A Numerical Study Of Magneto Transport In 2D Electronic Systems In The Presence Of Non-Uniform Magnetic Fields

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Abstract. We present a first approach to magneto transport of a Hall bar in non-uniform magnetic fields, which is based on a novel non-equilibrium network model. Such non-uniform fields generate magnetic barriers for current flow, which can be observed by a change of the longitudinal resistance R_{xx} that becomes a function of orientation and field amplitude of the superimposed magnetic field. For the case of a hybrid electric and magnetic confinement we find a significant suppression of equilibration between edge and bulk, resulting in a suppression of the longitudinal resistance.

Keywords: quantum Hall effect, magneto transport, non-uniform magnetic field, network model
PACS: 73.43.Cd, 73.43.Qt

INTRODUCTION

Non-uniform magnetic fields play an increasing role in device concepts during the last decade [1,2]. One key point is that magnetic field gradients create barriers [see e.g. 3], which act in addition to eventually present electric barriers. While theoretical approaches mostly rely on the equilibrium situation, experiments drive the system out of equilibrium so that in real experiments one always measures non-equilibrium currents and potentials. An appropriate transport model should take care of this and has also to provide a link between the microscopic physics and the experimental answer of the finally macroscopic sample. We developed a non-equilibrium network model for magneto transport in 2D electronic systems in the quantum Hall effect regime, which is able to capture the real sample geometry, including contacts, leads and in-homogeneities like introduced by gate electrodes [4-8]. This is the first time that we apply this network model also to the situation of non-uniform magnetic fields.

THE NON-EQUILIBRIUM NETWORK MODEL

The intention of our network approach to magneto transport is to address directly the non-equilibrium current flow. This means that we have to deal with the situation of a non-uniform lateral distribution of the chemical potentials. We use a network of directed quantum channels, which interconnect a 2-dimensional arrangement of nodes, which physically correspond to the saddles of the potential fluctuations in real systems. The directed channels keep their chemical potentials between the nodes, while the nodes transmit and modify the chemical potentials from the incoming to the outgoing channels [9,10]. The major ingredient in this context is the function P, which is related to the tunneling process across saddle points of the potential landscape in the bulk [9,10]:

$$P = \exp\left[-\frac{L^2 (E_F - E_{LL})}{e\tilde{V}} \cdot \frac{eB}{h} \right] \qquad (1)$$

E_F is the Fermi energy and E_{LL} is the center of the LL, (eB/h) is the number of LL states, L is the period and $\tilde{V}$ the amplitude of a two-dimensional Cosine-potential modulation, which is used as a representation of the potential fluctuations in the real system. Figs.1a-c illustrate how the network is composed.

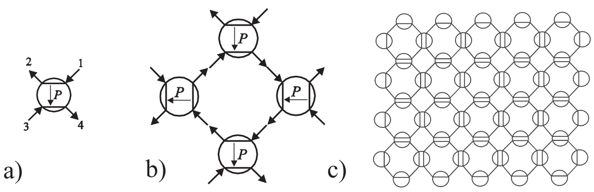

FIGURE 1. a) Node of the network with two incoming and two outgoing channels. b) Arrangement of the nodes for building the minimal physical element of a network, which is the closed loop of a so called magnetic bound state. c) The complete network is composed by putting together a sufficient number of such adjacent loops.

The design of the sample is managed by shaping the lateral confining bare potential and using a self consistent Hartree type approximation to calculate the Fermi energy and the lateral carrier distribution. The potentials, which are transmitted by each node can be easily calculated by using Eq.1, which finally allows solving the complete network (details in Refs. 9-10). Since Eq.1 is defined locally for each node, also the magnetic field B can be set locally and this allows us to introduce also non-uniform magnetic fields.

RESULTS AND DISCUSSION

For this short presentation, we restrict our considerations to two basic configurations for a standard Hall bar structure: (i) a hybrid magnetic-electric confinement at the edge and (ii) a magnetic barrier located in the bulk, which is aligned in longitudinal and transverse direction.

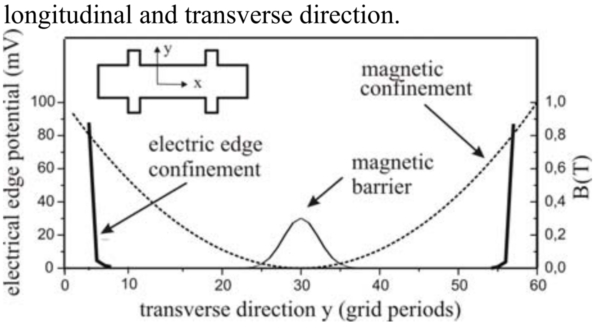

FIGURE 2. Different non-uniform magnetic field distributions as used for the simulations. For the hybrid confinement we use a parabolic function of B versus distance from the sample center (dashed line) and constant field in longitudinal direction. For the magnetic barrier we use a Gaussian function in one direction and constant field in the other direction (thin solid line), which in this figure corresponds the longitudinal orientation. The insert shows the sample layout. The selected carrier density is $4x10^{11}cm^{-2}$ and the Hall bar is mapped onto a 120x60 network grid.

Fig.2 shows the applied magnetic field distribution, which is superimposed on the main uniform sweeping magnetic field of the Hall experiment. Fig.3. shows simulation results for R_{xx} of the $\nu = 4 \rightarrow 3$ plateau transition for all different cases of the non-uniform field. For the hybrid magnetic - electric confinement one can clearly see, that R_{xx} gets more and more suppressed with increasing field gradient at the edge. This can be understood in terms of a suppression of edge bulk equilibration because of the additional magnetic field gradient. The magnetic field gradient near the edge creates compressible and incompressible stripes also away from the real sample edge. This acts like a softening of the real edge potential, which reduces equilibration. Therefore less dissipation occurs, which is responsible for the R_{xx} peak height. This reduces also the coupling between contacts and inner edge channels, which leads to a more complex lateral potential distribution and a slight shift of the R_{xx} peaks (details will be published elsewhere). R_{xy} (not shown) does not show significant features.

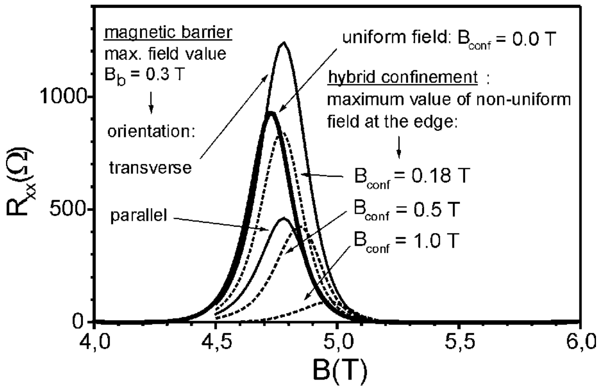

FIGURE 3. Results for R_{xx} of the $\nu = 4 \rightarrow 3$ plateau transition for hybrid confinement at different non-uniform field strength (dashed lines) and for a magnetic barrier of fixed shape but for longitudinal and transverse orientation (thin solid lines). The bold line represents R_{xx} for uniform field. B_{conf} represents the used value of the superimposed non-uniform field at the sample edges (see also Fig.2).

Looking at the effect of a magnetic barrier, which was chosen with fixed shape and height (B_b=0.3T), we can clearly see, that the parallel orientation of the barrier reduces R_{xx} as compared to the situation of a uniform magnetic field, while the transverse orientation of the barrier increases R_{xx}. Since the transverse orientation of the magnetic barrier creates a real barrier for the longitudinal current flow, the longitudinal orientation creates a barrier for the back scattering process, which is indicated by the reduction of R_{xx} (more details will be published elsewhere).

ACKNOWLEDGMENTS

Financial support by the Austrian Science Foundation (FWF) Project Nr. P19353.

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