Spin Polarized Tunneling Spectroscopy

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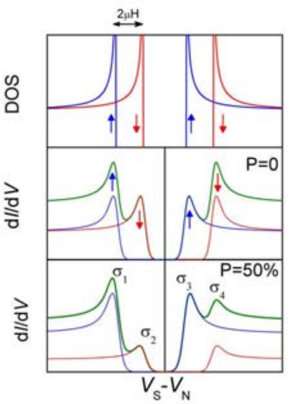
Abstract

Spin polarized tunneling spectroscopy of superconductor/ insulator/ normal metal (ferromagnetic metal) are studied at low temperature and in high magnetic fields. We have studied the conductance (dI/dV) versus energy. In superconductor/insulator/ferromagnet devices, the conductance peaks are split by the Zeeman interaction in the superconducting layer. Spin polarization of the ferromagnet, the superconducting energy gap and other quantities are found from fitting this data.

Zeeman splitting in a superconductor



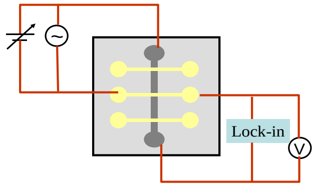
When the temperature is below the superconducting transition, we get a symmetric gap of 2Δ in dI/dV around E_F. The quasi particle density of states are very high near the gap energy. In presence of a magnetic field, the density of states on both sides of E_F Zeeman splits into spin up and spin down states, separated by $\Delta E = 2\mu H$.

Spin polarization (P) is related to the peak conductances σ_{1-4}:

$$P(E_F) \approx \frac{(\sigma_4-\sigma_2)-(\sigma_1-\sigma_3)}{(\sigma_4-\sigma_2)+(\sigma_1-\sigma_3)}$$

The measurement technique

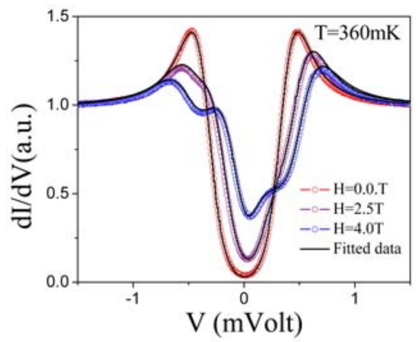
We apply a dc voltage sweep across the junction. A small ac modulation voltage (ω) with a voltage divider network is applied in series with the dc voltage. Then the Taylor expansion about the I_{dc} shows us that we can measure the dI/dV signal against the voltage by measuring the current response at ω.



dI/dV vs V in He3 cryostats

$$I(V_{dc}+\delta V_{ac}\cos\omega t) = I(V_{dc}) + \frac{dI}{dV}(\delta V_{ac}\cos\omega t) + \frac{d^2I}{dV^2}\left(\frac{\delta I_{ac}^2}{4}\cos(2\omega t)\right) + \dots$$

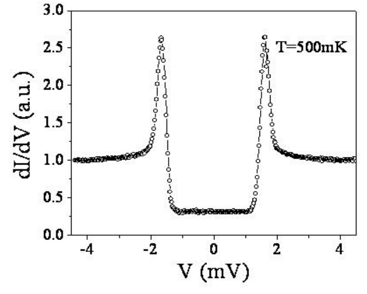
Al / Al_2O_3 / Co spin polarized tunneling spectrum



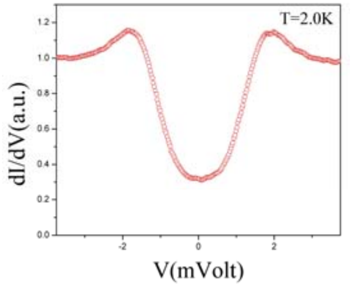
Parameters from the fit at different H

H (T)	0.0	2.5	4.0
Polarization (%)	---	41.7	39.9
Δ(meV)	0.364	0.369	0.334
Orbital depairing	---	0.031	0.124
Spin orbit scattering	---	0.057	0.095

Al / Al_2O_3 / Pb tunneling spectrum at H=0T



CrO_2 / Cr_2O_3 / Pb tunneling spectrum at H=0T



The PPMS

The MINT center has recently acquired a new Quantum Design Physical Property Measurement System (PPMS). Ultra low temperatures (350mK) can be obtained and magnetic field as high as 7T can be applied both parallel and perpendicular to the sample in this system. Temperature can be swept continuously from 350mK to 400K. The system runs on an open liquid ^{4}He bath and a closed cycle liquid ^{3}He bath. All our measurement were done using this system with electronics built in-house.

Future work

- Obtain SPT spectroscopy of other materials
- Spin-polarized inelastic tunneling spectrum
- R(H,T) of ferromagnetic and superconducting Ni/Bi
- Transport in novel materials (e.g. CrO_2)

Issues in the measurement

Suitably low-noise and high-impedance amplifiers as well as ground-loop noise were issues in the beginning and were eliminated to a great extent. Tunnel junctions can act as capacitors at high frequencies, and so frequency is kept low enough. To prevent current crowding we kept junction resistance at least five times higher than total lead resistance.

Conclusion

We are able to measure dI/dV signal of different tunnel junction and fit the data to our program. Our next step will be to fabricate better tunnel junctions and improve on our measurement system.

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