Transport in Ferromagnet/Semiconductor 2DEG Hybrid Network Structure

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Mesoscopic ferromagnet / semiconductor two-dimensional electron gas (2DEG) hybrid structures attract much interest not only as an experimental stage of novel magnetotransport phenomena but also as a prototype of future devices. We can study such systems from two different physical viewpoints; the magnetization process of a sub-micron scale ferromagnet and the transport in 2DEG under spatially varying magnetic field. In the past work, Johnson et al. detected the magnetization of a small ferromagnetic element by use of the local Hall effect [1]. We and other groups observed the so-called magnetic Weiss oscillations in 2DEG under 1D periodically modulated magnetic field which was generated by the stray field of an array of ferromagnetic strips [2]. In the present work, we investigate electronic transport in a novel hybrid structure which consists of a cobalt network and an etched GaAs/AlGaAs 2DEG network to explore the above-mentioned two aspects.

We fabricated a hybrid network structure as the following procedure. At first, we made a mesa of a network of a GaAs/AlGaAs single-heterojunction by chemical wet etching, which has a period 6μm and a width 1.5μm. Secondly, we placed a network of cobalt film, which has a width 0.5μm, on the surface of the etched 2DEG network. This system is similar to the device studied by Nogaret et al. [3] except that the ferromagnet/2DEG hybrid forms a network rather than a single wire. The device was fabricated in such a way that the electronic transport in the cobalt network could be measured simultaneously as that in the 2DEG network. Use of a cross-coil magnet system consisting of a 7T split coil and 1T solenoid enabled us to apply the horizontal and vertical magnetic field components independently.

Firstly, we set the magnetic field within the 2DEG plane at different azimuthal angle φ. Figure 2 shows the longitudinal resistance of the 2DEG network and the cobalt network for two orientations of the in-plane magnetic field $\varphi=0^o$ ($B\perp I$) and $\varphi=90^o$ ($B||I$). The resistance of the cobalt network exhibits the so-called anisotropic magnetoresistance (AMR) effect with hysteresis. The corresponding change in the resistance of the 2DEG is caused by the stray field. For $|B|>0.3T$ the magnetization of the cobalt network is saturated, and the resistance of 2DEG becomes constant. In the case of $\varphi=0^o$, the so-called snake orbits running along the line of zero magnetic field are parallel to the current direction. These orbits propagate in the direction determined by the sign of the magnetic field gradient. The contribution of the snake orbits to the conduction can be inferred from the behavior of the differential resistance under finite DC bias current. Figure 3 shows the change in the resistance difference ΔR_{xx} defined in Figure.2 as a function of the DC bias current. For $\varphi=0^o$, ΔR_{xx} changes linearly with the DC bias current in such a manner that the resistance is smaller when the current carrying direction of the snake states is the same as the DC bias current. For $\varphi=90^o$, such effect is absent.

Secondly, we measured the magnetoresistance as a function of a uniform perpendicular magnetic field while fixing the profile of the spatially varying magnetic field from the cobalt network by a relatively large in-plane magnetic field 5T. The spatial modulation of the magnetic field in the 2DEG network channel causes reduction of magnetoresistance and modulation of SdH oscillations. We also studied a magnetoresistance at higher field using 15T magnet in order to examine the effect of a gradient magnetic field on the quantum Hall effect.

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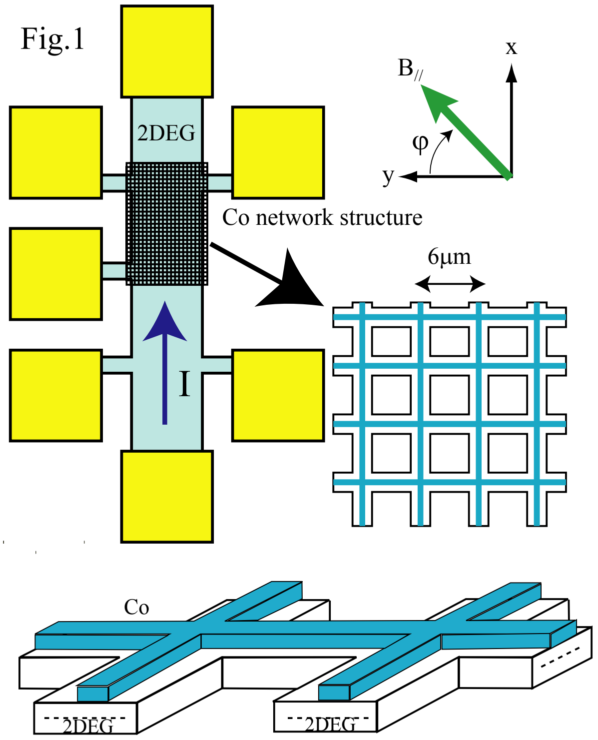
[2] S. Izawa et al., J. Phys. Soc. Jpn. **64** 706 (1995). H. A. Carmona et al., Phys. Rev. Lett. **74** 3009 (1995). P. D. Ye et al., Phys. Rev. Lett. **74** 3013 (1995).

[3] A. Nogaret et al., Phys. Rev. Lett. **84** 2231 (2000).



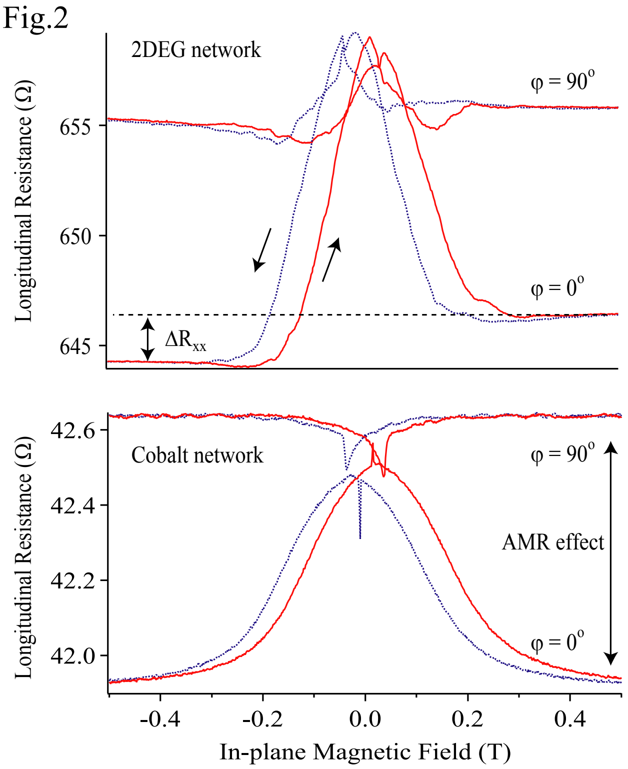
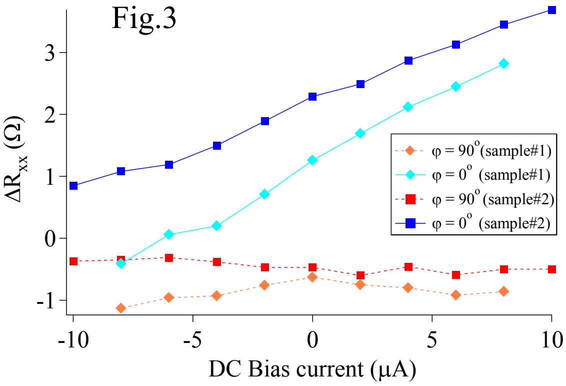


Fig.1. Schematic diagram of sample configuration.

Fig.2. Resistance behavior sweeping an in-plane magnetic field for $\varphi = 0^{o}$ or $\varphi = 90^{o}$.



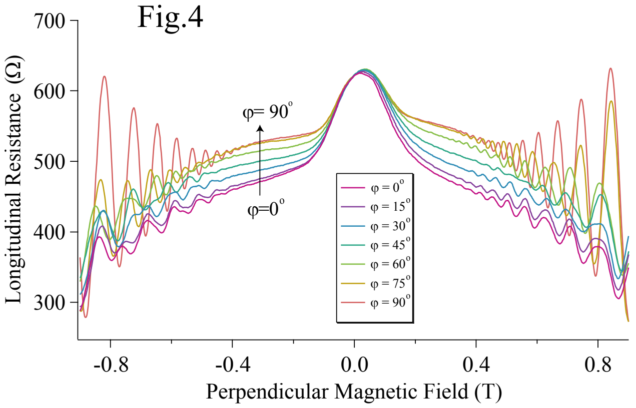


Fig.3. DC bias current dependence of the change of a differential resistance ΔR_{xx} as defined in Fig.2 for $\varphi = 0^{o}$ or $\varphi = 90^{o}$.

Fig.4. Magnetoresistance of a 2DEG network as a function of the uniform perpendicular magnetic field for different settings of the azimuthal angle φ of the parallel magnetic field 5T which keeps the spatially varying magnetic field from a cobalt network constant.