The Study of Sub-millimeter Wave Induced Zero Resistance Effect at $^3$He Temperature

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Introduction
Microwave induced resistance oscillations (MIROs) and zero resistance state (ZRS)[1,2] in the ultra high mobility two-dimensional electron system have attracted an intense interest recently. Under the illumination of an intense microwave radiation in the millimeter regime, the system exhibits a unique resistance oscillation with a microwave-frequency-dependent period. Earlier experimental works were all limited in low frequency range, and recently there have been attempts to increase the radiation frequency. But all these high frequency experiments were at $^4$He temperatures. We have recently built a $^3$He infrared probe, which allows in-situ electrical transport and IR transmission measurements at high magnetic fields. Our goal was to study the evolution of MIROs with increasing frequency of the radiation. Higher frequencies and lower temperatures allow determining whether this effect breaks down or evolves into new phenomena at higher fields and separating the fundamental excitations of the system, cyclotron resonance between LLs, spin-splitting of LLs, and magnetoplasmon modes.

Experimental
The magnetoresistance is measured by the standard low frequency lock-in technique and the double modulation technique is employed to directly probe the photoresistance. The radiation was generated by either BWO or FIR laser and sent to the sample, immersed in the refrigerated $^3$He. Transmittance is measured by a Si bolometer, and this setup offers a wide range of operating temperatures and the cryostat is designed to fit in a 31T resistive magnet.

Results and Discussion
A set of photoresistance data is plotted in Fig. 1 in which the position for $\varepsilon=1$ in each trace is marked by a downward arrow and a hint of a resistance maximum can be found around the arrows. As shown in the figure, the primary resistance minimum in each trace is fitted by a broad Lorentzian to locate its position. Instead of having the primary resistance minima ($j=1$) at $\alpha=1/2$ or 1/4 positions, these resistance minima now occur near the resonance of the MP frequency, $\omega_{mp} = \sqrt{(\omega_0^2 + \omega_c^2)}$, where $\omega_0$ is the plasmon frequency. This result is clearly evident as the photoresistance is plotted against the normalized magnetic field, $B/B_n$, where $B$ is the applied magnetic field and $B_n$ the field where CR frequency equals the radiation frequency, as shown in the top panel of Fig. 2. By scaling the magnetic field, the ordinary resistance oscillation should be roughly aligned. This procedure manifests itself by showing the unique $\varepsilon$=2 resistance peak aligned at $B/B_n=0.5$. The higher order harmonics of RIRO, though severely suppressed, can be found around $j=2,3,$ and 4.

Conclusions
We have investigated the submillimeter wave induced resistance oscillation up to 2.5THz at $^3$He temperatures in two ultra-high mobility GaAs/AlGaAs samples. RIROs have been observed for both samples, although the Corbino ring has more pronounced effect. None of the resistance minima have reached zero over the frequency range investigated due to reduced radiation intensity. The primary resistance minimum occurs near the MP frequency of the sample, which can be viewed as the deviation $\alpha$ for $j=1$ systematically evolves from $\alpha=1/4$ towards zero with increasing radiation frequency. This result suggests that the magnetoplasmon modes may play a role in RIRO for small samples within this frequency regime.

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References