Microwave optomechanics with a suspended carbon nanotube quantum dot[1]

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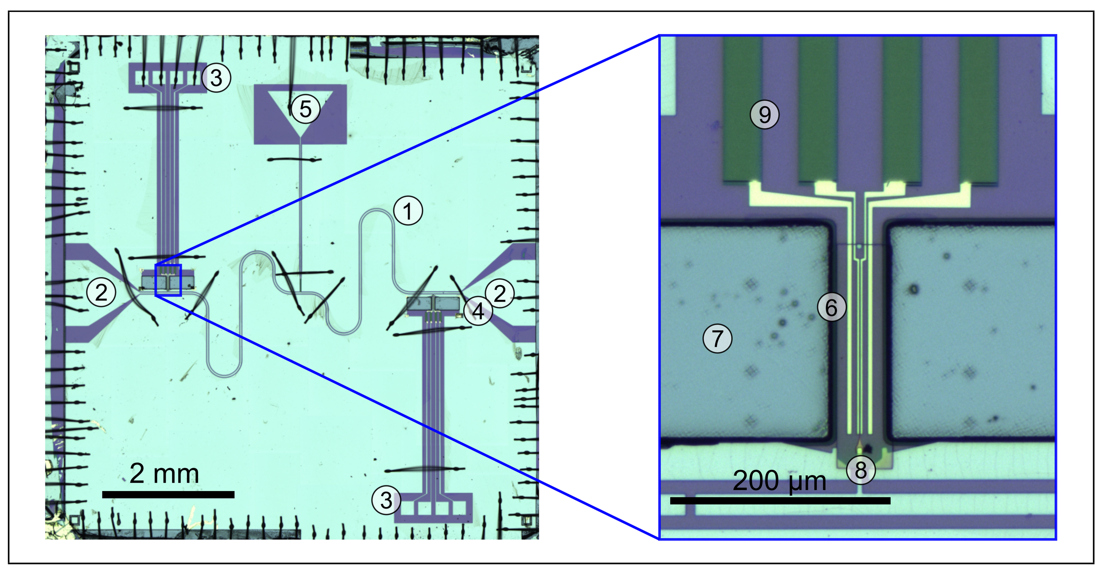
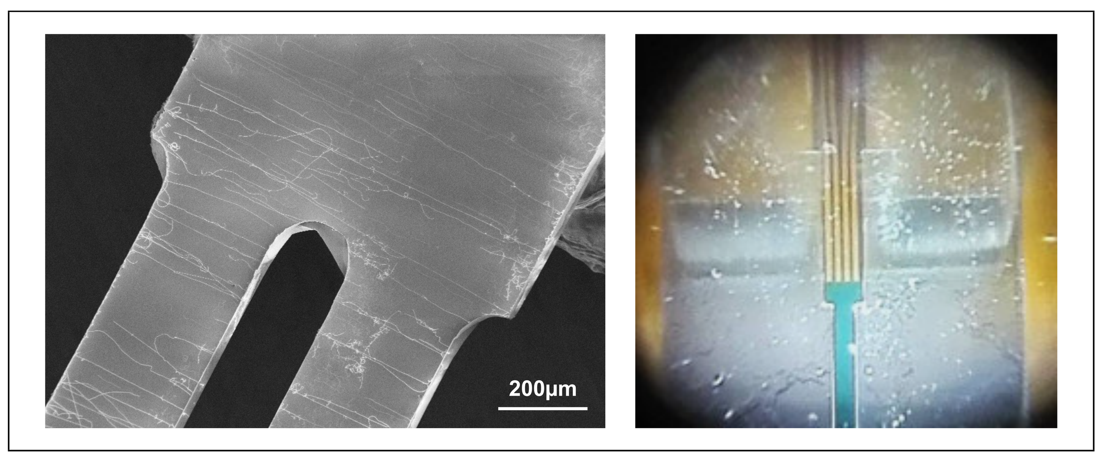
Coplanar resonator device



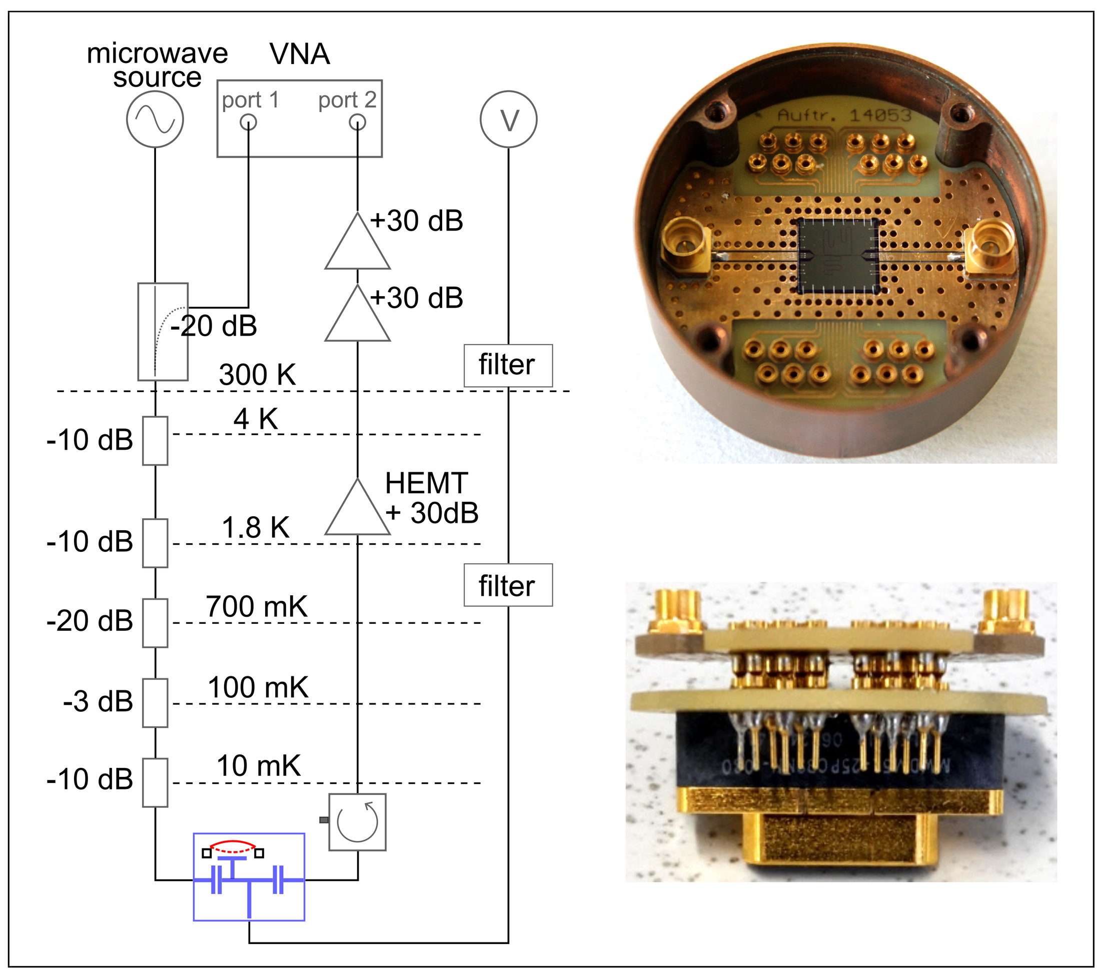
- niobium coplanar $\lambda/2$ cavity (1) with input/output ports for transmission measurement (2)
- nanotube transfer areas at voltage antinodes (4)
- center conductor dc bias connection near voltage node (5)
- nanotube dc leads (3), rf-block inductances (9), and contact electrodes (6)
- buried gate finger connected to cavity (8)
- deep-etched areas for transfer fork insertion (7)

Carbon nanotube transfer



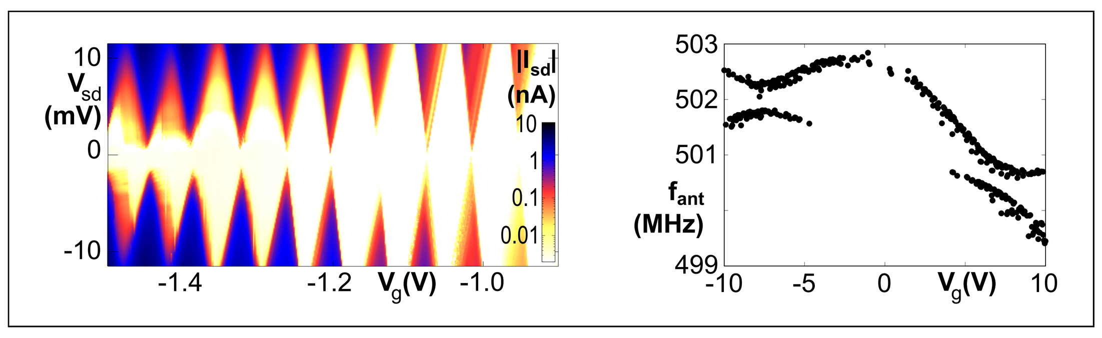
- carbon nanotube growth on commercial quartz tuning forks
- the forks are lowered onto the chip until electrical contact is detected
- nanotubes are then cut with a large current
- for the details, see [2]

Measurement setup



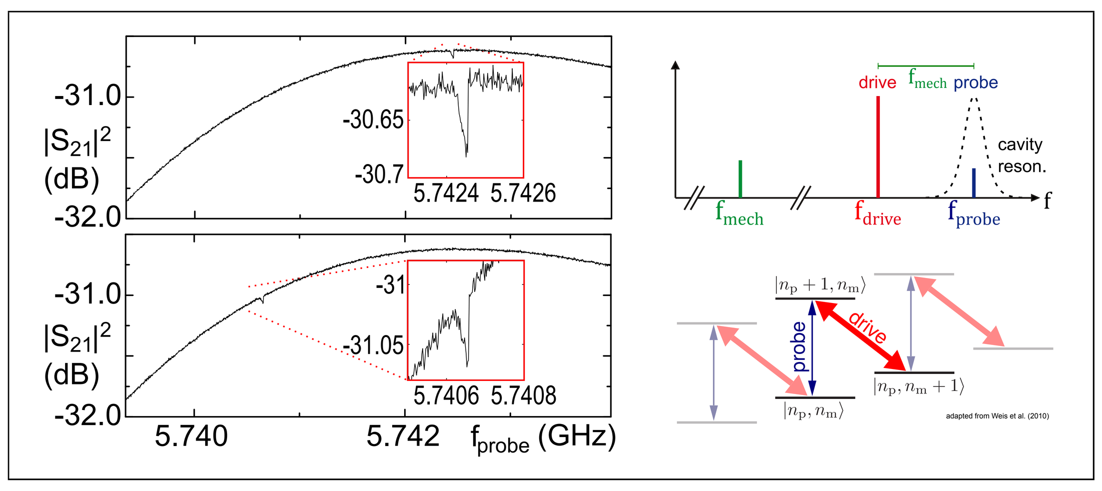
- dilution refrigerator, base temperature $\sim 10\,$mK
- combined dc- and GHz-setup
- Caltech CITCRYO1-12 wide band cryoamp

Nanotube properties



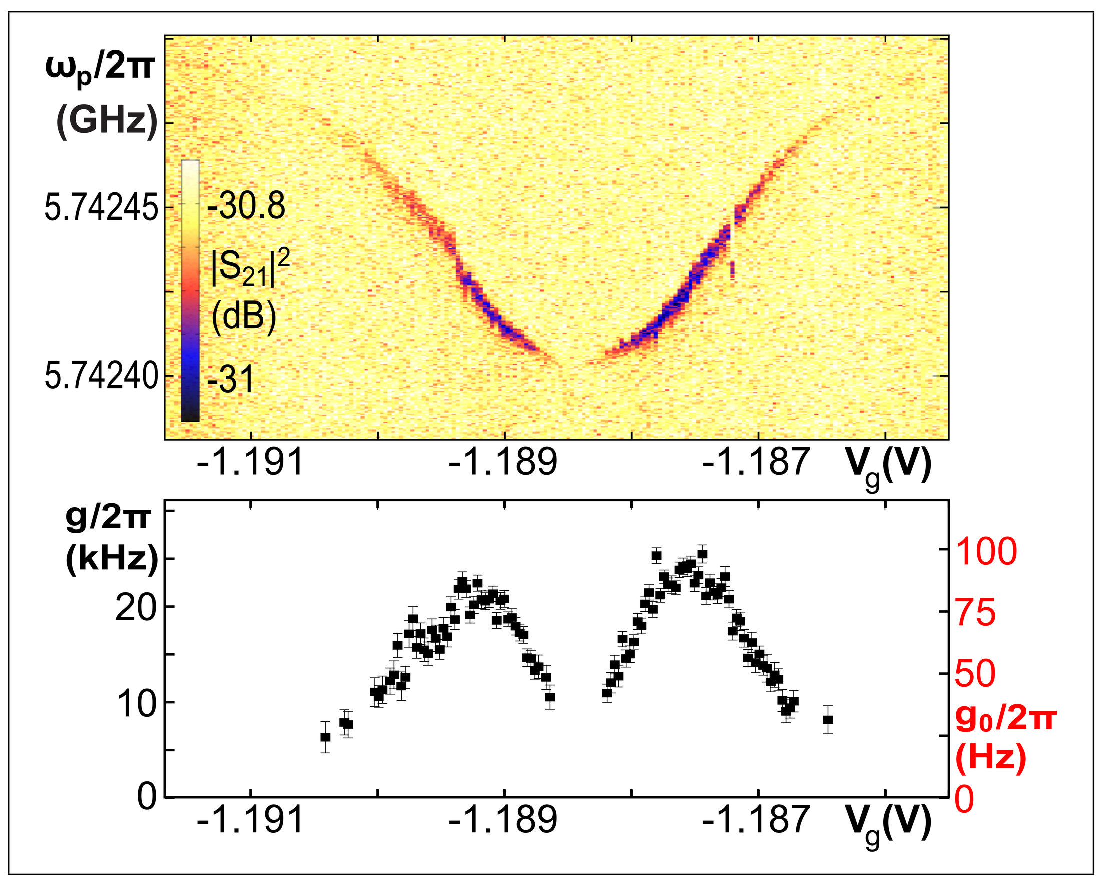
- small bandgap carbon nanotube
- quantum dot, regular Coulomb oscillations
- two mechanical resonances at $f \simeq 500\,$MHz detected in dc transport [3]

Optom. induced transparency



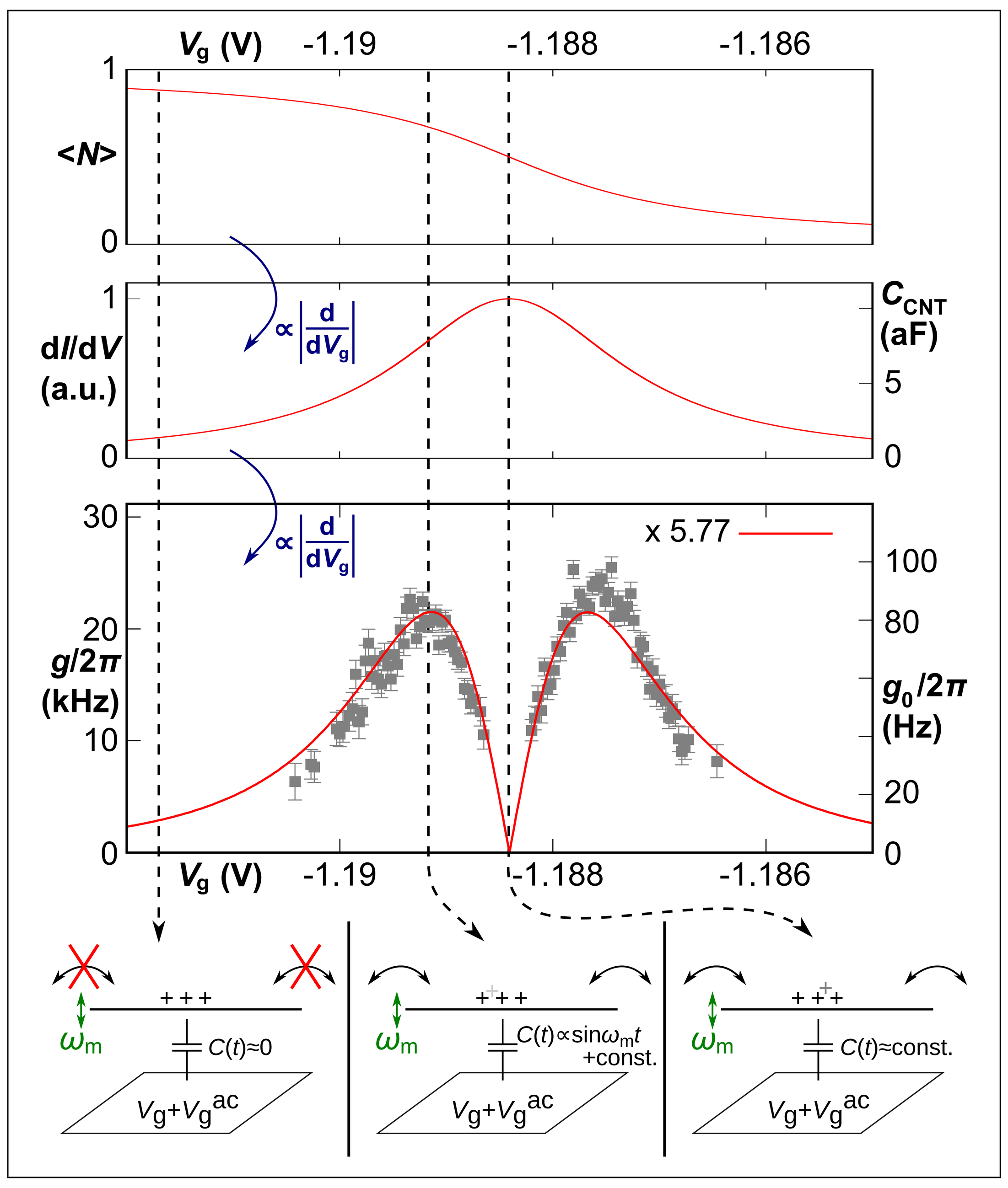
- drive the cavity at the red sideband, measure the cavity transmission with a weak probe signal
- $f_{\text{probe}} - f_{\text{drive}} = f_{\text{mech}} \longrightarrow$ coupling into mechanical mode, "OMIT" [4]
- mechanical resonance visible in transmission
- dispersively coupled optomechanical system [5]
- coupling up to $g \simeq 2\pi \cdot 20\,$kHz or $g_0 \simeq 2\pi \cdot 95\,$Hz
- far too large for a geometric capacitance effect

Gate-dependent coupling $g(V_g)$



- fix f_{drive}, measure cavity transmission as function of V_g and f_{probe}
- position of "OMIT" dip $\leftrightarrow$ mech. resonance frequency f_{mech}, well-known behavior $f_{\text{mech}}(V_g)$
- depth of "OMIT" dip $\leftrightarrow$ dispersive coupling $g(V_g)$
- g very large on the flanks of a Coulomb blockade (CB) conductance oscillation
- g zero / unmeasurable in CB and at the center of the CB oscillation
- CB enhancement of optomechanical coupling

Enhancement mechanism

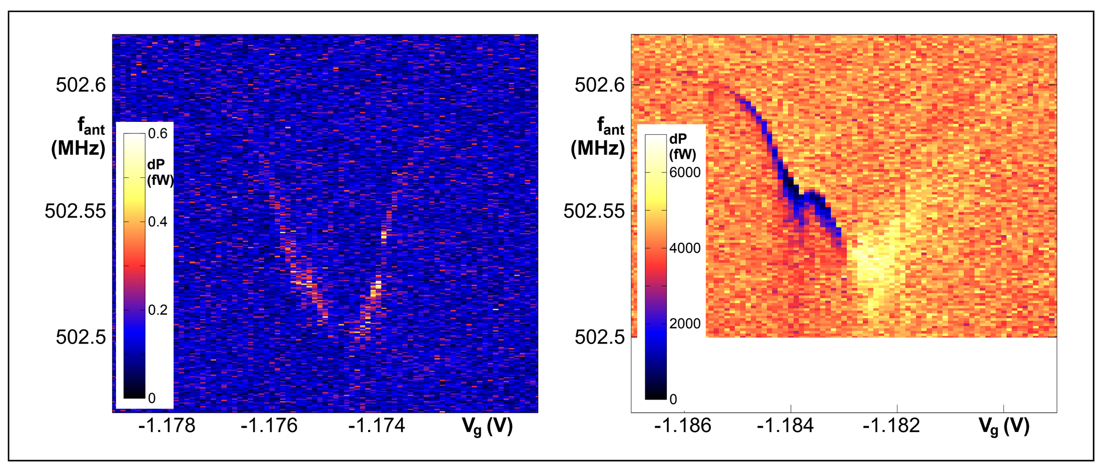


- around a CB oscillation, the charge $\langle N \rangle$ depends very strongly on the potential
- the GHz cavity "detects" $\partial \langle N \rangle / \partial V_g$
- on the CB oscillation flanks, this derivative is modulated by the motion!
- amplification factor for optomechanical coupling:

$$\eta = e \frac{\partial^2 \langle N \rangle}{\partial V_g^2} \frac{V_g}{C_\Sigma}$$

- values up to $\sim 10^4$ reached here!

Red sideband upconversion



- detect motion by removing energy from it!
- vibration driven by antenna, f_{mech}
- cavity pumped at sideband, $f_{\text{drive}} = f_{\text{cav}} - f_{\text{mech}}$
- detection of output power at f_{cav}
- thermal signal not resolved yet

Outlook

- thermal motion detection, ground state cooling
- vibration mode manipulation!
- interaction with SET current!

References

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