Transport in Two-Dimensional Electron Gas in Inhomogeneous Magnetic Field

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Abstract

Magnetotransport in two-dimensional electron gas (2DEG) under the influence of random magnetic field is studied. When the random component is turned on while keeping the average zero, the resistivity of the 2DEG shows an increase, which is proportional to the square of the random field amplitude. In the presence of a fixed random component, the system shows a large positive magnetoresistance as a function of the uniform magnetic field component. This positive magnetoresistance resembles that of a 2DEG around half-filled Landau level state and saturates at around the field value where the cyclotron radius crosses over the spatial correlation length of the random field.

Keywords: two-dimensional electron gas; random magnetic field

Two-dimensional electron gas (2DEG) in a spatially random magnetic field (RMF) has recently attracted much attention because of its relevance to the problem of half-filled Landau level. Spatially inhomogeneous magnetic field $B(\boldsymbol{r})$ can be generally decomposed into two components:

$$B(\boldsymbol{r}) = B_0 + \delta B(\boldsymbol{r}). \quad (1)$$

Here, $B_0 \equiv \overline{B(\boldsymbol{r})}$ is the uniform component and $\delta B(\boldsymbol{r})$ is the random component with zero average. There is a particular theoretical interest in the case of zero-average RMF, i.e. $B_0 = 0$ and $\delta B \neq 0$, that extended states might exist, which is considered exceptional for a two-dimensional system [1]. On the other hand, the case of varying B_0 around zero in the presence of RMF is relevant to the magnetoresistance of a 2DEG around half-filled Landau level state [2].

Here we present experimental results on 2DEG in RMF. By using a cross-coil system consisting of a 6T split-coil superconducting magnet and a small homemade solenoid, we were able to control the random component δB and the uniform component B_0 independently. Samples used in this study are GaAs/AlGaAs single heterojunctions with a standard Hall bar geometry decorated by randomly patterned dysprosium-copper alloy (DyCu) film on top of the current channel. A 300Å thick uniform gold frontgate was deposited prior to the deposition of DyCu. The electron density and

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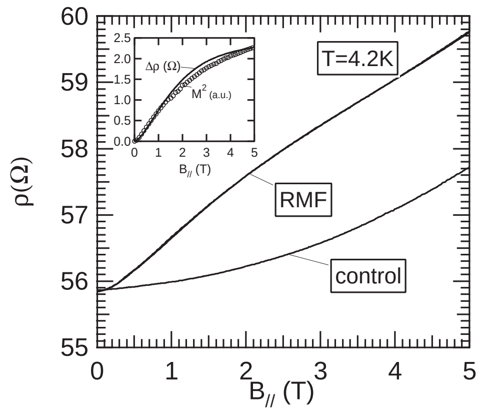

Fig. 1. Resistance of the 2DEG with and without randomly patterned DyCu. There is an excess resistance in the former sample with increasing amplitude of the RMF.

mobility of the 2DEG at 4.2K are $2.79 \times 10^{15}\mathrm{m}^{-2}$ and $40\mathrm{m}^2/\mathrm{Vs}$, respectively. This corresponds to the electron mean free path 3.5μm, while the mean spacing between the micropatterned DyCu islands is about 1μm. Strong magnetic field up to 5 Tesla applied parallel to the 2DEG plane magnetizes the randomly patterned DyCu to produce random magnetic field at the 2DEG plane while keeping the average perpendicular field zero.

Figure 1 shows the resistivity of the 2DEG as a function of the in-plane field, together with the data for a control sample without the patterned DyCu. The resistance of the former shows a considerably larger increase than the control sample as the random field is turned on. The difference of the resistivity between the RMF sample and the control sample is shown in the inset. It is roughly proportional to the square of the magnetization M^2 of the DyCu measured with a SQUID magnetometer. This corroborates the expectation that the additional scattering rate caused by the RMF is proportional to the square of the RMF amplitude.

Next, we measured the resistance as a function of the uniform component B_0 of the perpendicular field up to 0.7T with the random field component δB fixed by a strong in-plane field $B_{\|} = 5$T. As seen in Fig. 2, the magnetoresistance in the presence of RMF has some distinctive features. The magnetoresistance is positive and saturates at $\sim$ 0.3T, where the cyclotron radius crosses over the correlation length of the RMF. The characteristic feature of the magnetoresistance curve near $B_0 = 0$ is observed commonly in different samples. It resembles the feature observed in ρ_{xx} near $\nu = 1/2$ in some high mobility 2DEGs [3]. Although the origin of this feature is not clear at the moment, it is noted that this feature is only observed when the mean free path of the 2DEG is fairly long compared to the spatial correlation length of the RMF. When a negative bias voltage on the front gate lowers the mobility of the 2DEG, the behavior of the magnetoresistance becomes close to that of the control sample.

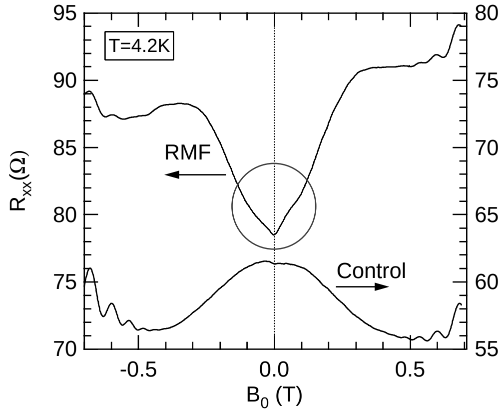

Fig. 2. Magnetoresistance as a function of B_0 in the RMF and control samples.

To conclude, we have studied the 2DEG in a RMF, controlling B_0 and δB independently and observed a feature in the magnetoresistance curve similar to that of a 2DEG near half-filled Landau level state.

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