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Towards microwave optomechanics using a superconducting carbon nanotube weak link

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Abstract

Utilizing the ultra-high sensitivity of a superconducting single-walled carbon nanotube (SWCNT) sensor to probe the quantum ground state is a promising experimental approach for investigations of macroscopic quantum phenomena. We approach the challenge with suspended, 300 nm long SWCNT contacted on MoRe leads. MoRe is used because it can withstand temperatures above 900 °C. Such temperatures are used in our annealing process as well as in CNT CVD growth processes. Good transparency of the superconductor-nanotube contacts allows observation of proximity induced supercurrents of up to 50 nA, tuneable by gate induced charge. Additionally, we have developed a method to pick-up and place individual suspended SWCNT selectively on metal-electrodes. Using such weak links in an optomechanical microwave setting, coupling emerges on the order of 2 MHz can be reached between the mechanical resonator and the electrical cavity.

Limits of CNT supercurrent

- CNT coupled to two leads with equidistant energy levels and four time degenerate (two valleys and two spins) channel with a transparency

\[ \tau = \frac{1}{1 + \left(\frac{\delta V_g(1 - \delta V_g)}{\sqrt{\delta V_g(1 - \delta V_g)}}\right)} \approx 0 \]

- The escape rates to both sides are then given by

\[ \partial V_g \approx \frac{\delta V_g}{\sqrt{\delta V_g(1 - \delta V_g)}} \]

- We can express the conductivity and the critical current as follows

\[ G = \frac{\delta V_g}{\delta I_c} \quad \text{and} \quad I_c = \frac{\delta V_g}{\sqrt{\delta I_c}} \]

- We can estimate the maximum critical current \( I_c \) and responsivity \( \delta I_c/\delta V_g \) for our geometry

\[ \frac{\partial I_c}{\partial V_g} \approx \frac{2\sqrt{\Delta}}{k_B T} \]

- We can measure a supercurrent of up to 52 nA with a responsivity of \( \delta I_c/\delta V_g = 290 \text{nA/V} \).

Coupling the CNT to a Cavity

- \( V_0 \) = 9.45 V
- Measuring supercurrent in CNT
  - We fabricated source/drain pairs of 200 nm MoRe [1] and a separation of 300 nm and deposited aerosol-synthesised [2] carbon nanotubes onto a chip with multiple pairs.

![Image of Measuring supercurrent in CNT](image)

- Promising tubes are selected and cooled down to 10 mK.

- We can measure a supercurrent of up to 52 nA with a responsivity of \( \delta I_c/\delta V_g = 290 \text{nA/V} \).

Carbon nanotube transfer

- CVD grown CNTs are picked up from a separate chip at 70 °C. The PMMA is patterned with holes of 2 µm × 10 µm.

- CNT coupled to two leads with equidistant energy levels and four time degenerate (two valleys and two spins) channel with a transparency.

- We can measure a supercurrent of up to 52 nA with a responsivity of \( \delta I_c/\delta V_g = 290 \text{nA/V} \).

Summary and Future outlook

- We analyzed the working principle and limiting factors of a suspended CNT resonator on MoRe source/drain pairs.
- The contact resistance of the metal-CNT interface can be decreased by annealing at \( T = 900^\circ \text{C} \) and critical currents of 50 nA are measured.
- We characterize CNTs by Raman spectroscopy before transferring these onto pre-patterned electrodes on a device chip.
- A Cavity-CNT single photon-phonon-coupling rate of \( \bar{g} = 2 \text{MHz} \) is predicted.
- The cavity readout frequency is around \( f_c = 7 \text{GHz} \) and a realistic operation point of \( f_c = 50 \text{nA} \) corresponds to a Josephson energy of \( E_J/2\hbar = 24 \text{GHz} \) and a charging energy \( E_C/2\hbar = 2 \text{GHz} \).
- The coupling between the Qubit and phonon corresponding to the CNT vibration is

\[ \bar{g} = \frac{\delta E_C}{\delta L_{zpm}} \approx \frac{\Delta}{L_{zpm}} \approx 2 \text{MHz} \]

References

[5] Manuyama Lab webpage, Univ. of Tokyo

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