Measurement of spin-dependent conductivities in a two-dimensional electron gas

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Spin accumulation is generated by injecting an unpolarized charge current into a channel of GaAs two-dimensional electron gas subject to an in-plane magnetic field, then measured in a non-local geometry. Unlike previous measurements that have used spin-polarized nanostructures, here the spin accumulation arises simply from the difference in bulk conductivities for spin-up and spin-down carriers. Comparison to a diffusive model that includes spin subband splitting in magnetic field suggests a significantly enhanced electron spin susceptibility in the 2D electron gas.

Interplay between superconductivity and ferromagnetism in crystalline nanowires

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The interaction between superconductivity and ferromagnetism, which entails incompatible spin order, is one of the problems of fundamental interest in condensed-matter physics. In general, when a ferromagnet is placed in contact with a superconductor, the Cooper pairs from the superconductor are not expected to survive beyond at most a few nanometres into the ferromagnet. Here we present a systematic study of single-crystal ferromagnetic cobalt nanowires sandwiched between superconducting electrodes. Surprisingly, we find that a cobalt wire as long as 600 nm attains zero resistance at low temperatures. For even longer nanowires, the transition to incomplete superconductivity is foreshadowed by a strikingly large and sharp resistance peak near the superconducting transition temperature of the electrodes. Although the origin of the ‘critical peak’ remains mysterious, our analysis strongly points against charge or spin imbalance as its underlying cause.
Superconductivity vs ferromagnetism

- Sample: Co Nanowire 40nm*600nm W Electrodes
  $T_C = 4.4-5.1$K

- Prox. effect
  - up 1$\mu$m in normal metal$^1$
  - s wave SC and FM $\rightarrow$ 1nm
    (incompatible spin order)
  Confirmed in submicron Al-Ni structures$^2$

- SC observed below 3.5K ($R<0.01\Omega$)
  $R_{Wire,6K} = 200\Omega$
  $R_{Contact} = 1\Omega$

- Typical I-V curves observed

$^1$ De Gennes, Rev.Mod.Phys 36, 225-237 (1964)
Spin dependent conductivity in a 2DEG

- Narrow channel on AlGaAs substr. 
  \( n = 1.11 \times 10^{11} \text{cm}^{-2}, \mu = 4.44 \text{m}^2/\text{Vs} \)
  
  Channel width 1(2) \( \mu \) m 
  
  \( T = 300 \text{mK} \)

- Injector QPC: Charge \( \rightarrow \) Drain

- Meas. of \( V_{\text{nonlocal}} \) (Detector – floating) as a function of \( V_{g}^{\text{inj}}, V_{g}^{\text{det}} \)

- \( V_{\text{nl}} > 0 \) for Inj, Det spin-sensitive, e.g. \( \{1,1\} \)

- \( V_{\text{nl}} < 0 \) one QPC sensitive, e.g. \( \{1,0\}/\{0,1\} \)
• Chemical potential landscape in channel (without spin relaxation)

• Equal conductivity for spin up/down

• Different spin up/down conductivity

• Injector at $x=0$
• Detector at dashed line

• Nonlocal Voltage: 
  \{1,1\}: $V_{nl} = \mu^{\uparrow} - \mu^{\downarrow} (R)$  
  \{1,0\}: $V_{nl} = \mu_{avg} - \mu^{\downarrow} (R)$  
  \{0,1\}: $V_{nl} = \mu^{\uparrow} - \mu (R)$
BSP (ballistic spin resonance)

- ESR (Electron spin resonance)
  - Ext. B-field $\rightarrow$ Zeeman splitting ($\sim B$)
  - Shine light $\rightarrow$ transitions if $h\nu = g\mu_B B$
  - Spin relaxation time $\downarrow$ for $h\nu = g\mu_B B$

- BSP (ballistic spin resonance)
  - Only external B-field and eff. oscillating B-field trough SOI
  - Res.condition: $g\mu_B B = 2\hbar\tau_c^{-1}$

- EDSR (Electron dipole spin resonance)
  - Ext. B-field, ext. oscillating E-field
  - SOI $\rightarrow$ k-dependent eff. B-field

Nonlocal voltage vs perp. B-field:
-Voltage drop at 6T due to ballistic spin resonance

Nonlocal voltage vs parallel B-field:
-increasing voltages (QPC more polarized at higher B-field)
-no bsr dip observed
More evidence for spin related effect

- From 1D diffusion equation incl. spin relaxation:

\[
\Pi_{01(10)} = \frac{1}{2} \left( 1 - \frac{\sigma_{D(R)\uparrow}}{\sigma_{D(R)\downarrow}} \right)
\]

\[
\Pi_{01} \equiv \frac{V_{nl}(0, 1)}{V_{nl}(1, 1)}
\]

\[
\Pi_{10} \equiv \frac{V_{nl}(1, 0)}{V_{nl}(1, 1)}
\]

- The density can be extracted assuming equal mean free path for spin up/down using:

\[
\sigma_{\uparrow(\downarrow)} = g e^2 \lambda_c \frac{v_{F\uparrow(\downarrow)}}{4} = e^2 \lambda_c \sqrt{\frac{\sqrt{2m^* n_{\uparrow(\downarrow)}}}{4m^*}}
\]

\[
v_{F\uparrow(\downarrow)} = \sqrt{2(E_F^0 \pm g^* \mu_B B/2)/m^*} = \sqrt{\frac{4n_{\uparrow(\downarrow)}}{g m^*}}
\]