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Magnetoconductance of a magnetic double barrier in a quantum wire

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ABSTRACT

Magnetotransport measurements of a ballistic quantum wire exposed to two magnetic barriers of opposite polarity in series are reported. We find two types of conductance resonances with quite different characteristic magnetic fields. Numerical simulations show that the first type, characterized by a larger fluctuation period of the magnetoconductance, originates from bound states localized at the magnetic barrier oriented in the same direction with the perpendicular component of the external magnetic field, and the second type of conductance fluctuation can be traced back to states that reside close to the second magnetic barrier with antiparallel alignment. The simulations furthermore show that the confinement mechanism for these states can be understood in terms of spatially varying diamagnetic shifts of the one-dimensional wire modes.

1. Introduction

The transmission properties of quantum wires exposed to two magnetic barriers in series, i.e. two strongly localized magnetic field spikes oriented perpendicular to the wire, have received considerable attention over the past few years [1–11]. From the theory side, these systems have been suggested as tunable spin filters [5–8]. As far as the experimental side is concerned, measurements on such a

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magnetic double barrier in a ballistic quantum wire have not yet been reported, let alone studies related to spin polarization. This is possibly due to the technological challenge the sample preparation process poses. However, closely related structures have already been implemented, like magnetic double barriers in a two-dimensional electron gas [12,13], the transport properties of which can be interpreted within a classical picture, as well as single magnetic barriers in a quantum wire [14]. In these experiments, the magnetic barriers are formed by the perpendicular component of the fringe field of a ferromagnetic film on top of the sample surface, which is magnetized by an external in-plane magnetic field. For ferromagnets where the two opposite edges cross the quantum wire, a magnetic double barrier structure results, with two identical barriers in shape and amplitude, but of opposite polarity. Within a quantum picture, the effect of the local magnetic field on the transport properties of the quantum wire can be understood qualitatively by a spatially varying diamagnetic shift. It generates a longitudinal potential landscape which depends on the mode index and can lead to confinement. Such states have been predicted to mark their fingerprint in the conductance as a function of the Fermi energy [9,1,3,10,11]. It has been shown that measuring the conductance of a single magnetic barrier in a quantum wire as a function of an additional, homogeneous perpendicular magnetic field is a powerful tool to identify the character of the bound states in such systems [14]. The observed conductance peaks have been attributed to resonant tunneling via bound states which can be understood semiclassically as combinations of snake- and cycloid-type trajectories in transverse direction with skipping trajectories due to $\vec{E} \times \vec{B}$ drift in longitudinal direction.

Here, we report conductance measurements on a magnetic double barrier in a ballistic quantum wire as a function of a homogeneous perpendicular magnetic field. Resonances are found as the double barrier is displaced in B_z-direction by a superimposed homogeneous magnetic field. Two different types of transmission resonances are measured, the origin of which is identified and interpreted with the help of numerical simulations, based on a tight binding model in combination with the recursive Green's functions technique.

The paper is structured as follows. In Section 2, the experimental setup is described, followed by the experimental results and their interpretation in Section 3. The paper concludes with a summary in Section 4.

2. Experimental setup

A schematic top view of the sample is shown in Fig. 1(a). A GaAs/$Al_{0.3}Ga_{0.7}As$ heterostructure with a two-dimensional electron gas (2DEG) at 45 nm below the surface was used. The 2DEG has a mobility of $\mu = 34\ m^2\ V^{-1}\ s^{-1}$ and an electron density of $n_{2DEG} = 3.8 \times 10^{15}\ m^{-2}$ measured at 2 K. First, a Hall bar was patterned by standard optical lithography and wet chemical etching. Then, ohmic contacts were prepared by a second lithography step, followed by thermal evaporation of AuGe/Au and successive annealing. Afterwards, a ballistic quantum wire (QWR), was defined by the local anodic oxidation technique based on scanning probe lithography [15]. The geometric length and width of the wire was L = 500 nm and W = 400 nm, see Fig. 1(b). The Hall bar was covered with a homogeneous Cr/Au-film of 10 nm thickness which can be used as a gate for tuning the Fermi energy, and also avoids ambiguities by strain effects which may be present in case the ferromagnetic film were defined directly on top of the semiconductor surface. On top of the Cr/Au film, we evaporated a stripe of dysprosium (Dy) with a width of $\ell = 300$ nm and a height h = 250 nm, located at the center of the quantum wire and oriented along the y-direction, through a poly(methyl methacrylate) (PMMA) mask defined by electron beam lithography. Since the oxide lines are invisible in the electron microscope, the alignment of the Dy stripe with respect to the oxide lines was carried out with the help of gold markers that were patterned in a separate electron beam step. Their location with respect to the oxide lines was then measured with an atomic force microscope. These offsets were used to align the electron beam lithography pattern for the Dy stripe. The wire length L was kept sufficiently short to be able to observe conductance quantization [16,18] when the Dy stripe was not magnetized, which shows that the QWR is ballistic, as can be seen in Fig. 1(d) where the conductance of the wire is shown as a function of the top gate voltage V_{tg} with the coercive magnetic field applied such that the magnetic texture is absent [28]. In the measurements presented below the voltage of the top gate was kept constant at $V_{tg} = -135$ mV.