Temperature-Dependent Asymmetry of the Nonlocal Spin-Injection Resistance: Evidence for Spin Nonconserving Interface Scattering

Wilfried Meindl

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Abstract

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Temperature-Dependent Asymmetry of the Nonlocal Spin-Injection Resistance: Evidence for Spin Nonconserving Interface Scattering

Samir Garzon,[1] Igor Žutić,[1,2] and Richard A. Webb[1,3]
[1]*Department of Physics and Center for Superconductivity Research, University of Maryland, College Park, Maryland 20742, USA*
[2]*Center for Computational Materials Science, Naval Research Laboratory, Washington D.C. 20375, USA*
[3]*Department of Physics and USC NanoCenter, University of South Carolina, Columbia, South Carolina 29208, USA*
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We report nonlocal spin injection and detection experiments on mesoscopic $Co - Al_2O_3 - Cu$ spin valves. We have observed a temperature-dependent asymmetry in the nonlocal resistance between parallel and antiparallel configurations of the magnetic injector and detector. This strongly supports the existence of a nonequilibrium resistance that depends on the relative orientation of the detector magnetization and the nonequilibrium magnetization in the normal metal providing evidence for increasing interface spin scattering with temperature.

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Motivation

Effect

Spin injection in F/N/F-contacts

Result

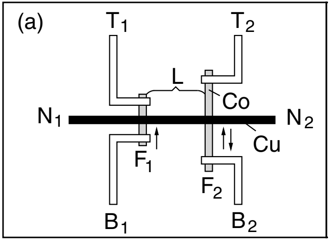
Previously unseen spin- and temperature-dependent asymmetry in the interface scattering

Applications

Spectroscopic tool:

- pairing symmetry of unconventional superconductors
- Skyrmion excitations in the quantum Hall regime
- spin-charge separation in non-Fermi liquids

Sample



F_1: Injector, F_2: Detector

F_1/N, F_2/N: tunnel contacts

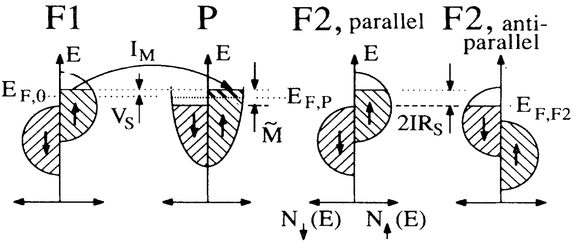
Sample data

- F/N tunnel contacts:
  Co – Al_2O_3 – Cu
- layer thicknesses:
  Co 36 nm, Al(!) 2 nm, Cu 54 nm
- line widths: 100 nm
- length of lines:
  F_1 2.4 μm, F_2 4.5 μm

Nonlocal measurement

current: T_1, N_1 $\longrightarrow$ voltage: T_2, N_2

Electrochemical Potential I



Injector F1

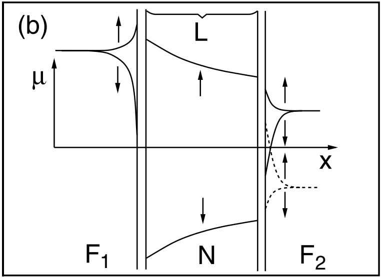
- *no* $\downarrow$-electrons at $E_{F,F1,\downarrow}$
- *many* $\uparrow$-spins at $E_{F,F1,\uparrow}$

$\rightarrow$ $\uparrow$-magnetization current

Detector F2

- $F_1 \uparrow F_2 \uparrow \rightarrow E_{F,F2} = E_{F,P,\uparrow}$
- $F_1 \uparrow F_2 \downarrow \rightarrow E_{F,F2} = E_{F,P,\downarrow}$
- voltage: $V \propto E_{F,F2} - E_{F,0}$

Electrochemical Potential II



Nonlocal Voltage

Current between F1 and N

- $\longrightarrow$ spin accumulation at the interface F_1/N
- $\longrightarrow$ non-uniform spin distribution in N
- $\longrightarrow$ at F_2 voltage $V \propto \mu_\uparrow - \mu_\downarrow$

Definitions

Nonlocal Resistance

$$R_{NL} = V_{T_2-N_2}/I_{T_1-N_1} = \pm(\rho_N \lambda_N / 2A_N)\exp(-L/\lambda_N) P_1 P_2$$

- ρ bulk resistivity
- A cross sectional area of the interface
- $+/-$ $F_1 \uparrow F_2 \downarrow$ / $F_1 \uparrow F_2 \uparrow$
- λ_N spin diffusion length in N

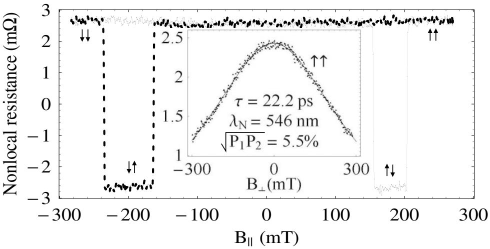
Contact Resistance

$$R_\sigma = (\mu_\sigma^F - \mu_\sigma^N)/(eI_\sigma)$$

Interface Polarization at F_i/N_i

$$P_i = (R_{i\uparrow}^{-1} - R_{i\downarrow}^{-1})/(R_{i\uparrow}^{-1} + R_{i\downarrow}^{-1})$$

Switching, Spin Polarization, Spin Diffusion Length



Switching

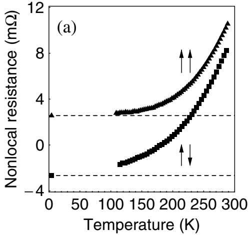
- ac current 10 to 50 μA
- $T = 4.2K$
- B-field sweep: 0.18 mT/s

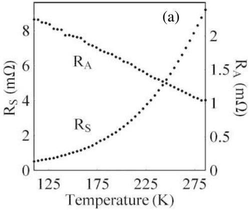
Hanle effect (inset)

- $F_1 \uparrow F_2 \uparrow$
- $B_\perp \rightarrow$ spin precession

$\longrightarrow$ decreasing $R_{NL} \propto \vec{\sigma} \cdot \vec{M}$

Temperature Dependent Measurements: R_{NL}





Nonlocal Resistance

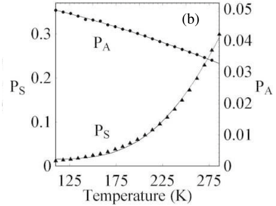
Asymmetry between $R_{NL}^{\uparrow\uparrow}$ and $R_{NL}^{\uparrow\downarrow}$

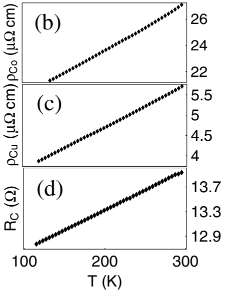
Symmetric/Antisymmetric Resistance

$$R_{S,A} = (R_{NL}^{\uparrow\uparrow} \pm R_{NL}^{\uparrow\downarrow})/2$$

- R_A spin scattering in Cu, reduction of magnetization in Co (magnons)
- R_S spin-dependent scattering at detector interface!

Polarizations





Symmetric/Antisymmetric Polarization

$$P_{S,A} = (P_2^{\uparrow\uparrow} \pm P_2^{\uparrow\downarrow})/2$$

P_2: N/F_2 spin transport

Fits

$$P_A \propto P(T) = P_0(1 - \eta T^{3/2})$$
$$\tau_p \propto \tau, \tau_p/\tau = a^p$$

- $\rho_{Cu} \Rightarrow \lambda_N(T)$
- $\lambda_N(T), P(T), \sqrt{P_1 P_2}, R_A, R_S \Rightarrow P_A, P_S$

Interfacial Spin-Scattering

Model

The behavior of P_A and P_B can be modeled by

$$P_2 \rightarrow \tilde{P}_2 = \frac{(R_{2\uparrow}^{-1} - R_{2\downarrow}^{-1}) \pm (R'^{-1}_{2\uparrow} - R'^{-1}_{2\downarrow})}{(R_{2\uparrow}^{-1} + R_{2\downarrow}^{-1}) + (R'^{-1}_{2\uparrow} + R'^{-1}_{2\downarrow})} = P_A \pm P_S$$

$R'_{2\uparrow,\downarrow}$ spin-scattering contact resistances at F_2

A First Explanation

Spin- and temperature-dependent interface scattering is attributed to the **large spin polarization** (50%) of **surface states** of Co.

Summary

- measurement: **temperature-dependent nonlocal resistance** of $F_1/N/F_2$ junctions
- result: **asymmetry** in the contact resistance for different relative orientations of F_1 and F_2
- control experiments: **spurious origin** can be **ruled out** (electrostatic field distribution, imperfect contacts, Joule heating, magnetothermal effects)
- phenomenological model: **temperature-dependent spin-flip scattering**