Microwave Absorption of Edge States in Quantum Hall Droplets

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Outline

- Background
- Setup
- System calibration
- Test with CR
- Discussion and Modification
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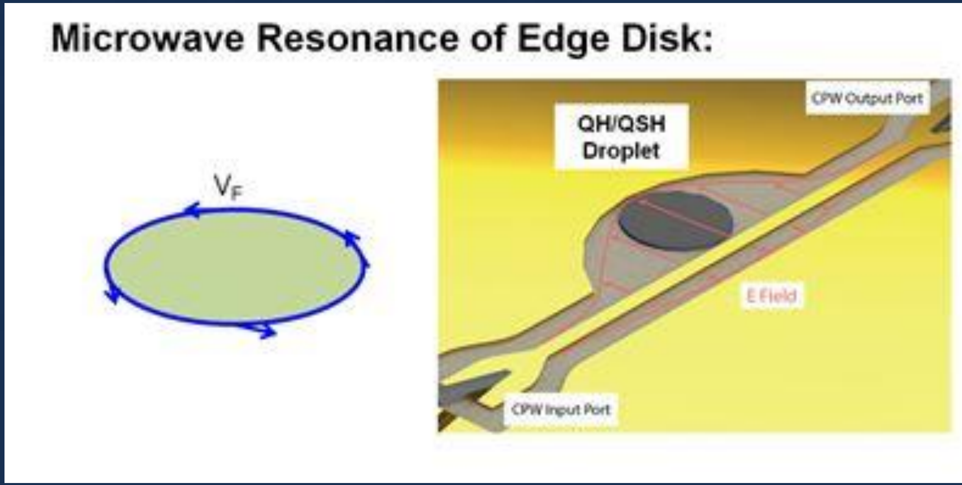


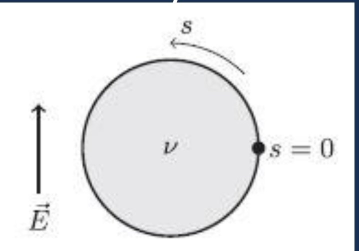
Introduction

Adapted from ref[2]

- Edge state on two dimensional electron gas – pure one dimensional dissipationless edge
- Investigating the number and velocity of the charge mode
- Microwave absorption spectroscopy (~GHz)
- High mobility GaAs/AlGaAs circular disc sample ($n_e \sim 1 \times 10^{11}/\mathrm{cm}^2$, $\mu \sim 15\mathrm{Mcm}^2/\mathrm{V \cdot s}$) patterned by lithography (~ um)

Calculation of resonant frequency

- Minimum energy of the excitations of the edge of a quantum Hall droplet -- $2\pi\hbar\upsilon/L$, Circumference of the droplet $L = 2\pi \mathrm{R}$, velocity of the charge mode $\upsilon \sim 10^4 - 10^5 \mathrm{m/s}$



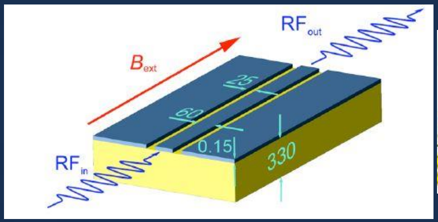
(a) Circular droplet without QPC

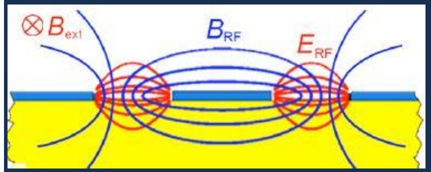
Adapted from ref[2]

- Matching incident microwave energy -- $\hbar\omega_M$ => $\boxed{\upsilon = R\omega_M}$
- Velocity of electrons go on cyclotron motion under magnetic field $\upsilon = 2 f_c l_B = 2\frac{\omega_c}{2\pi} l_B$, where $\omega_c = \frac{eB}{m^* m_0}$, $l_B = \sqrt{\frac{\hbar}{eB}} = \frac{257}{\sqrt{B}}$ Å
- For electrons in GaAs/AlGaAs:

$$\boxed{R_e = \frac{\omega_c}{\omega_M} \cdot \frac{l_B}{\pi} = \frac{eB}{m^* m_0} \cdot \frac{257\text{Å}}{\sqrt{B}} \cdot \frac{1}{2\pi^2 f_M} = 3.4\mathrm{um}\,\frac{\sqrt{B}}{\mathrm{GHz}}}$$

Experimental setup I





- Co-planar meander line waveguide
  adapted from ref[3]

- Broad-band sample holder with mini-SMP connector
- Co-axial cable transmission probe
- He_3 top loaded cryostat

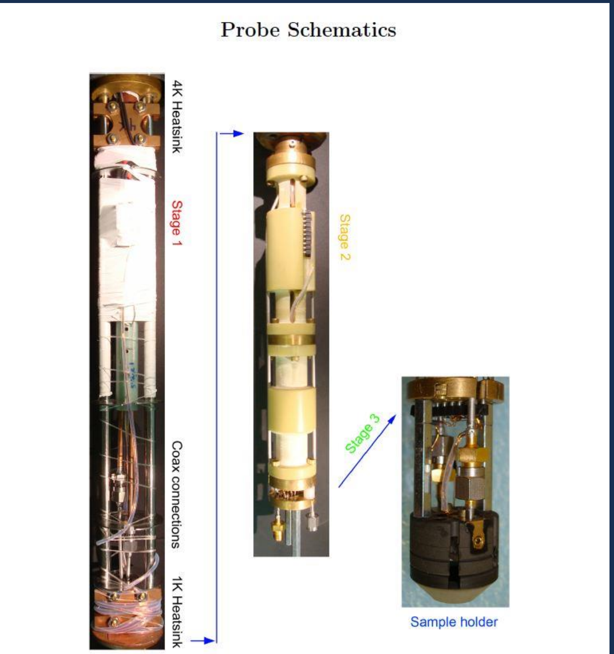
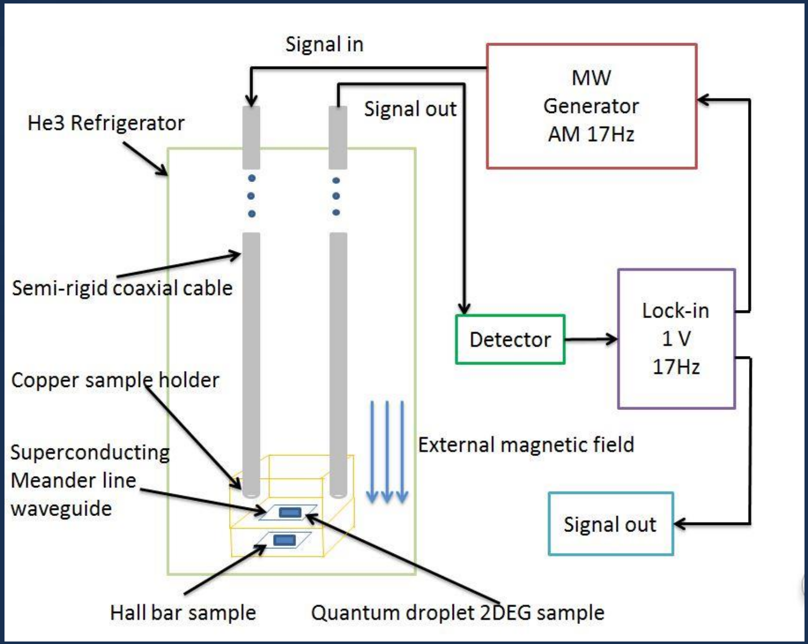


Figure D.1: Pictures of the probe stages: 4K, 1K, and the sample holder.

Experimental setup II



Measuring tools :

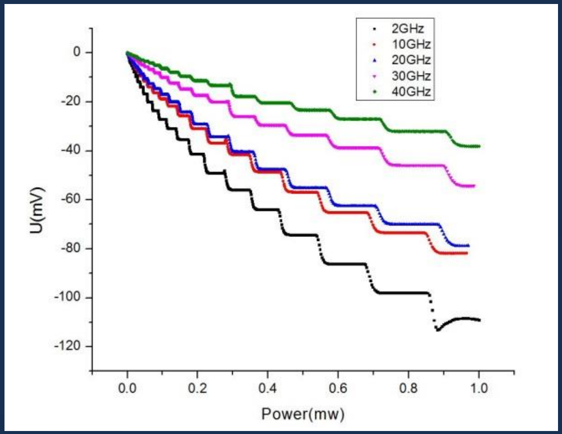
- Microwave generator (2-40GHz)
- Schottky diode detector (10MHz-40GHz, +20dbm max)
- Lockin amplifier for small signals (negative voltage from detector)

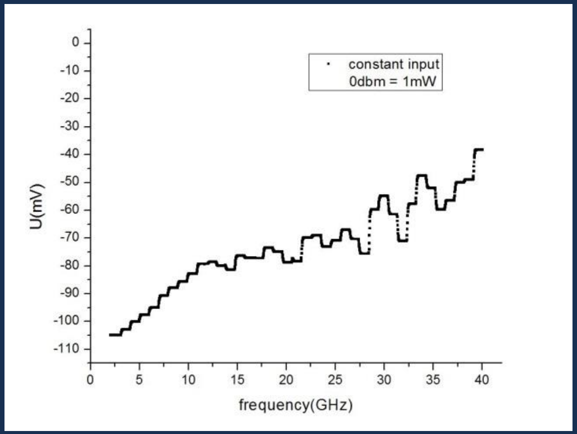
Measuring technique :

- Amplitude modulation at 17Hz

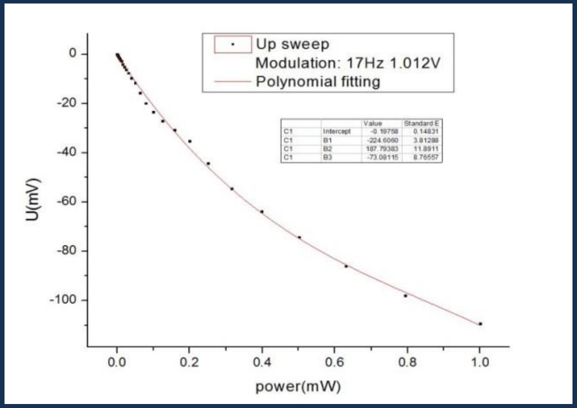
System calibration

- Output voltage vs. input power at different frequency (sampling every 1dbm)



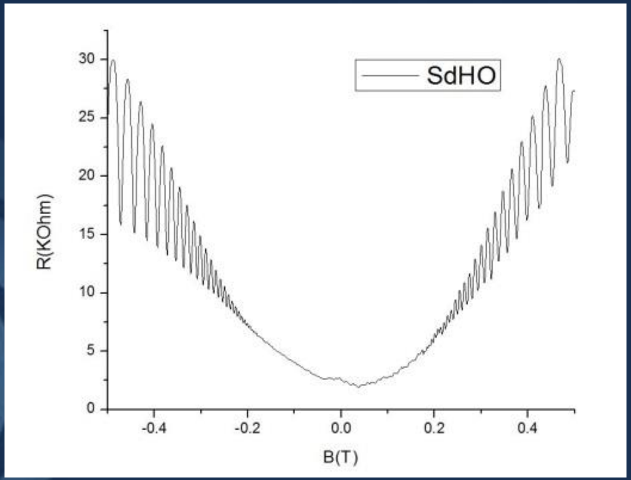


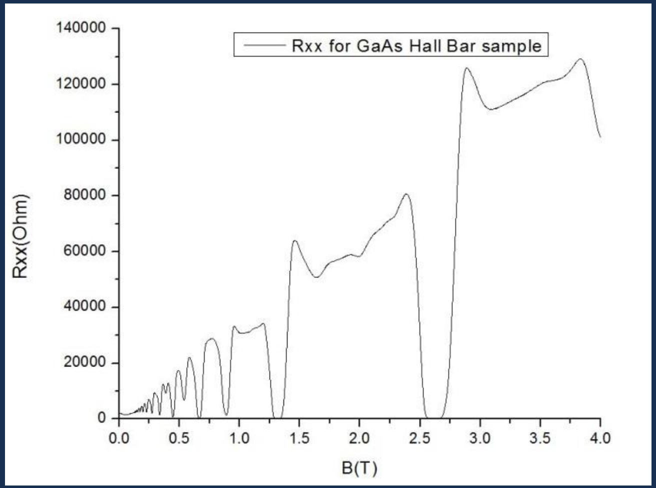
- Output voltage vs. input frequency at constant power (fluctuations at large frequency)
- Polynomial fitting at 2GHz

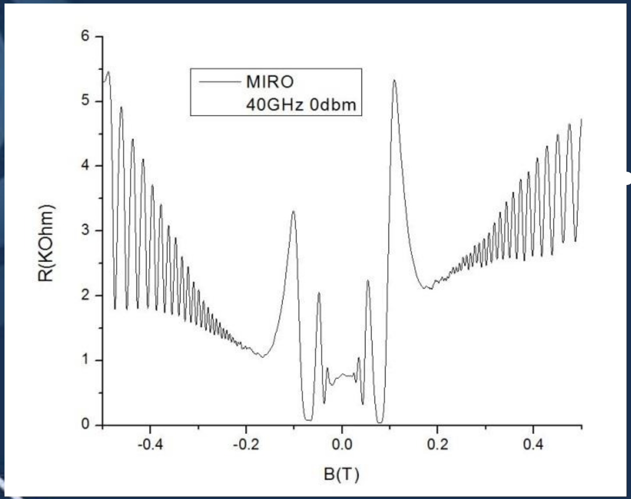


Transport measurement (Hall bar sample)

- Shubnikov–de Haas oscillations (SdHO)
- Integer Quantum Hall Effect (IQHE)



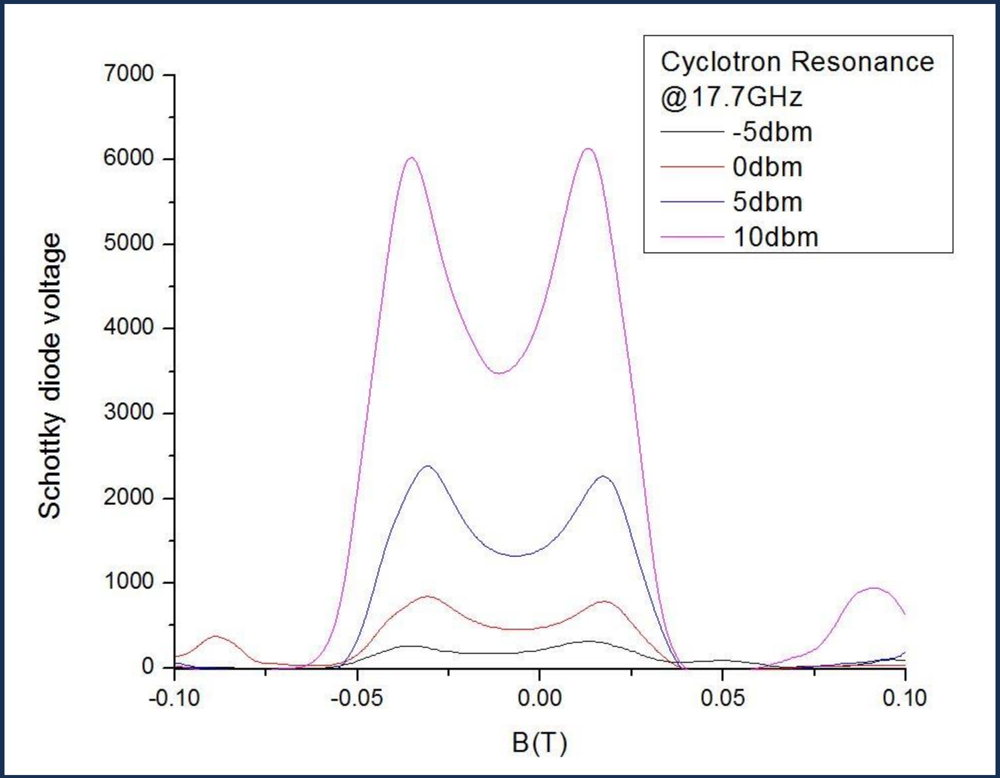




- Microwave Induced Resistance Oscillations (MIRO)
- Zero Resistance State (ZRS)

Demonstration with Cyclotron Resonance for microwave absorption spectroscopy

- Symmetric resonance peaks
- Larger signal with higher input power



Issues for resonance detection:

- Unable to see authentic repeatable edge state absorption peaks
- There are sudden bursts of noise due to reflection and thermal fluctuation

Possible reason:

- Noise level too high
- N-grease too thick for electric field to probe edge state
- Current equipment precision is not high enough to resolve the edge state absorption

Modification:

- Fabricate dot pattern 2DEG and meander line waveguide on the same sample
- Reducing noise level by eliminating possible reflections on connections

Reference

- [1] Kristjan Jakob Stone, PhD thesis, *Millimeter Wave Transmission Spectroscopy of 2D Electron and Hole Systems*.
- [2] Jennifer Cano, Andrew C. Doherty, Chetan Nayak, and David J. Reilly *Microwave absorption by a mesoscopic quantum Hall droplet* Phys. Rev. B 88, 165305 (2013)
- [3] C. Clauss, D. Bothner, D. Koelle, R. Kleiner, L. Bogani, M. Scheer, and M. Dressel *Broadband electron spin resonance from 500 MHz to 40 GHz using superconducting*
- [4]*coplanar waveguides* Applied Physics Letters (2013), Bd. 102, H. Article 162601, S.

Thank you!