Bipolar supercurrent in graphene

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1.) Josephson effect

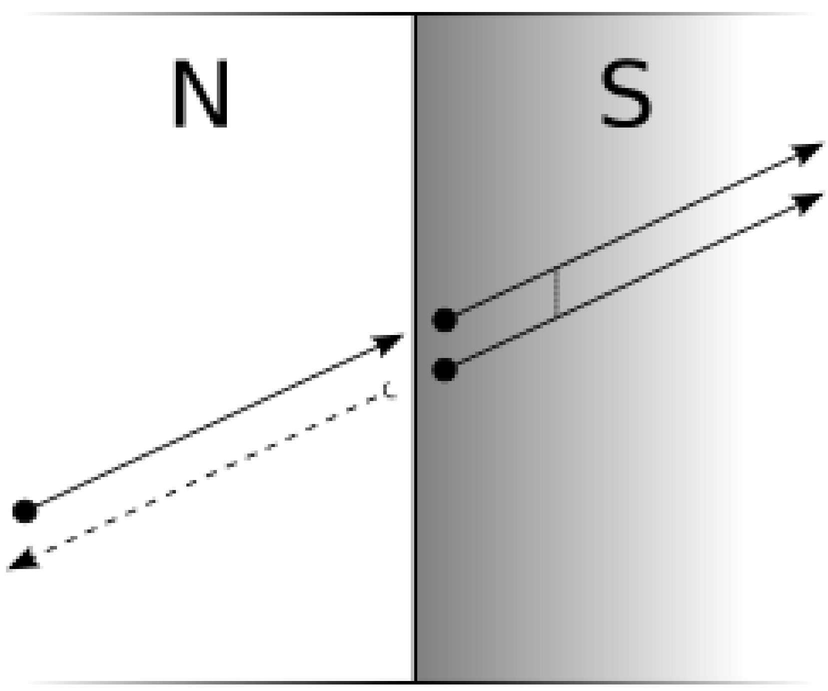
2.) Why graphene?

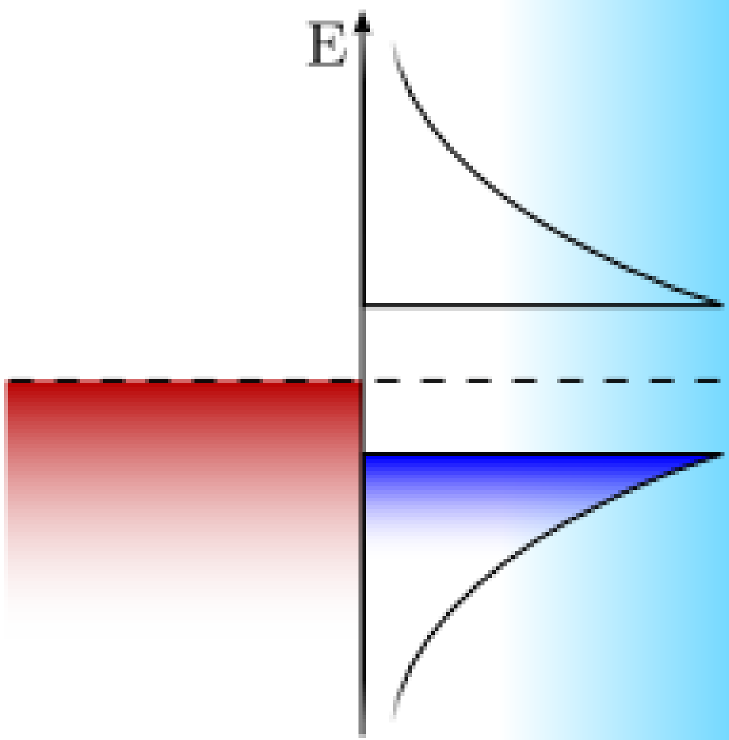
3.) Sample preparation & characterization

4.) Results

The Josephson effect

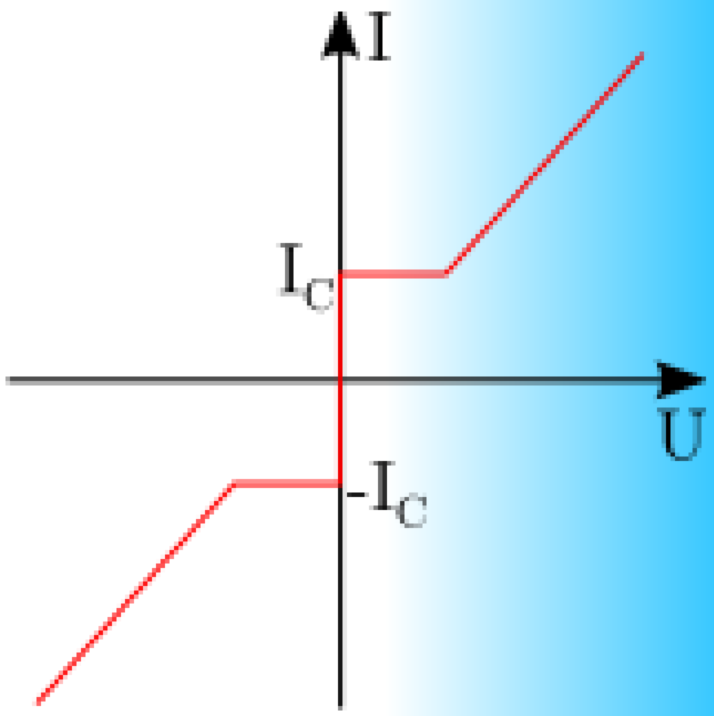
- One superconducting electrode
- Non-superconducting material
- Andreev reflection

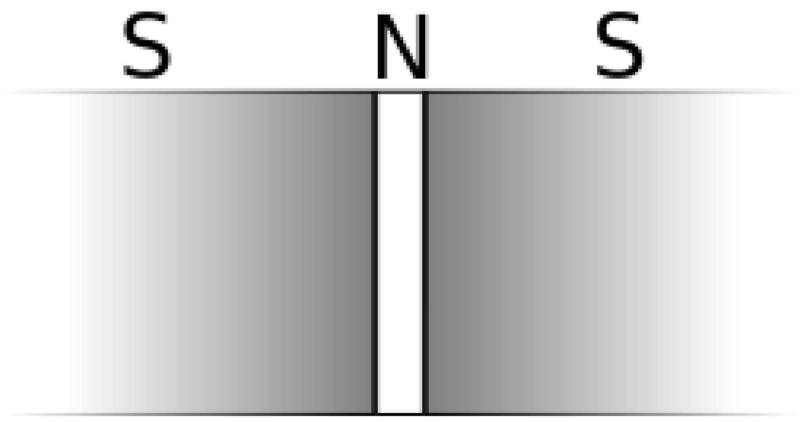




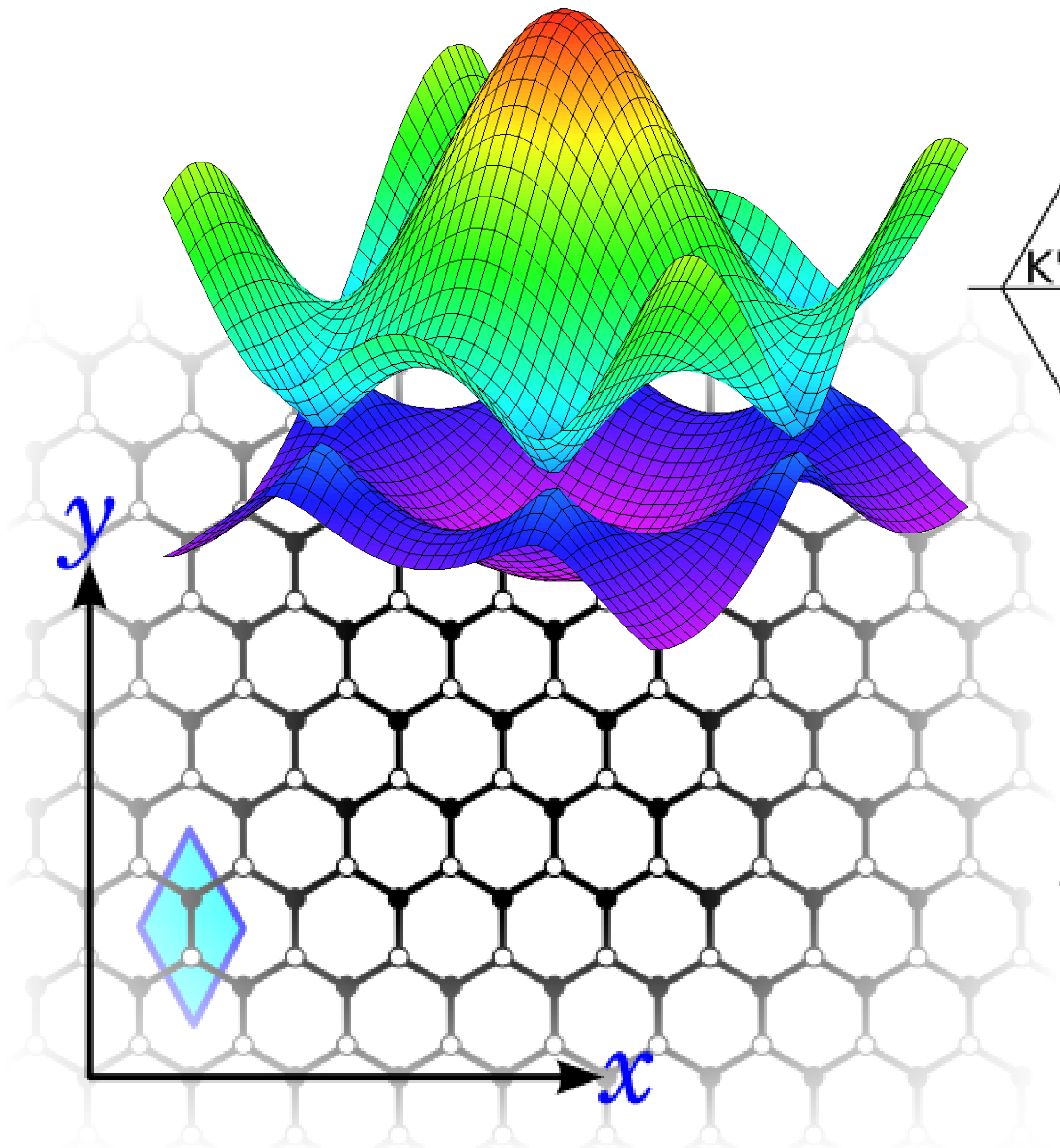
The Josephson effect

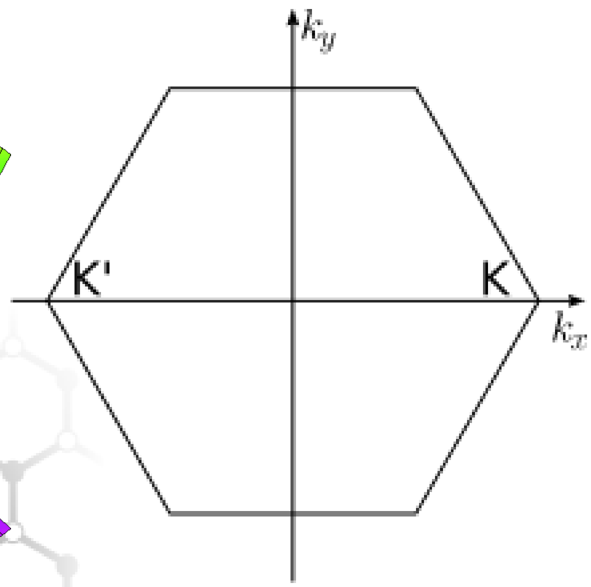
- Two superconducting electrodes
- Thin, non-superconducting barrier
- Andreev reflection on both contacts
- Proximity effect
- Tunneling of Cooper-pairs possible

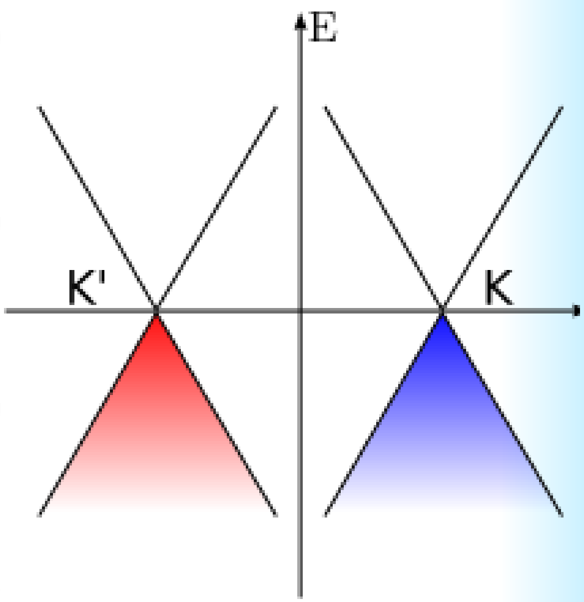




Why graphene?

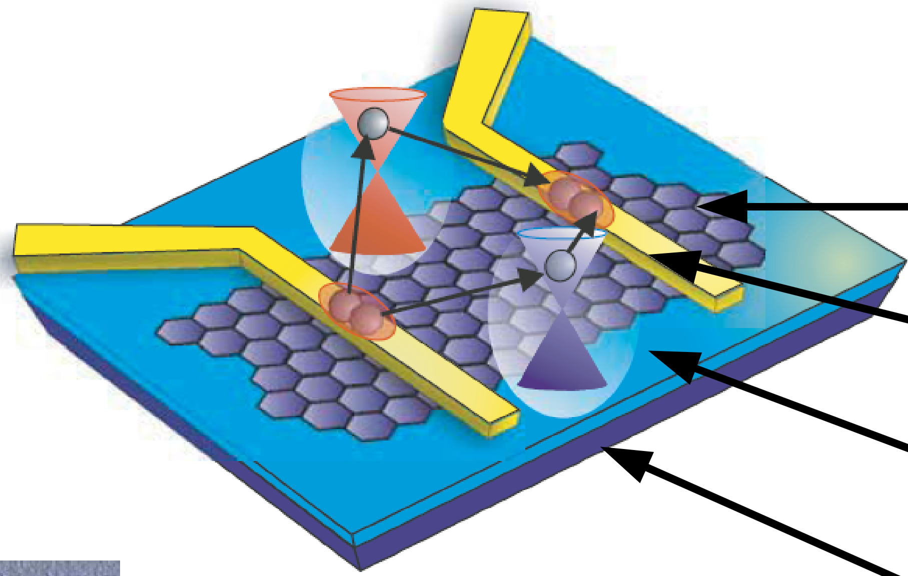


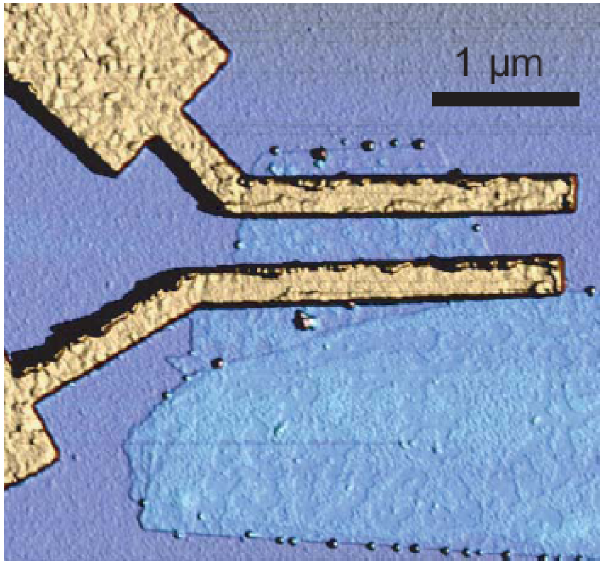




Sample preparation

schematic

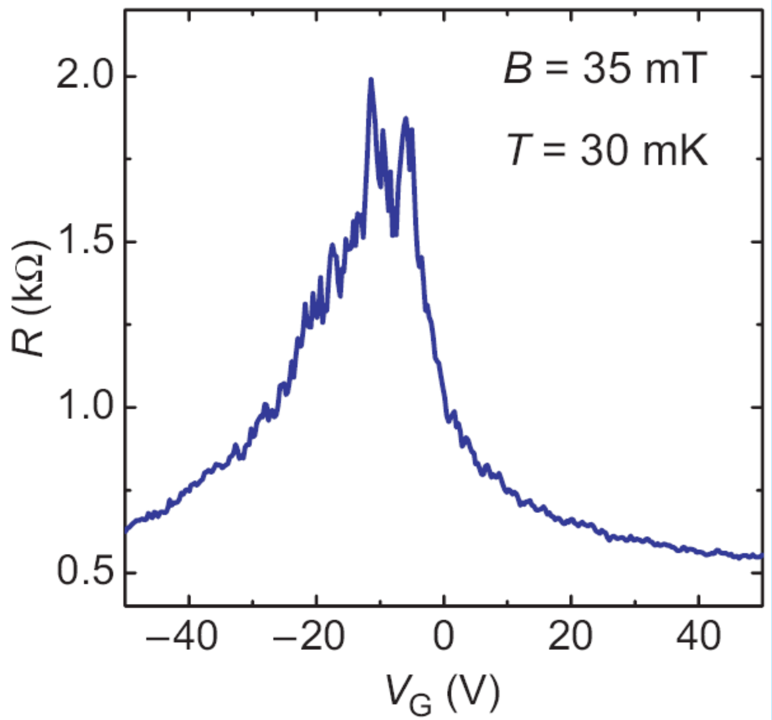


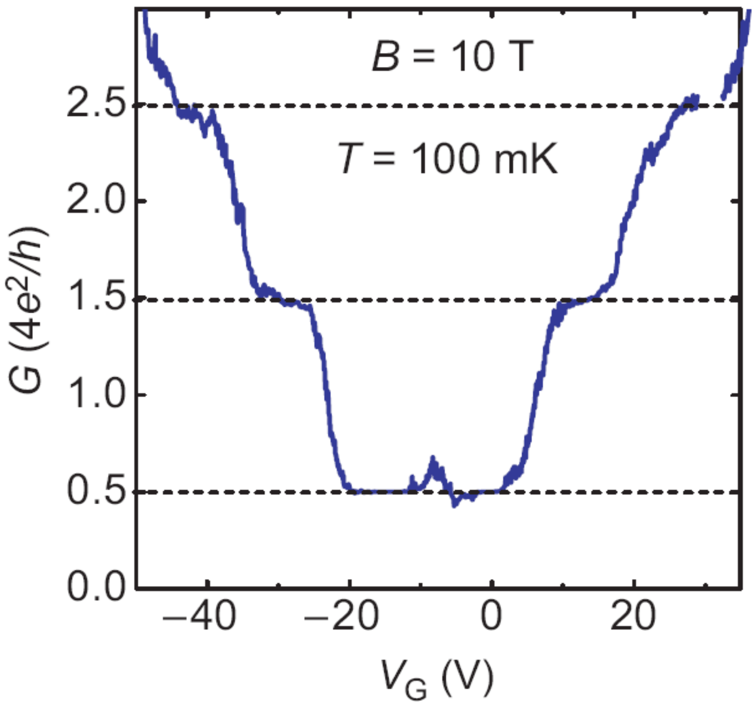


AFM image

Sample characterization

- Two-terminal resistance vs. gate voltage
  - Magnetic field → normal state
- Typical for electric field effect in graphene
  - Dirac point at highest resistance

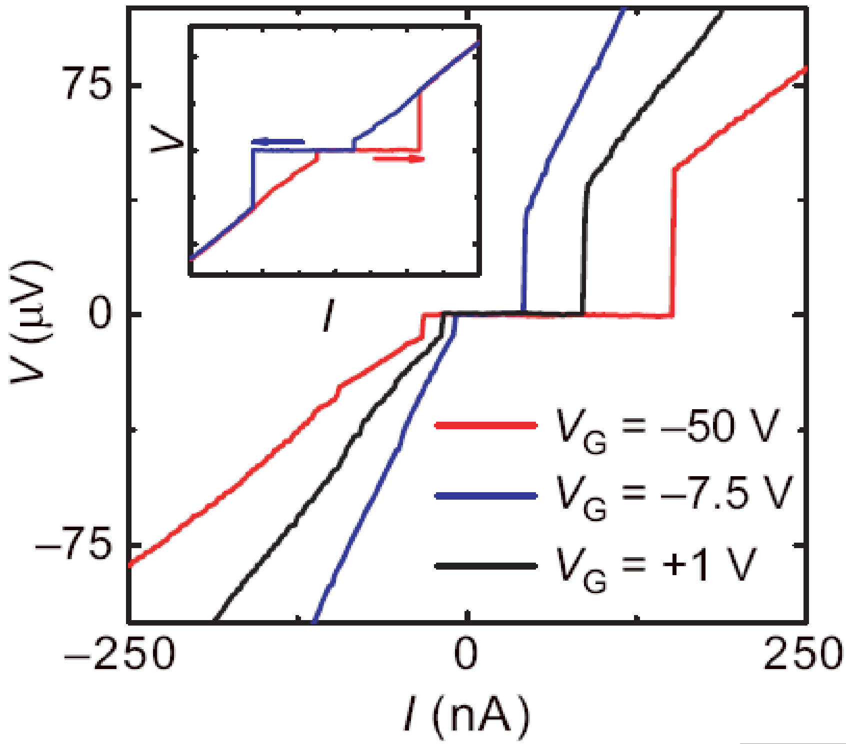




- Two-terminal conductance vs. gate voltage
- Steps at half-integer values of $4e^2/h$
- Signature of anomalous QHE

→ <u>single layer graphene</u>

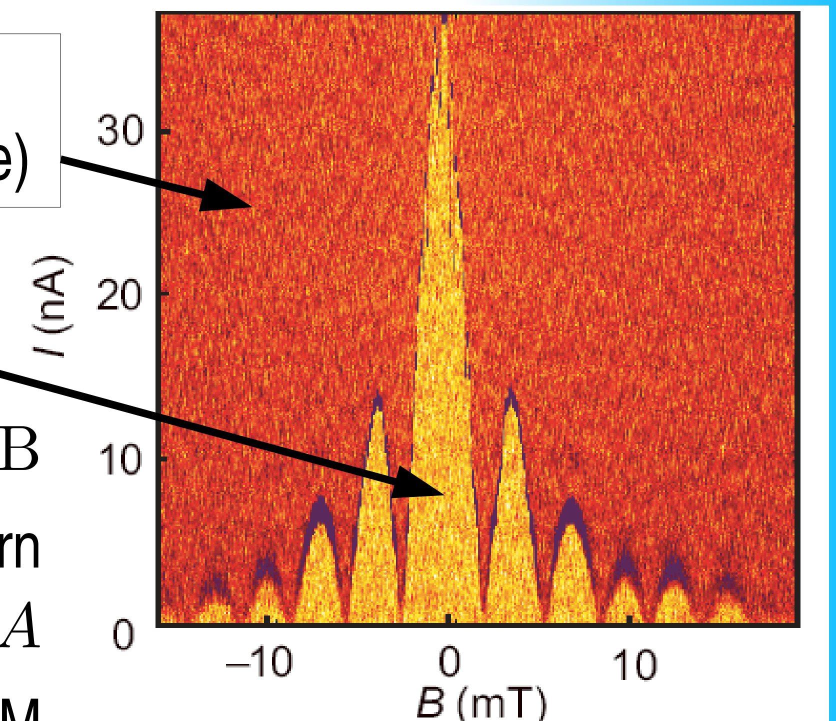
Results



- Critical current depends on gate voltage
- Asymmetry due to hysteresis (cf. Inset)
- Observed in single- and few-layer graphene

dV/dI>0 (normal state)

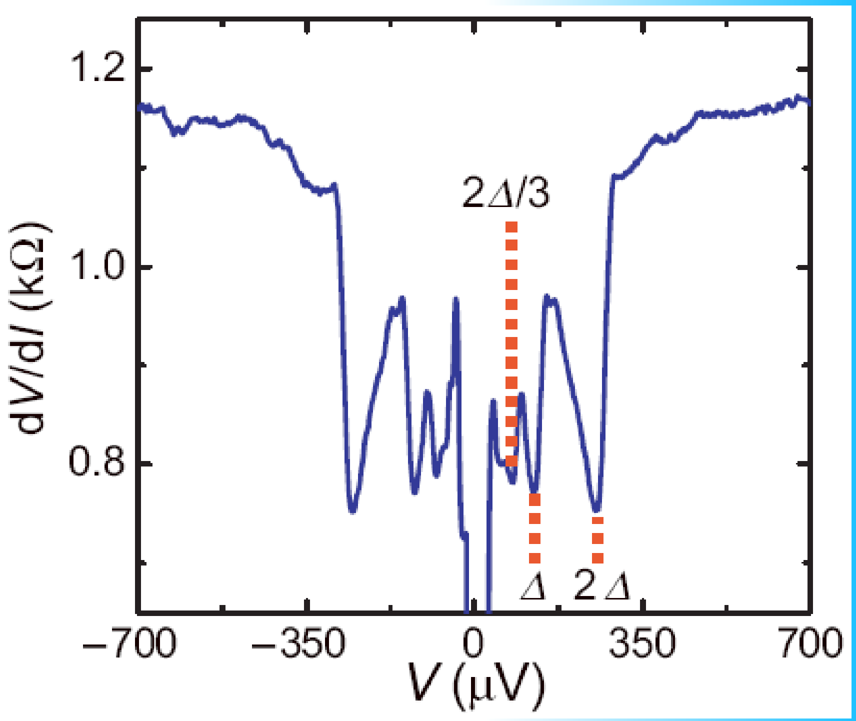
dV/dI=0 (supercurrent)

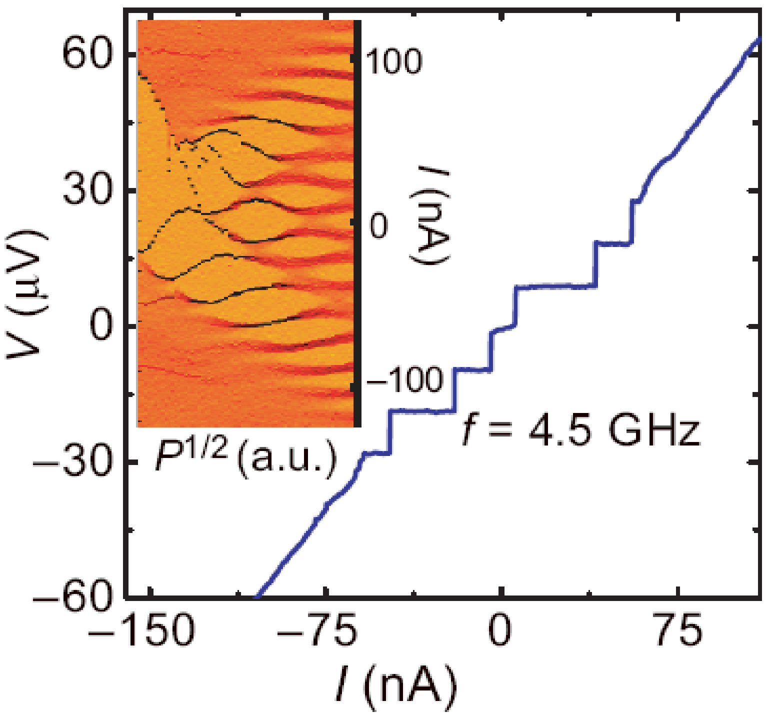


- Critical current I_C oscillates with magnetic field B
- Fraunofer-like pattern
- Observed periodicity $2.5 \pm 0.5\mathrm{mT} \equiv \Phi_0 / A$
- Good agreement with area A measured by AFM

Results

- Dips in $\mathrm{d}V/\mathrm{d}I$ due to multiple Andreev reflections
- Dips occur at $V{=}2\Delta/en$, with $n\epsilon\mathbb{N}$
- Superconducting gap: $\Delta{=}125\mu\mathrm{eV}$ in accordance with expectations for Ti/Al bilayer

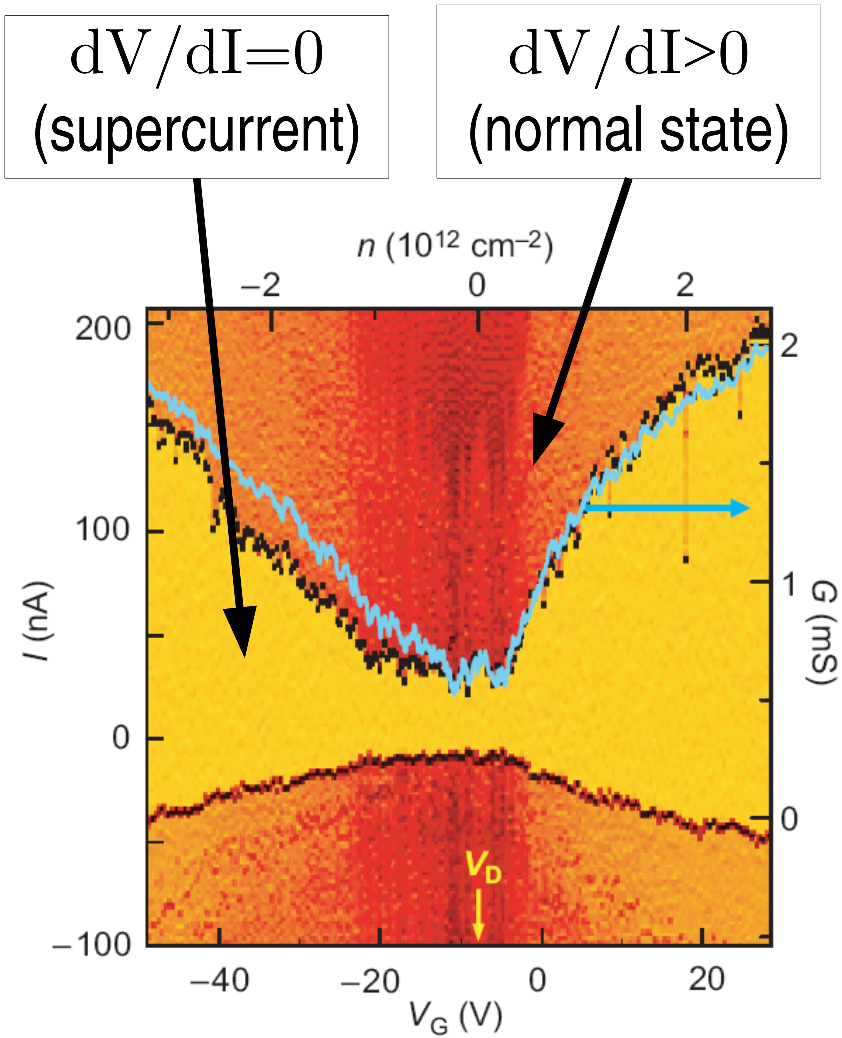




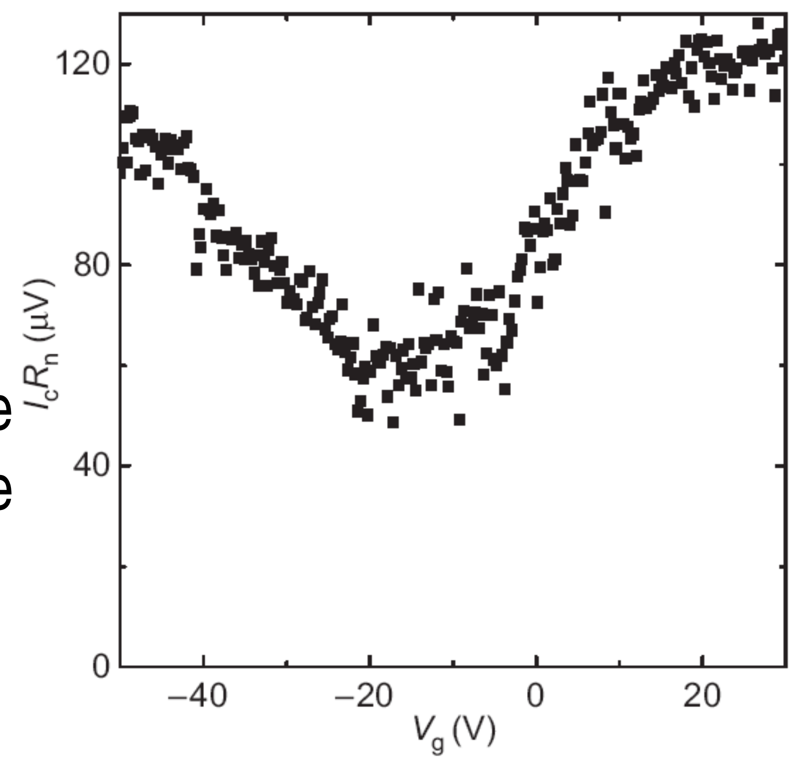
- Application of external microwave field
- AC-Josephson effect
- Shapiro steps of amplitude $\hbar\omega/2e$
- ω: microwave frequency

Results

- Bipolar supercurrent
- Both electron- and hole-Cooper pairs
- Finite supercurrent at Dirac point
- I_C-Asymmetry due to hysteresis

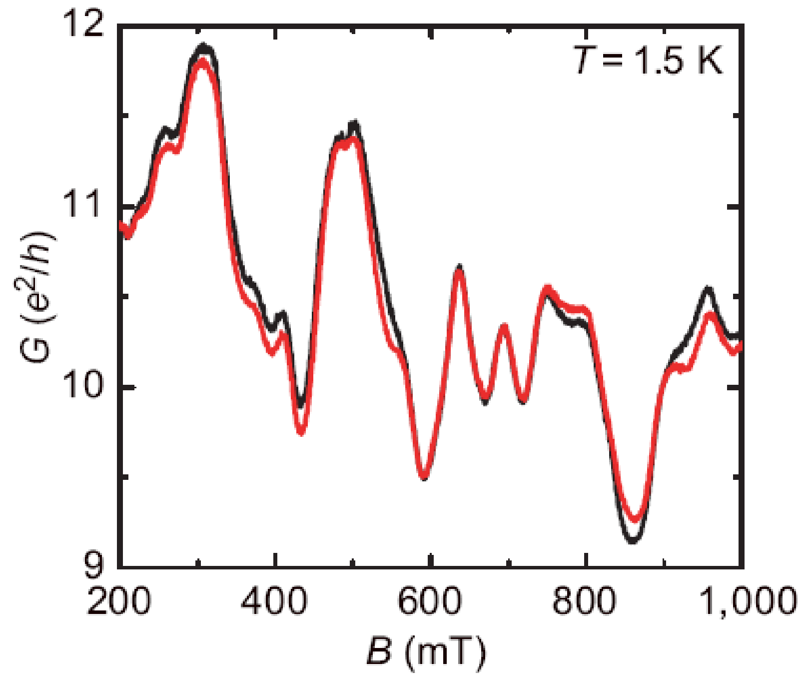


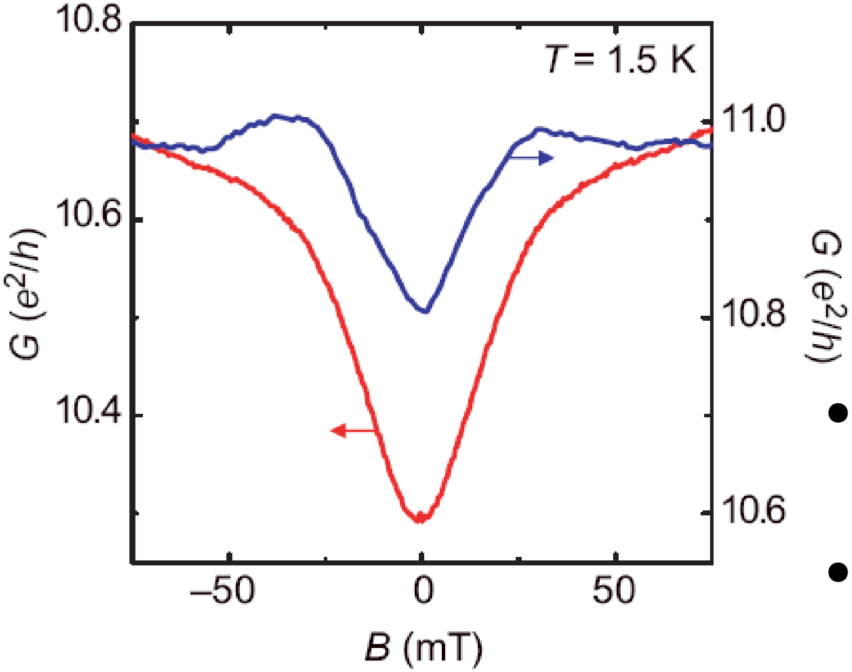
- Product of critical current and normal state resistance
  - $I_C R_n \sim \Delta/e$, should be $\sim 2.5\Delta/e$
- Stronger suppression around Dirac point



Results – normal state

- Reproducible, aperiodic conductance fluctuations of amplitude e^2/h
- Requires phase coherence, but not time reversal symmetry (TRS)





- Magnetoconductance for two different single layer graphene samples
- Weak localization is sample dependent

TRS usually suppressed in normal state (no coupling between valleys), but can be restored by impurities or edges.