Zero-resistance states induced by electromagnetic-wave excitation in GaAs/AlGaAs heterostructures

R. M. MacFarlane, J. R. Schmiedmayer, B. J. Johnson, and V. Umansky

The observation of vanishing electrical resistance in condensed matter has led to the discovery of new phenomena such as, for example, superconductivity, where a zero-resistance state can be detected in a metal below a transition temperature T. Here we report the observation of zero-resistance states and energy gaps in a surprising setting: all-aluminium-oxide GaAs/AlGaAs heterostructures that contain a 2DEG exhibiting vanishing diagonal resistance without Hall-resistance quantization at low temperatures and low magnetic fields when the specimen is subjected to electromagnetic wave excitation. Zero-resistance states occur at magnetic fields B = 1.98 T and B = 3.6 T, where \( \rho_{xx} \approx 2 \times 10^{-3} \Omega \cdot m \) is the electron mass, \( \omega \) is the electron charge, and \( \omega \) is the electromagnetic wave frequency. Activated transport measurements on the resistance minima also indicate an energy gap at the Fermi level. The results suggest an unexpected radiation-induced electron-state transition in the GaAs/AlGaAs 2DEG.

Figure 1 shows the dependence of the \( \rho_{xx} \) oscillators. For gap frequencies of 40 GHz (not shown), \( \rho_{xx} \) exhibits just a minimum at 4.7 GHz. A data fit with exponentially damped oscillations suggests that the radiation-oscillation frequency increases linearly with \( \omega \) and that the oscillation amplitude decay in \( \omega \) is characterized by a \( \omega \)-independent damping parameter. An analysis of the data using \( \rho_{xx}(\omega) = \rho_{xx}(0) + \rho_{xx}(\infty) \left( 1 - \frac{\omega^2}{\omega_0^2} \right) \), where \( \omega_0 = 2 \pi \times 10^9 \), yielded \( \rho_{xx}(\infty) = 6.9 \times 10^{-6} \), consistent with expectations for GaAs (refs 9, 11, 12). Over the intermediate frequency range (Fig. 1b), a zero-resistance state is first observed at 3.5 GHz. This shifts to higher \( \omega \) with increasing \( \omega \). Similar behaviour continues onto the

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becomes evident around $h$.

Here, the sample quality seems shown in Fig. 3b demonstrate insensitivity to the current and the Landau level broadening, $\Delta E_N$, here $E$ is the transport mean free path, $\Delta E_N = 2\sqrt{\hbar q/2m}$.

The transport life-time, $\tau = q/2\hbar \Delta E_N$. The single particle lifetime $\tau_0 \approx 4 \times 10^{-15} s$, $\tau_0 \approx 3.4 \times 10^{-14} s$ indicative of somewhat small angle scattering$^{1\text{1}}$. The predominance of small angle scattering, and a 7–10 times higher sample mobility, differentiates these the samples examined in ref. 7. We attribute the occurrence of zero-resistance states in our study, and the lack of them in ref. 7, to these differences. Notably, level broadening determined from $T_N$ suggests that the density of states at $h$ looks approximately like that at $h = 0$ (ref. 3e).

In traditionally in systems, cyclotron resonance is independent of electron–electron interactions and consists of $n = h_N + \frac{1}{2}$, our samples include impurity scattering, surface roughness, and a Hall electric field, which could make possible transitions at $h_N = h_{\text{Bar}}$.

In a bounded specimen, the collective plasma mode can also hybridize with cyclotron resonance, yielding magnetoplaismons at $B > 0$ (refs 16, 17), a search for plasma frequency, $\omega_{\text{p}}$ (ref. 16), activity produced a null result$^{1\text{1}}$. In addition, $\omega_{\text{Bar}}$ under radiation does not directly manifest the bare cyclotron resonance ($h_{\text{Bar}}$), or its harmonics ($h_{\text{Bar}}$, as evidenced by the phase of the resistances to the magnetic field.

The dependence of the magnetoresistance upon the radiation power, current and temperatures. Note that additional, reproducible, weak resistance oscillations occur about $B = 0$, when Landau level quantization is imperceptible.

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