ELECTRON TRANSPORT PHENOMENA THROUGH A SINGLE InAs QUANTUM DOT COUPLED TO Nb SUPERCONDUCTING LEADS

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Electrically tunable semiconductor quantum dots (QDs) are known as artificial atoms, where phenomena governed by quantum mechanics are relevant. In this project, we aim at understanding the quantum transport through a QD coupled with superconducting leads. In particular, the QD system combined to a Nb Josephson junction has not been fully demonstrated experimentally yet. The device was a single InAs self-assembled quantum dot (SAQD) placed in a 40 nm-wide nanogap between two superconducting Nb nanowires. The typical diameter of the InAs SAQD was about 80 nm. First we characterized the superconductivity of Nb thin films deposited using an electron-beam evaporator. The films exhibited low resistance at 4 K, indicating the existence of a superconducting state. We also applied the similar process to characterize a Nb nanowire for the use of superconducting leads. Then we prepared Nb nanogaps by electron-beam lithography on the InAs SAQD wafer, which already had a built-in back gate, using the conventional lift-off process. Using scanning electron microscope (SEM) to check the surface, we can select Nb nanogaps bridged well by an InAs dot. In the presentation, we will show results of electrical transport through such devices and discuss the proximity supercurrent flowing through the QD. The proximity supercurrent can be tested by current-biased 4-terminal measurements. Comparing to our previous work using the Al leads, the enhanced supercurrent can be expected because of the large superconducting gap of Nb.

Electron Transport Phenomena Through A Single InAs Quantum Dot Coupled To Superconducting Leads

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Abstract

We aim at investigating the quantum transport through an InAs self-assembled quantum dots (SAQD) coupled with superconducting leads. We will show results of electrical transport through a single QD coupled with Al leads. Transports specific for superconductivity, quasiparticle tunneling and Andreev reflection have been observed. In particular, the Andreev reflection peaks are enhanced in Kondo regime. We have characterized the superconductivity of Nb thin films and nanowires deposited by electron-beam evaporator to realize the enhanced supercurrent in the new type of InAs SAQD devices with Nb leads. We have done the preparation works of making Nb devices.

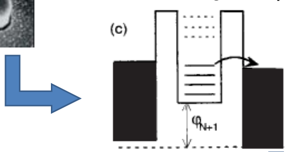
Goal

- Observe proximity supercurrent (Josephson current)
- Side gate control of the supercurrent in Al device
- Study of the interplay between Kondo effect and superconductivity phenomena
- Realize Nb/InAs/Nb system

Background

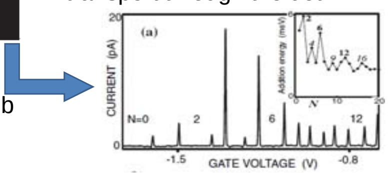
Semiconductor quantum dot (QD)

1. Small size of QD→ quantize energy level



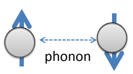
2. When Fermi energy of the lead match the energy level in the dot, the electron can transport through the dot.

3. Gate voltage can tune the dot energy level and coulomb oscillation occur



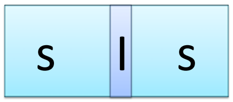
Superconductivity

At very low temperature, two electrons form a Cooper pair and zero resistance state appears in the material



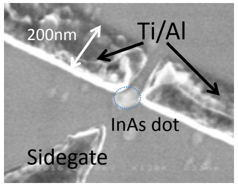
Cooper pair

- Josephson Junction
  - Cooper Pair tunneling
  - Supercurrent

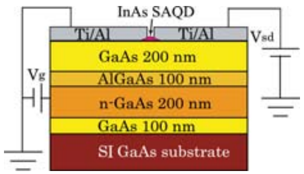


Josephson Junction

Al QD Josephson device



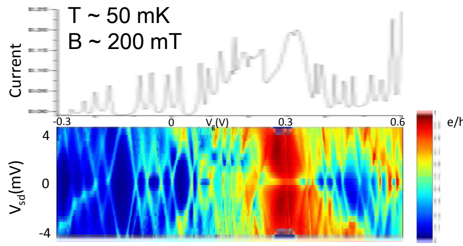
SEM Image



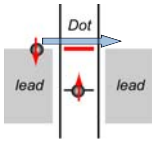
Device crossection

- Uncapped InAs SAQD: Diameter ~ 80nm, Height ~ 20nm
- Gap size ~30nm, in plane sidegate is100nm from gap
- Superconducting electrodes (thickness Ti/Al : 5/100 nm)
  - Critical temperature T_c ~ 1.2K
  - Critical magnetic field B_c ~ 120mT
- Source-drain biased: controlled by the voltage cross the lead

Coulomb Oscillation and Diamond



Charging energy E_c ~ 3 meV

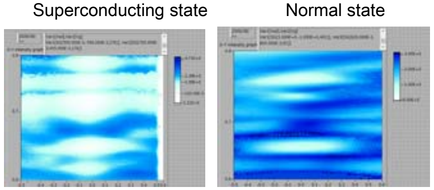


Kondo effect

Superconducting and normal states

Superconducting state

Normal state

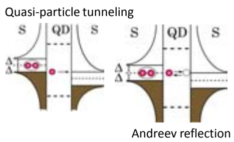


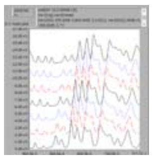
−2Δ −Δ +Δ+2Δ

Superconducting gap Δ ~ 150 μeV

2Δ: quasiparticle tunneling

Δ: Andreev reflection





Kondo effect

Sidegate effect

Change in conductance in Kondo valleys by sidegate

Andreev transport and Kondo effect?

Kondo regime

Andreev reflection peaks are enhanced

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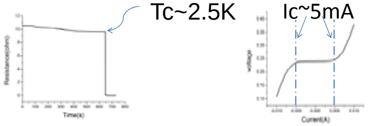
Nb device fabrication

Superconducting Nb thin film evaporation

Evaporate pure Nb to GaAs wafer and test its superconductivity (T_c ~9.25k)

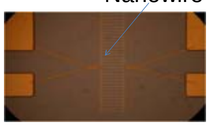


- At 2.5K, the resistance suddenly drop to zero
- I_c ~3mA at 2.409K

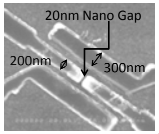
Nb lead fabrication and

- The pattern of the nanowire is made by electron beam lithography
- Evaporate Nb/Ti on the e-beam resist and lift off the extra part

Nanowire



- Test the superconductivity through gold pad, 4-termnal measurement
- By the similar method, we make Nano gap between superconducting Nb nanowire



Summary & Conclusion

- We measured the transport though the single InAs self-assembled QD coupled to Al leads
- Superconducting transports were observed but the supercurrent could not be measured due to the weak coupling
- We have tested the Nb deposition using EB evaporator and prepared the Nb thin films and nanowires
- Some of the films could have critical temperature at 2.5 K at most

Future works

- Improve the superconductivity of the Nb thin film
- Complete Nb/InAs/Nb device and test the electron transport with higher critical current
- Study the interplay between Kondo effect and superconductivity using the side gate effect