EDGE MAGNETOPLASMONS IN THE QUANTUM HALL EFFECT REGIME

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Edge magnetoplasmons are studied in GaAs/AlGaAs heterojunctions of a typical size of 3×3 mm^2 in the regime of the quantized Hall effect at frequencies below 500 MHz and low temperatures. The resonance frequency scales with integer Landau level filling factor. With increasing temperature, in the 0.4–4 K temperature range, the resonance frequency decreases slightly, whereas the linewidth increases about linearly with temperature. The experimental results are compared to theoretical predictions.

Edge magnetoplasmons (EMP) are collective electronic excitations propagating along the perimeter of a bounded quasi two-dimensional electron system (2DES). Driven by the Hall conductivity σ_{xy} and little damped by the dissipative conductivity σ_{xx} they may be considered as the dynamical equivalent of the Hall effect. Experimentally they have attracted much recent attention, both in a classical 2DES on the surface of liquid helium [1,2] and in a degenerate 2DES of GaAs/AlGaAs heterojunctions [3–6], where they have been observed in the frequency regime $\omega\tau \gg 1$ ($\tau = m^*\mu/e$) [3] and $\omega\tau \ll 1$ [4,6]. Their resonance behavior has been calculated classically as a 2D limiting case of 3D depolarisation [3,7]. A strictly 2D approach has been used by Volkov and Mikhailov [8] by introducing a characteristic length l within which the EMP is located at the perimeter of the 2DES.

Here we study the EMP spectrum experimentally in the regime of the integer quantum Hall effect on GaAs/AlGaAs heterojunctions containing a 2DES with mobility $\mu \geq 10^5$cm^{-2}/V·s and areal electron density $n_s \simeq 3\times 10^{11}$cm^{-2} in the low frequency regime $\omega\tau \ll 1$. Our experiments focus on the temperature dependence of the resonance frequency and linewidth in the temperature regime between 0.4 and 4.2 K. We excite an EMP at radio frequencies by using a coupling technique that avoids strong perturbation of the EMP mode. We attach the center conductor of an open ended coaxial cable, fed by the RF source and oriented normal to the sample plane, to one edge of an GaAs/AlGaAs sample typically 3×3 mm^2 large. We use a second coaxial cable attached to the opposing edge of the sample to detect the EMP mode in transmission. With a strong magnetic field applied perpendicularly to the sample plane, we observe strong transmitted signals on resonance, provided the damping of the EMP is sufficiently small. Classically, one would expect that well defined EMP resonances should become observable at frequencies $\omega\tau \ll 1$ whenever $\sigma_{xy}/\sigma_{xx} = \mu B \gg 1$ [3,6]. In this regime the resonance frequency ω_0 of the lowest mode is expected to be proportional to σ_{xy}/P, where P is the sample perimeter. Experimentally, at magnetic fields with $\mu B \gg 1$ we only observe EMP resonances whenever the Landau level filling factor hn_s/eB is close to an integer ν so that the conductivity σ_{xx} approaches a minimum.

Typical transmitted signals for the lowest EMP mode for a sample of carrier density $n_s = 2.6\times 10^{11}$ cm^{-2} at different magnetic fields corresponding to integer filling factors $\nu = 1$, 2 and 4, respectively, are shown in fig. 1 at our lowest temperature. We have studied similarly well defined EMP resonances in

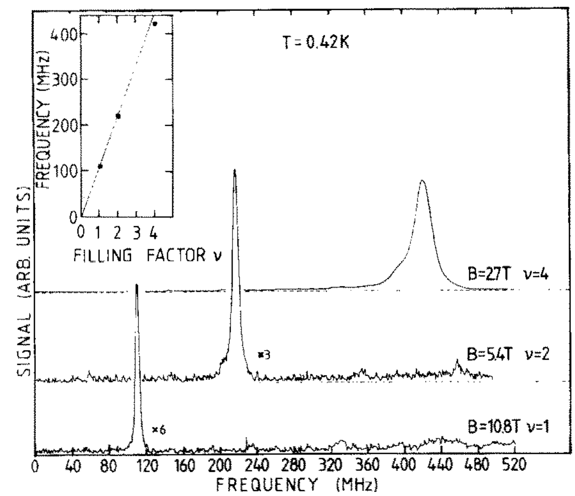

Fig. 1. Transmitted RF signal at different magnetic fields showing the lowest EMP resonance for a sample with carrier density $n_s = 2.6\times10^{11}$ cm^{-2} at a temperature of $T=0.42$ K. The inset shows the dependence of the resonance frequency on the integer filling factor ν.

many samples and at temperatures up to 4.2 K. In fig. 2 we present the dependence of the resonance frequency $\omega_0/2\pi$ and the linewidth (full width at half heights) on the magnetic field (fig. 2a) and temperature (fig. 2b) for the lowest EMP mode around filling factor $\nu=2$. The observed linewidth exhibits a minimum around $\nu=2$ (fig. 2a) and this minimum value increases about linearly with increasing temperature (fig. 2b). Around a given filling factor the dependence of the resonance frequency on magnetic field B deviates from the $1/B$-behavior expected classically and seems to approach a plateau, as shown in fig. 2a around $\nu=2$. The value of ω_0 is found to vary to good accuracy linearly with integer ν and thus with σ_{xy} as demonstrated in the inset of fig. 1. As visible in fig. 2b for $\nu=2$ the resonance frequency at integer ν decreases with increasing temperature. Generally we find that increased damping results in a decreasing ω_0 in agreement with ref. [5]. Though suggested by the appearance of a plateau-like structure around a given ν and by the linear dependence on ν we thus conclude that the resonance frequency ω_0 is not exclusively controlled by the quantized Hall conductivity $\sigma_{xy}=\nu e^2/h$. In many calculations ω_0/σ_{xy} is expected to depend logarithmically on the magnetic field [5,8]. For the quantized Hall regime ref. [8] also predicts that ω_0 is a power law of temperature. Neither of the two predictions can be verified by our experimental results.

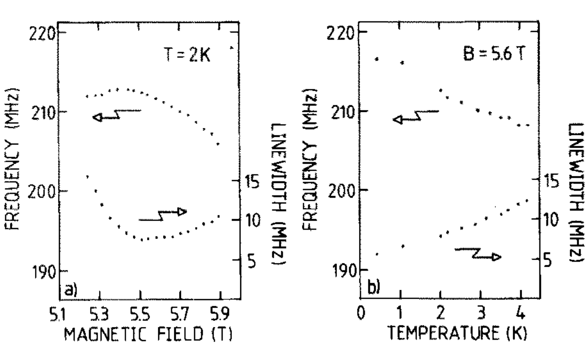

Fig. 2. Dependence of the resonance frequency (left scale) and linewidth (right scale) of the lowest EMP mode around filling factor $\nu=2$ on the magnetic field (a) and temperature (b).

Similarly we cannot use present theories to satisfactorily describe the observed linewidth and its dependence on the magnetic field and temperature. Using a classical $\sigma_{xx}=\sigma_0/(1+\mu^2B^2)$ and $\mu = 5\times10^5$ cm^2/V·s one predicts a linewidth of about 1.5 MHz for the data in fig. 2 significantly smaller than observed. Also, studying various samples with different mobilities $\mu > 5\times10^5$ cm^2/V·s we do not find a simple correlation between EMP linewidth and DC mobility. For the quantized Hall effect regime Volkov and Mikhailov [8] predict a damping independent on temperature at variance with our observations. Also in an attempt to use their theory to describe some of our results it remains unclear which physical meaning is attached to the length l that appears both in their expressions for the resonance frequency and the linewidth of the lowest EMP mode.

On a particular sample we also have observed additional EMP modes with frequencies above ω_0. As in previous work [5] we relate these modes to higher harmonics in which the EMP wavelength is a fraction of the sample perimeter. However in contrast to ref. [5] we do not find those modes to follow a simple harmonic law $\omega = n\omega_0$ $(n=1,2,3,...)$. The details of these results will be discussed elsewhere.

In conclusion we have extensively studied EMP resonance frequencies and linewidths on large perimeter (~10 mm) GaAs/AlGaAs heterojunctions in the magnetic and temperature regime of the quantized Hall effect using a simple direct excitation and detection scheme. Comparison of our experimental results with various theoretical models demonstrates that a detailed understanding of the EMP frequency is still missing. Even less clear are the mechanisms that control the damping of such EMP resonances in the quantized Hall effect regime. Particularly it remains to be understood why the extended plateaus observed in our samples in measurements of the DC Hall resistivity ρ_{xy} are not reflected equally well in the EMP resonance frequency.

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