Will, Marco; Kaikkonen, Jukka-Pekka; Hakonen, Pertti J.; Thanniyil Sebastian, Abhilash; Golubev, Dmitry

Feasibility study on superconducting carbon nanotubes coupled to microwave cavities

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Towards microwave optomechanics using a superconducting carbon nanotube weak link

Marco Will1, Jukka-Pekka Kaikkonen1 and Pertti J. Hakonen1

1School of Science, Low Temperature Laboratory, Aalto University, FI-00076 AALTO, Finland

Abstract

Utilizing the ultra-high sensitivity of a superconducting carbon nanotube (CNT) sensor to probe the quantum ground state is a promising experimental approach for investigations of microscopic quantum phenomena. However, reproducible and reliable fabrication of such devices is still to be shown due to the demands on high temperature stable materials that the CNT growth requires and the crucial role the contact resistance plays for inducing superconductivity into the CNT. We approach the challenge using molybdenum rhenium (MoRe) microwave cavity, which withstands high temperatures. As an alternative for pure MoRe, we have also explored palladium (Pd) cover on top of the MoRe contacts. Pd should prevent the MoRe from oxidization between the mechanical resonator and the electrical cavity.

Many features are an indication for multiple tubes. We fabricated source/drain pairs of 50 nm MoRe [1] and a separation of 250 nm and decreased the contact resistance by a factor of 5 compared to the device without Pd. The combination of suspended CNT and readout cavity introduces new challenges, but also new opportunities. However, reproducible and reliable fabrication of such devices is still to be shown due to the demands on high temperature stable materials that the CNT growth requires and the crucial role the contact resistance plays for inducing superconductivity into the CNT. We approach the challenge using molybdenum rhenium (MoRe) microwave cavity, which withstands high temperatures. As an alternative for pure MoRe, we have also explored palladium (Pd) cover on top of the MoRe contacts. Pd should prevent the MoRe from oxidization between the mechanical resonator and the electrical cavity.

Measuring supercurrent in CNT

• We fabricated source/drain pairs of 50 nm MoRe [1] and a separation of 250 nm and deposited aerosol-synthesized [2] carbon nanotubes onto a chip with multiple pairs.
• Promising tubes are selected and cooled down to 10 mK.
• We can measure a supercurrent of up to 22 nA with a responsivity of \( \partial I_C / \partial V_g = 85 \text{nA V}^{-1} \).

Limits of CNT supercurrent

• CNT coupled to two leads with equidistant energy levels and four time degenerate (two valleys and two spins) opportunities.
• The escape rates to both sides are then given by \( \tau_R > 0.5 \text{ and } \tau_L > 0.5 \) (no Coulomb blockade) and the CNT has 4 channel with a transparency

\[
T = \frac{\tau_L}{\tau_L + \tau_R} \approx 0.5
\]

• We can express the conductivity and the critical current as followed

\[
G = \frac{\tau_L}{\tau_L + \tau_R} \quad \text{and} \quad I_{C_{\max}} = \frac{2e}{\hbar} \ln \left( \frac{\tau_L}{\tau_R} \right)
\]

• We can estimate the maximum critical current \( I_{C_{\max}} \) and sensitivity \( \partial I_C / \partial V_g \) for our geometry.

\[
\frac{\partial I_C}{\partial V_g} \approx (4e^2/h) \ln \left( \frac{\tau_L}{\tau_R} \right)
\]

• The combination of suspended CNT and readout cavity introduces new challenges, but also new opportunities.
• On one hand the contact resistance of the CNT-metal interface is very important for obtaining high critical currents. We will further improve our approach with thin Pd films.

Coupling the CNT to a Cavity

• We demonstrated the working principle of a CNT resonator on Pd/MoRe source/drain pairs.
• The combination of suspended CNT and readout cavity introduces new challenges, but also opportunities.
• One important factor is the placement of the CNT onto the cavity with sufficient accuracy and without degrading the cavity quality factor. We plan to stamp the CNT using a PMMA stamp onto the pre patterned cavity.
• The stamping approach yields another advantage: it enables the characterization of the CNT before transferring resulting in higher yield of useful devices.

Future outlook

• First device with 5 nm palladium (Pd) cover on top of the MoRe contacts.
• Pd should prevent the MoRe from oxidization.
• The device shows supercurrent, however, it is very small compared to the device without Pd.
• Many features are an indication for multiple tubes.

References


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*email: marco.will@aalto.fi