Transport studies of individual crystalline nanowires contacted by superconducting electrodes

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Outline

- Proximity-induced superconductivity in crystalline Au nanowires;

- Interplay between superconductivity and ferromagnetism in crystalline Co, Ni nanowires, and MnAs nanotubes;

- Topological insulator nanoribbons and nanowires contacted by superconducting electrodes.
1. Proximity-induced superconductivity in crystalline Au nanowires

Proximity Effect:
For a superconductor-normal metal system:

\[ \xi_N = \sqrt{\frac{\hbar D}{k_B T}} \sim 100 \text{ nm} \]

The leakage of Cooper pairs make the local normal metal superconducting and simultaneously weakens the superconductivity of the superconductor near the interface.

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Au nanowires fabricated by template-based electrodeposition

Counter Electrode

Electrolyte

Working Electrode

70 nm diameter single crystal Au nanowires

2 nm
Au nanowires contacted by superconducting W electrodes

We measured three Au samples with different $L$ of 1.0 μm, 1.2 μm and 1.9 μm.

Excitation current: 50 nA

J. Wang et al, Phys. Rev. Lett. 102, 247003 [2009]

Two transitions!

A possible theoretical model: quantum superposition?
(Suggested by Dr. Lin He from Beijing Normal University)

At an applied magnetic flux $\Phi / 2\pi = \Phi_0 / 2\pi^2$ ($\Phi_0 = h/2e$ is the superconducting flux quantum), a single superconducting vortex generated in the nanowire can be put into a superposition of two distinct magnetic-flux states $|0>$ and $|1>$, which correspond to flux quanta 0 and $\Phi_0$ trapped in the vortex respectively.
The differential magnetoresistance color contour maps for the oscillations

1 μm Au nanowire 1.2 μm Au nanowire

Superconducting vortex model for the oscillations:

L. He and J. Wang, arXiv:1103.2173v1
Another possible model for the observed oscillations

In our situation:
1. Proximity induced superconductivity instead of superconductor;

The study of vortices in proximity induced superconducting nanowires is new.

2. Interplay between superconductivity and ferromagnetism in crystalline Co, Ni nanowires, and MnAs nanotubes

Superconductor + Ferromagnet = Spins in CONFLICT

Theoretical prediction ~ few nm in transition metals

"Peak effect" and "Long range proximity effect"!

Resistance Color Contour Map

3D image
For the Long-range proximity effect:
F. Konschelle, J. Cayssol and A. Buzdin, PHYSICAL REVIEW B 82, 180509R 2010:

1. The contact regions produce triplet correlations thereby leading to long ranged proximity effect.
2. The Josephson current is associated with weakly damped singlet superconducting correlations.
3. Finally in a third scenario a nonmagnetic dead layer provides a channel for long-ranged propagation of the superconducting correlations.

Further experiments which realize the low-temperature determination of the current-phase relation to discriminate between those scenarios are necessary.

For the “peak effect”:
Scattering of quasiparticle of spin-triplet pairs in diffusive superconductor-ferromagnetic nanowire-superconductor junction
arXiv:1103.2176v1 [cond-mat.supr-con]

Summary: Interplay between superconductivity and ferromagnetism in crystalline nanowires


Reported by the view and news: T. Klapwijk, Nature Physics, 6, 329 (2010)

Supercurrents in ferromagnets
3. Topological insulator nanoribbons and nanowires contacted by superconducting electrodes

**Motivations:**

I. Systematic study of proximity induced superconductivity in TI is still lacking;
II. Search for Majorana fermions in superconductor-topological insulator heterostructure;
III. Interplay between superconductivity and spin-polarized surface state;
IV. Large surface to volume ratio in nanowires and nanoribbons.

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**Four Superconducting Electrodes**

- MR oscillations observed in perpendicular fields when W contacts are superconducting
- Periodic at higher fields
- No MR oscillations observed in devices with non-superconducting contacts (Pt)

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There is a temperature window for the oscillations!
Four Superconducting Electrodes

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- Periodic at higher fields.
- No MR oscillations observed in devices with non-superconducting contacts (Pt).

There is a temperature window for the oscillations!

Multiple Andreev Reflections Measured by Quasi-two Superconducting Electrodes

\[ \Delta = 0.671 \text{ meV} \]
\[ (T_C = 4.42 \text{ K}) \]

Duming Zhang's Talk
Session W35: Topological Insulators, Superconductivity
11:15 AM–2:15 PM, Thursday, March 24, 2011
Room: C140
Conclusion

- Proximity-induced superconductivity in crystalline Au nanowires: minigap state and differential magnetoresistance oscillations

- Proximity-induced superconductivity in crystalline Co, Ni nanowires, and MnAs nanotubes (the interplay between superconductivity and ferromagnetism): resistance peak effect and long range proximity effect

- Superconductor-topological insulator interaction in nanowires and nanoribbons contacted by superconducting electrodes: magnetoresistance oscillations