Random telegraph photosignals in a microwave-exposed two-dimensional electron system

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The magneto-resistance of high-mobility two-dimensional electron systems exposed to microwaves exhibits radiation-induced oscillations with some minima approaching zero within experimental accuracy. Consensus has been reached that they originate from disorder-assisted indirect optical transitions and a non-equilibrium population of the electronic states. Both mechanisms capture the hall-marks of the observed oscillations except for the appearance of zero resistance. Theory has predicted that in the minima the resistivity can become negative. Then a homogeneous system turns unstable and current domains with large internal Hall electric fields pointing in opposite directions spontaneously form to produce zero resistance. Direct evidence for such domains has remained elusive. Here we introduce time as an unexplored parameter. Probing internal Hall voltages reveals random telegraph signals in the zero-resistance regime. They provide compelling evidence for spontaneous switching between two different distributions of the electric field, which is attributed to two distinct current domain configurations.

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MIROs

- Magnetoresistive effects in 2DES:
  - QHE, fQHE
  - Microwave-induced resistance oscillations (MIROs)

- MIROs look like SdH-oscillations
- Are also periodic in $1/B$
- Appear at lower fields
- Also have minima with $R_{xx} \approx 0$
MIROs

Two models for different regimes:

- Inelastic scattering time < elastic scattering time (higher T):
  - MW absorption resonant for $\omega/\omega_c = n$
  - LL tilted if voltage is applied
  - MW absorption also possible for larger/smaller $\omega$
  - Absorption followed by spatial displacement (elastic scattering event)

MIROs

Second model:

- Inelastic scattering time > elastic scattering time (lower T):
  - MW absorption resonant for \( \omega/\omega_c = n \)
  - From self-consistent Born-Approx:

\[
\sigma_{xx} = \frac{e^2}{\pi^2 \hbar} \sum_{n=0}^{\infty} \left( \frac{\Gamma_n}{\Gamma_n} \right) \int \left( \frac{df}{d\epsilon} \right) Z_s(\epsilon) d\epsilon
\]

- for \( \omega_2 > \omega_c \): non-equilibrium e-population in LL
- Negative contribution to resistivity, \( \sigma_{xx} < 0 \) possible

- Both models predict negative \( \sigma_{xx} < 0 \), but experimentally never observed

Domain model

- Domains unexplored
  - Size
  - Dynamics
  - Formation
  - ...

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Experiment

- \(^3\)He refrigerator (0.5 – 1.5 K)
- microwave @ 40 – 50 GHz
- time resolution 2e\(^{-5}\) s
- perp. magnetic field

\[ R_{\text{ZRS}} = \frac{dV}{dc} \]

zero resistivity state ZRS
- GaAs/AlGaAs heterostructure
  - $n=2.9\times10^{11}$ cm$^{-2}$
  - $\mu=17\times10^6$ cm$^2$/Vs
- 60 x 60 $\mu$m ohmics in 40 x 40 $\mu$m holes
- $a=150$ $\mu$m, $b=400$ $\mu$m
Domain Formation/Fluctuation

- No source-drain voltage applied
  - No net current

- However, Hall voltages build up inside the Hall bar
  - $\Sigma U=0 \rightarrow$ no net Hall voltage
  - Current loops forming

- Time dependence:
  - Clear signature of bi-stability
  - $T_{\text{puls}}>T_{\text{switch}}, T_{\text{switch}}<10^{-4}\text{s}$
  - No periodic signal

$\rightarrow$ random telegraph noise
Current loops

- Voltage between B3 and B4 stable -> current loop constant (blue loop)
- Voltage between B4 and B5 changes -> large current loop has to change
- Change same as $U_{B3,D}$
Current Loop Fluctuations

- Fluctuations not correlated throughout the whole sample
  - Slower switching with A1 from B-region
  - Faster ones with A2 amplitude from C-region
Timescales

- Two timescales: $T_{\text{puls}} > T_{\text{switch}}$
- $T_{\text{switch}} < 10^{-4} \text{s}$
- $T_{\text{puls}}$ depends strongly on temperature
- Amplitude shows also temp. dependence

$$W \propto \exp\left(-\frac{E_a}{k_B T}\right)$$
Timescales

- Additional dependences:
  - irradiation power
  - B-field
  - d.c. current applied to Hall bar
Summary

- ZRS of Microwave-induced resistance oscillations investigated
- Local current loops in absence of source-drain voltage
- Current loop configuration bi-stable (RTN)
  - Pulse length up to 100ms
  - Temperature activated process
- Results support theory predicting domains
  - Domains in ZRS unstable
  - Imposing d.c. current leads to disappearance of effect
  - Theory is not predicting slow switching behaviour
  - Correlations macroscopic
  - Domain size remains unclear