Lateral electron tunneling through single self-assembled InAs quantum dots coupled to superconducting nanogap electrodes

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The authors have fabricated superconductor-quantum dot-superconductor (SC-QD-SC) junctions by using SC aluminum electrodes with narrow gaps laterally contacting a single self-assembled InAs QD. The fabricated junctions exhibited clear Coulomb staircases and Coulomb oscillations at 40 mK. Furthermore, clear suppression in conductance was observed for the source-drain voltage $|V_{SD}|<2\Delta/e$, where $\Delta$ is the SC energy gap of Al. The absence of Josephson current that flows through QDs is due to the strong Coulomb interaction and non-negligible thermal fluctuation in our measurement system. © 2007 American Institute of Physics [DOI: 10.1063/1.2983325]
Outline

- Motivation
- Experiment
  - Device
  - Results
- Summary
Motivation

- Different types of quantum dots
  - Electrically confined QDs in a 2DEG
  - Vertical QDs
  - Self-assembled epitaxially grown QDs
Motivation

- Well studied properties of **self-assembled** InAs quantum dots
  - Optical properties
  - Large orbital quantization
  - Strong carrier-carrier interactions

- Still little known
  - Electrical **transport properties**
  - Especially on a **single** self-assembled dot
Experiment

- Investigation of a single InAs QD in a Al nanogap

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 nm</td>
<td>GaAs buffer</td>
</tr>
<tr>
<td>100 nm</td>
<td>AlGaAs</td>
</tr>
<tr>
<td>Si doped</td>
<td>backgate</td>
</tr>
</tbody>
</table>
Experiment

- Investigation of a **single** InAs QD in a Al **nanogap**

- Superconductor-QD-Superconductor made by e-beam lithography
- Single dot in gap (probability = 5%)
- Si doped layer 300 nm below surface act as a backgate
- 4-terminal measurement at 40 mK
Results I

- Single electron transistor behavior
- Suppressed current around $V_{SD}=0$
- Coulomb staircases
Results II

\[ V_{SD} = 500 \mu V \]

\[ U_C \approx 3 \text{meV} \]
Results III

- Superconductor characteristic:

  Energy gap in DOS at Fermi level due to Cooper pair formation:

  \[ \Delta = 140 \mu eV \]

  Co-tunneling transport only for \[ |V_{SD}| > 2\Delta/e \]

  \[ \Rightarrow \Delta = 140 \mu eV \]
Results IV

Verifications:

- Should vanish in magnetic field
- BSC relation
  \[ \Delta = 1.76 \, k_B \, T_C \]
  \[ \Rightarrow T_C = 0.92 \, K \]
Josephson effect: Superconducting tunneling current carried by paired electrons

- High $U_C$ -> strong Coulomb interaction: Cooper pair transport is a fourth-order co-tunneling process
- Superconducting current $I_C$ expected to be small

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Results VI

- Josephson current ~100 pA, far below noise level
Summary

- Electrical transport through a single self-assembled InAs quantum dot can be measured
  - Coulomb diamond structure
  - Single electron tunneling (SET) behavior
- Physics of contacts also plays an important role
  - Signature of superconducting leads clearly visible and verified
Thank you for your attention!