaAs-microtubes. This enables us to measure for the first time magnetotransport with perpendicular magnetic field components varying sinusoidal along a Hall-bar of high quality and with a bending radius in the micrometer scale. Clear magneto oscillations and a pronounced background are observed. Except for the case of a symmetric field distribution the measured curves exhibit a breakdown of magnetic field inversion symmetry.

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