Magnetoplasmon resonance in a two-dimensional electron system driven into a zero-resistance state

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Outline

• Introduction
  • Microwave-induced zero-resistance states
    • Absolute negative resistance and domains
    • Magnetoplasmon resonance (MPR)

• Motivation
  • Can one probe absolute negative resistance using MPR?

• Experimental results
  • Concurrent observation of MPR and ZRS

• Summary
Microwave-induced resistance oscillations

• MIRO are controlled by:

\[ \epsilon \equiv \frac{\omega}{\omega_c} = \frac{2\pi m^*}{e} \frac{f}{B} \]

Zudov, Du, Simmons, Reno, PRB 64, 201311(R) (2001)
Ye, Engel, Tsui, Simmons, Wendt, Vawter, Reno, APL 79, 2193 (2001)
Zero-resistance states (ZRS)

$R_{xx} \Omega$

$B \text{ kG}$

$T = 1 \text{ K}$

$f = 57 \text{ GHz}$


ZRS and current domains

- Current-Voltage curve of irradiated 2DES:
  - negative resistance (at low currents)
- Negative resistance is unstable! ZRS!
- Current domains with $j_0$

Studies with bichromatic microwaves

Zudov, Du, Pfeiffer, West, PRL 96, 236804 (2006)
Magnetoplasmon resonance (MPR)

• 2D Plasmon:

\[\omega_p^2 = \frac{e^2 n_e \pi}{2\varepsilon_0 \varepsilon m^* w}\]

• Magnetoplasmon:

\[\omega^2 = \omega_C^2 + \omega_p^2\]

**MPR as a probe of negative resistance?**

- **Question:**
  - Can one use magneto-plasmon resonance to probe absolute negative resistance?

- **The tuning:**
  - ZRS and MPR have different dispersions:
    - **MIRO minimum:** \( \omega_c = (i + 1/4)^{-1} \omega \)
    - **MPR:** \( \omega_c = \sqrt{\omega^2 - \omega^2_p} \)

- One can adjust microwave frequency and overlap MPR and ZRS

Hatke, Zudov, Watson, Manfra, PRB 85, 121306(R) (2012)
Previous observations of MPR/MIRO/ZRS

- ZRS is destroyed completely
  - even in ultra high mobility samples!

Yang, Du, Pfeiffer, West, PRB 74, 045315 (2006)
Bykov, JETP Lett. 87, 551 (2008)
Unusual properties of the MPR peak

• The MPR peak is:
  1). Strong!
  • similar to MIRO
  • order of magnitude larger than dark resistance

2). Narrow!
• ZRS is not completely destroyed but split into two parts

Hatke, Zudov, Watson, Manfra, PRB 85, 121306(R) (2012)
MPR dispersion

- Dispersion:
  \[ \omega^2 = \omega_c^2 + \omega_p^2 \]

- Plasmon (calculated):
  \[ f_p \approx 107 \text{ GHz} \]

- Plasmon (measured):
  \[ f_p \approx 112 \text{ GHz} \]
Negative magnetoresistance

- Deep minimum:
  \[ B_0 \approx 1 \text{ kG} \]

- Low T:
  \[ \frac{\rho_{\min}}{\rho_0} \approx 0.2 \]

- Temperature dependence is strongest at lowest temperature

Hatke, Zudov, Reno, Pfeiffer, West, PRB 85, 081304(R) (2012)
Probing negative resistance

- Origin of MPR photoresistance:
  - no theory!
  - likely originates from heating
- The idea:
  - Fit the MPR peak with a Lorentzian
- The fit generates
  - Negative background:
    \[ \approx -0.45 \, \Omega \]

Hatke, Zudov, Watson, Manfra, PRB 85, 121306(R) (2012)
• In the ZRS regime
  • Negative background

• Outside the ZRS regime:
  • Positive background

Hatke, Zudov, Watson, Manfra, PRB 85, 121306(R) (2012)
Summary

- Photoresistance due to MPR can be several times larger than dark resistance
  - Due to strong negative magnetoresistance
- When overlapped with a zero resistance state, MPR can be used to probe absolute negative resistance

Hatke, Zudov, Watson, Manfra, PRB 85, 121306(R) (2012)