Electron beam collimation and non-ohmic resistance addition in quasi-ballistic magnetic barriers

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Magnetic barriers (MBs) [1] are localized magnetic field structures that produce a magneto-resistance in two-dimensional electron gases (2DEGs) due to electron trajectories being deviated by the Lorentz force. They can be generated by the perpendicular component of the stray field under the edge of a ferromagnetic film magnetized along the electron transport direction. Their strength can be tuned by in plane magnetic fields which vary the magnetization of the film. In the open regime, MBs represent filters which transmit only a certain interval of angles of incidence. One would expect that all electrons get reflected at sufficiently strong MBs, which would lead to an infinite resistance. However, this magnetoresistance is limited by both scattering which helps electrons pass through the barrier and by $E\times B$ drift at the edges of the 2DEG. [2]

Here, we show theoretically and experimentally that MBs represent electron collimators, i.e., the selective transmission of certain angles of incidence transforms into a collimated beam of ejected electrons. This manifests itself in a non-ohmic addition of the resistance of two MBs in series. Two regimes can be distinguished: at open barriers, the electrons are emitted homogeneously along the barrier and move in a preferred direction. At closed barriers, a collimated electron beam is ejected at one edge of the Hall bar.

Devices feature a set of samples containing two MBs of opposite polarity in series, placed on top of a Hall bar etched into a GaAs/AlGaAs heterostructure. The size of the magnetic structure is comparable to the mean free path of the electrons, which places the structure in the quasi-ballistic regime [3]. The MB amplitude is tuned by an external magnetic field, and the electron density can be varied by a metallic top gate.

The collimated beam ejected from the first MB is probed by the second MB of opposite polarity acting as collector, which is located at various distances from the injecting MB. We find that the series resistance of the two barriers depends non-monotonously on the barrier spacing as well as on the magnetic barrier strength. Transmission resonances are found which can be explained semiclassically in terms of snake-orbit and cycloid trajectories that form in between the barriers and that get selectively occupied by the collimation effect. The maximum magneto-resistance is furthermore larger than twice the magneto-resistance of a single-barrier.

Simulations of the measurements based on the Landauer-Büttiker model in the semiclassical limit [4] with the experimentally determined parameters as input [3] reproduce the transmission functions and reveal the quasi-ballistic nature of the effects observed.

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