Direct Observation of Nonequilibrium Spin Population in Quasi-One-Dimensional Nanostructures


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van Houten et. al. RPL 1988

Charge detector
Luscher et. al. PRL 2007

Rejec and Meir, Nature 2006

QPC Microscopy
Zhang et. al. Nano Lett. 2011
Outline

- Basic transport of QPC
- $ac$ Conductance ($G_{ac}=dI/dV_{sd}$) vs $dc$ Conductance ($G_{dc}=I/V_{sd}$)
- Observation of nonequilibrium spin population
- summary
Basic transport of QPC

\[ G = \frac{2e^2}{h} \sum T_n(E_F) = \frac{2e^2}{h} \sum \frac{1}{1 + e^{-\beta_n|E_F - E_n|}}, \]

\[ \beta_n = \sqrt{\frac{2m^*}{\alpha \hbar^2 E_n}}. \]

(e.g. Ferry and Goodnick, Cambridge University Press, 1997)
Basic transport of QPC

\[ G = \frac{2e^2}{h} \left( \frac{1}{a} \sum_{n} \frac{1}{1 + e^{-\beta_n [\mu_L - e(\phi_0 - V_{ds}/a) - \varepsilon_n]}} - \left( \frac{1}{a} - 1 \right) \sum_{n} \frac{1}{1 + e^{-\beta_n [\mu_R - e(\phi_0 - V_{ds}/a) - \varepsilon_n]}} \right) \]
ac Conductance vs dc Conductance

\[ G_{ac} = 2e^2/h \]
\[ G_{dc} = 2e^2/h \]

- **Plateau in** \( G_{dc; ac} \) **when** \( E_n \) **lies below both** \( \mu_s \) **and** \( \mu_d \)

\[ G_{ac} = 0.5(2e^2/h) \]
\[ G_{dc} = 2e^2/h(\Delta E/eV_{sd}) \]

- \( G_{ac} \) **rises sharply by** \( 0.5(2e^2/h) \) **when** \( E_n \) **passes** \( \mu_s \) **or** \( \mu_d \)
- \( G_{dc} \) **rises continuously with the** \( E_n \) **filling:** \( I = (2e^2/h)[\Delta E/e] \) (no plateau!)

Chen et al. APL 2008
Device information

- GaAs/Al$_{0.33}$Ga$_{0.67}$As / 96 nm below
- Mobility: $3.97 \times 10^6$ cm$^2$/V s
- Electron density: $3.37 \times 10^{11}$ cm$^{-2}$
- ac excitation: 5 µV
- $T \sim 130$ mK
- $B \sim 14$ T

W: 0.8 microns
L: 0.3 ~ 1 microns
At zero bias, \( G_{ac} = 0.5(e^2/h) \) at 8 T (fully spin-polarized).

At \( V_{sd} = 0.5 \) mV, \( G_{dc} \) (partially-spin polarized)

\[
P_{1D} = \frac{n_{\downarrow} - n_{\uparrow}}{n_{\downarrow} + n_{\uparrow}} < 1
\]
• e\(V_{sd}\) > \(E_n\) spacing: NO Plateau in \(G_{dc}\)
• Shoulderlike feature in \(G_{dc}\)
• Anomalies become more announced at \(B=12\) T
High transconductance 
\( \frac{dG_{ac}}{dV_g} \): 
\( E_n \) pass through \( \mu_s \) or \( \mu_d \)

\( E_n \) configuration

0.85 subband

\( G_{dc} \) has a plateau even an \( E_n \) lies between \( \mu_s \) and \( \mu_d \). **Unusual!**
\[ G_{dc} = \frac{e^2}{h}[1 + \Delta E / eV_{sd}] \]

\[ eV_{sd} - \Delta E = (2 - G_{dc} / G'_0) \times eV_{sd} \]

\[ G'_0 = \frac{e^2}{h} \]
Summary

• dc conductance feature directly related to a nonequilibrium spin population behavior. \( G_{ac} \sim 0.85(2e^2/h) \).

• the population of the minority up-spins and the spontaneous spin polarization changes as a function of B and \( V_{bias} \).

• providing a key to a more complete understanding of Coulomb and exchange interactions and the 0.7 anomaly in quasi-1D systems; a fully electrical method for creation and manipulation of spin-polarized currents.