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Electron–electron umklapp scattering in two-dimensional electron gas under lateral magnetic periodicity

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Abstract

Two-dimensional electron gas at GaAs/AlGaAs heterointerface subjected to a lateral magnetic superlattice exhibits a T^2-dependent excess resistivity, which is attributed to electron–electron umklapp scattering. The current density dependence of the excess resistivity proves that the phenomenon is governed by the electron temperature. The umklapp scattering gives rise to a transverse component of resistivity in the case of an oblique lateral superlattice. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: 2D electrons; Electron–electron umklapp scattering; GaAs/AlGaAs; Lateral magnetic superlattice

Recently, we and other workers have shown that a two-dimensional electron gas (2DEG) at GaAs/AlGaAs heterointerface subjected to a lateral magnetic superlattice, i.e. a spatially periodic magnetic field modulation with zero mean, exhibits an excess resistivity, which shows a characteristic T^2-dependence at low temperatures [1–3]. Similar effect is also reported for electrostatic potential modulation [4]. The T^2-term is attributed to the electron–electron umklapp scattering, which is absent in a plain 2DEG but can occur in the presence of the imposed superperiodicity. In this paper, we present two kinds of phenomena which corroborate the above identification; the anisotropy of the effect and the dependence on electron temperature.

The samples were fabricated from a GaAs/AlGaAs single heterojunction wafer with carrier density $n_e \approx 3.4\times10^{15}\ \mathrm{m}^{-2}$ and mobility $\mu \approx 60\ \mathrm{m}^2/\mathrm{V\,s}$ at 4.2 K. A grating gate electrode was fabricated on top of the current channel of a standard Hall bar pattern. The grating gate consisted of ferromagnetic metal (cobalt) strips with thickness 60 nm and width 250 nm, placed at a 500 nm period, as shown in the inset of Fig. 1. The ferromagnetic grating was magnetized by a strong external field applied exactly parallel to the 2DEG plane. When the field is parallel (perpendicular) to the modulation wavevector, the spatial modulation amplitude of the fringing field is maximum (zero). The modulation amplitude at the 2DEG plane can be known from analysis of the commensurability oscillation of magnetoresistance (magnetic Weiss oscillation). The maximum amplitude for the present sample geometry was 52 mT. The temperature dependence of resistivity was measured in zero average perpendicular field, for different values of the magnetic field modulation amplitude. Three types of samples with different angles of the modulation wave vector with respect to the current direction, parallel, perpendicular and 45° oblique, were studied.

The lower right inset of Fig. 1 shows the temperature dependence of resistivity in the 45° oblique grating sample, with the magnetic field modulation turned on and off. The excess longitudinal resistivity $\Delta\rho_{xx}$ is defined as the difference between the two data, and is plotted against T^2 in the main panel with solid circles. They obey the relation $\Delta\rho_{xx}(T) = AT^2 + C$, as we reported in our previous papers [1,2]. Also shown here is the transverse resistivity ρ_{xy} (open circles), which occurs only in the case

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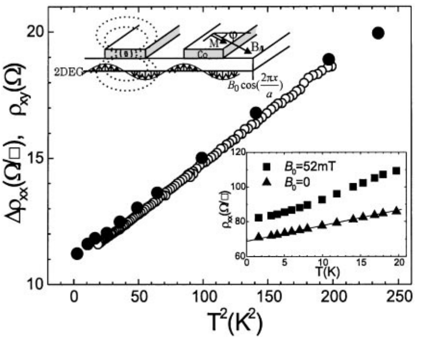

Fig. 1. Upper left inset: Schemetic of sample geometry. Lower right inset: The temperature dependence of resistivity in the presence and absence of the magnetic field modulation. Main panel: The excess longitudinal resistivity and the transverse resistivity plotted against T^2.

of oblique lateral superlattice. It is seen that the relation $|\rho_{xy}(T)| = \Delta\rho_{xx}(T)$ holds very well for the 45° oblique grating, indicating that both the transverse resistivity and the excess longitudinal resistivity are caused by the same back scattering process. In the sample with the modulation wave vector perpendicular to the current channel, the resistivities in the presence and absence of the magnetic field modulation shows no difference. These results provide compelling pieces of evidence that the observed effect is associated with the umklapp process.

The inset of Fig. 2 shows resistivity as a function of current density with the sample kept at the lowest temperature (1.25 K) in the presence and absence of the magnetic field modulation. The current density independence in the latter case ensures that there is no Joule heating effect in this range. The current dependence in the former case is attributed to increased electron–electron scattering at higher electron temperature. The electron temperature can be estimated from the standard analysis of the Shubnikov–de Haas oscillation amplitude.

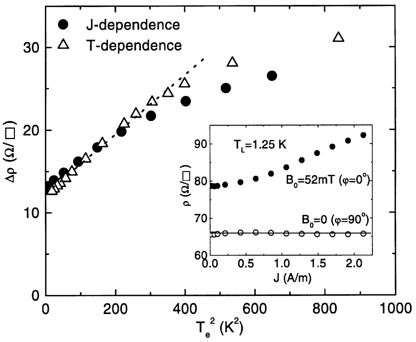

Fig. 2. Inset: The resistivity as a function of the current density. Main panel: The excess longitudinal resistivity plotted against T^2. The triangles and the circles represent the lattice and electron temperature dependence, respectively.

The main panel of Fig. 2 shows the dependence of the excess resistivity on the electron temperature, in comparison with the data of the (lattice-)temperature dependence. The agreement between the two sets of data indicates that the excess resistivity is governed by the electron temperature and hence is associated with the electron–electron scattering process.

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