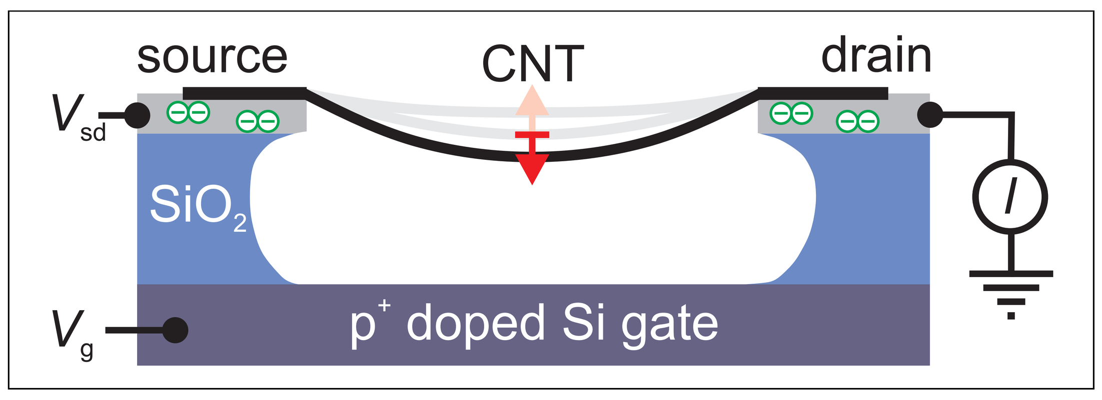
Hybrid nanotube – superconductor NEMS systems

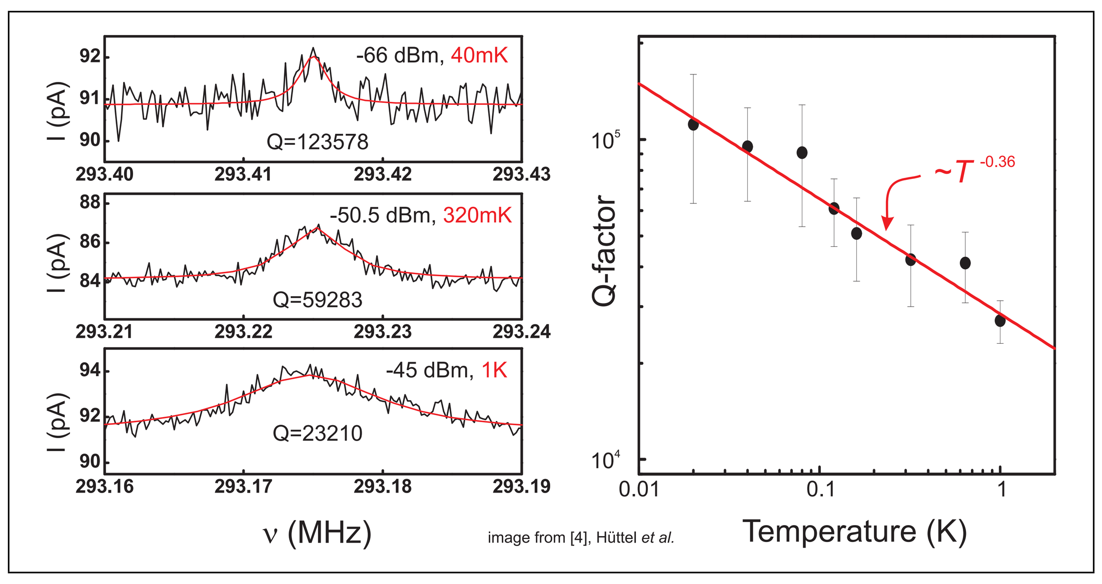
D. Schmid, D. Preusche, P. Stiller, Ch. Strunk, and A. K. Hüttel
Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

Ultraclean carbon nanotubes as NEMS resonators

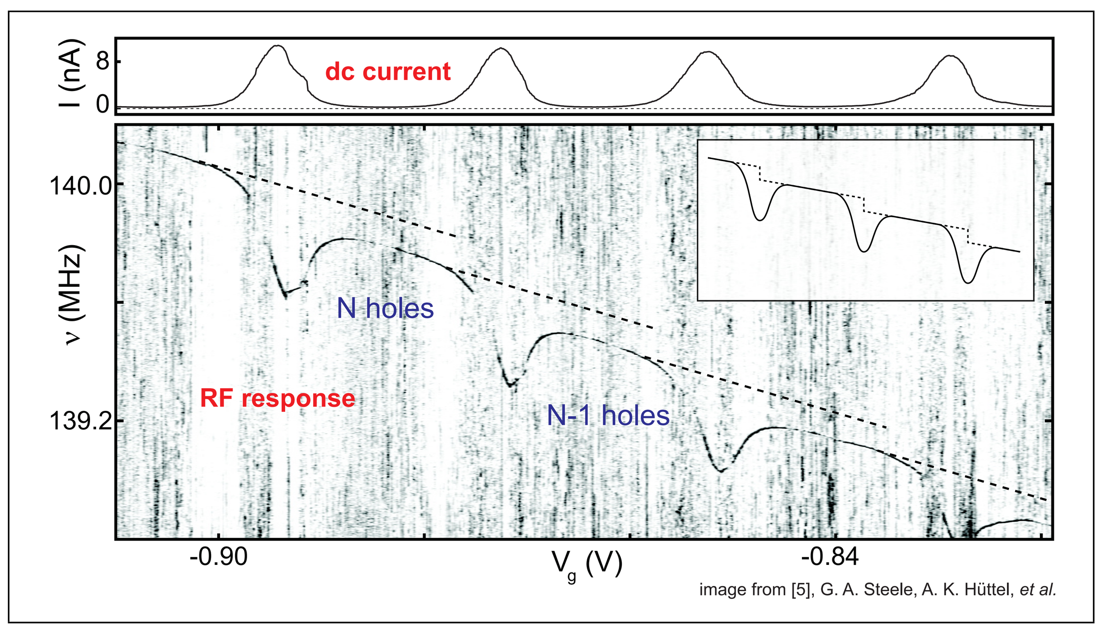


- first prepare all on-chip infrastructure: contacts, gates, trenches, ...
- then grow nanotubes across the chip
- no lithography or wet chemistry afterwards!
- → no chemical or mechanical damage
- → no resist residues
- → no e-beam irradiation
- → chip structures must survive the chemical vapour deposition (CVD) nanotube growth
- typically, platinum thin films as contacts
- → transport spectroscopy of clean few-electron systems [1, 2, 3]
- → nanotubes as high-Q nanomechanical resonators [4]
- → strong coupling of single electron tunneling and mechanical motion [5]

Driven resonator detection [4, 5]

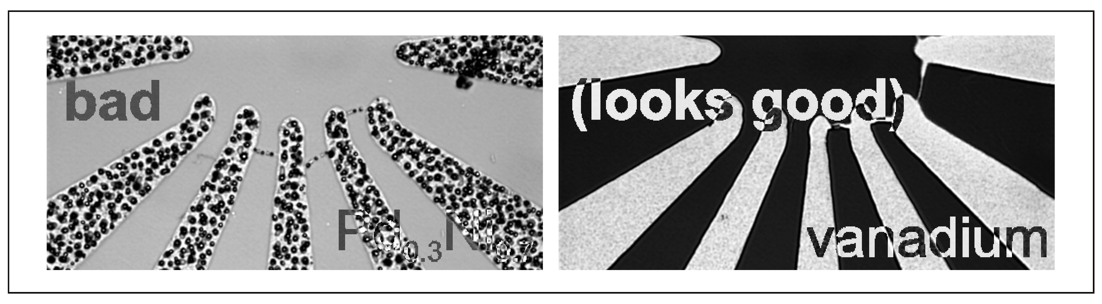


- driving the resonator contact-free with RF signal
- mechanical resonance emerges as sharp feature in dc SET current
- at $T \simeq 20$ mK, mechanical quality factors of $Q \gtrsim 10^5$ are obtained!



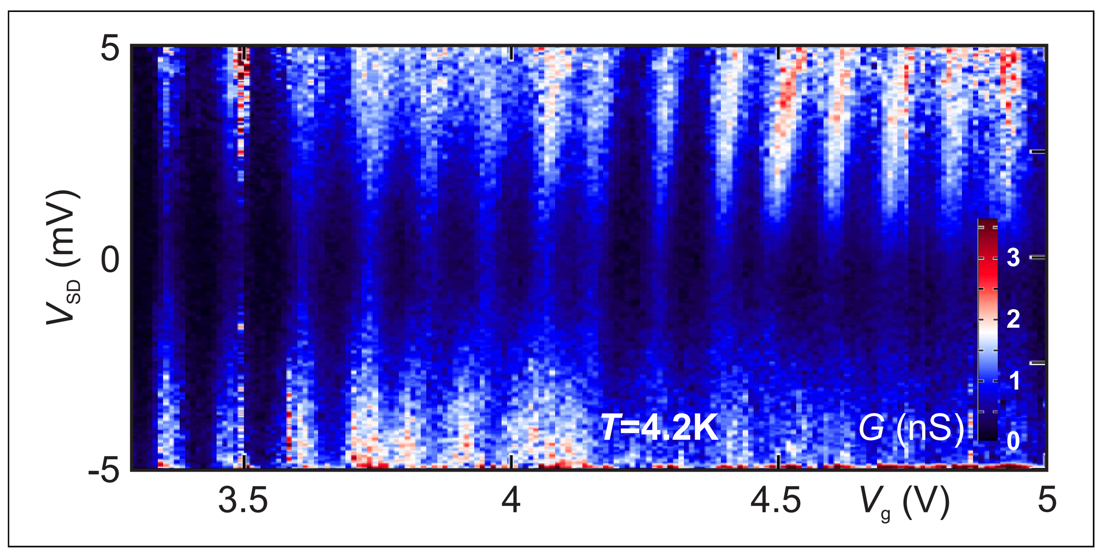
- "Coulomb blockade oscillations of mechanical resonance frequency"
- continuous charge on back gate ⟶ slope
- discrete charge on nanotube ⟶ steps
- SET current: dynamic contribution to spring constant ⟶ dips in resonance frequency!

Typical issues with alternative contact metallizations

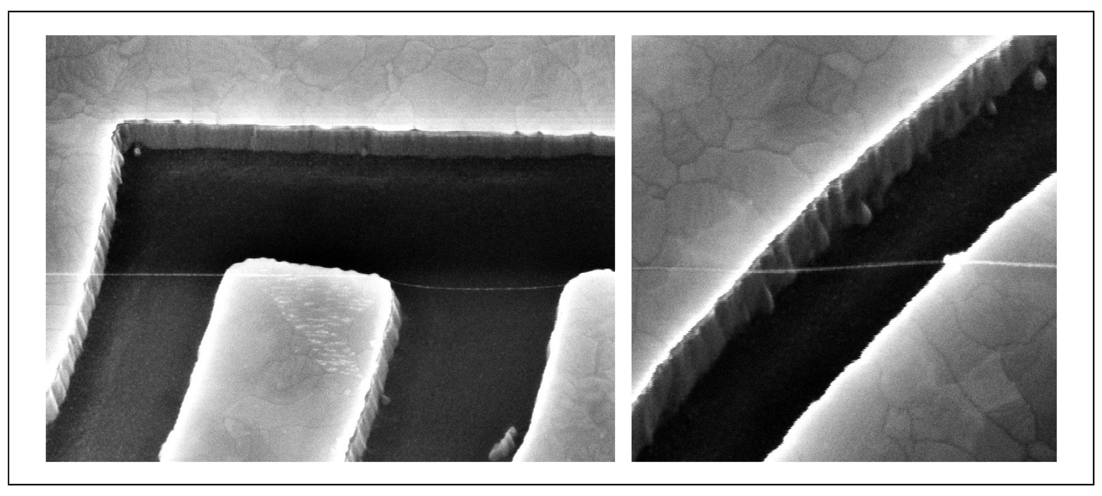


- CVD: 10min, 900°C, CH_4 and H_2: for a metal thin film "as bad as it gets"
- melting, recrystallization
- → deformation, loss of conductivity
- hydrogen / carbon storage in metal
- → lowering of superconductor T_c
- influence of metal on nanotube growth?
- properties of nanotube–metal contact?

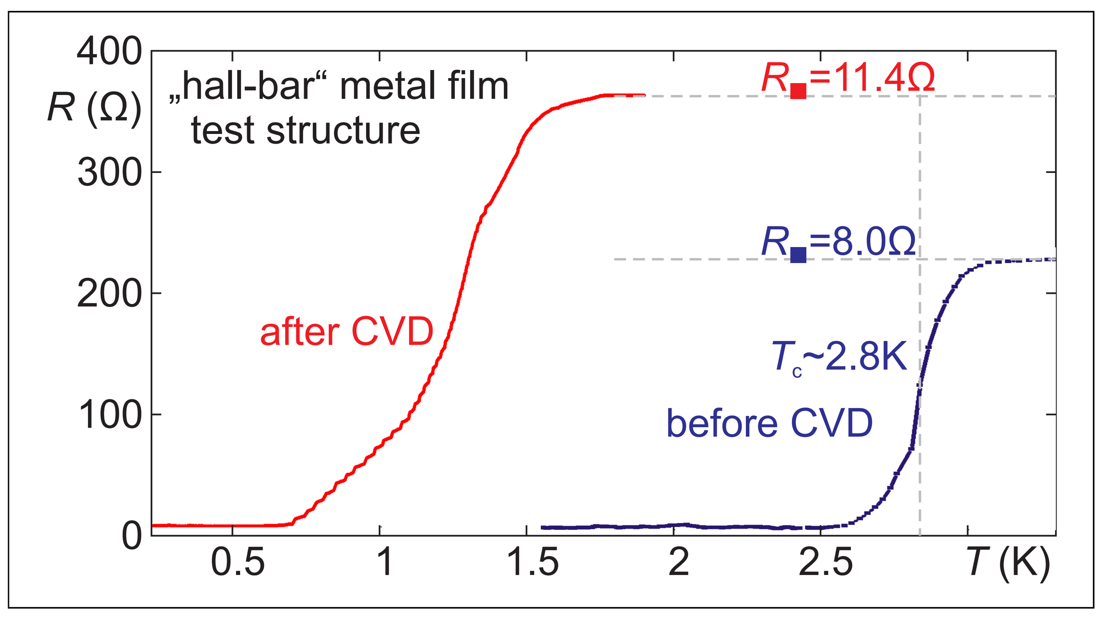
Recent advances in Regensburg

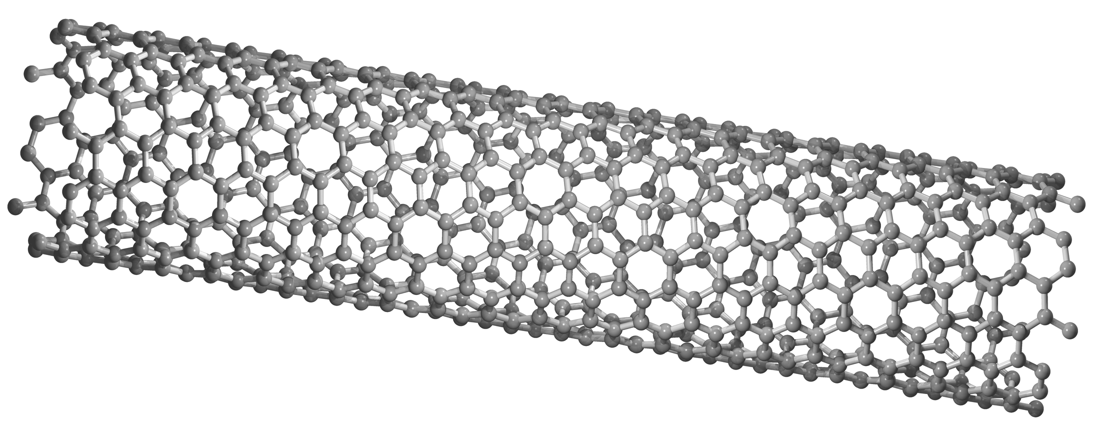


- first suspended CNT quantum dots with Pt contacts (i.e. normal metal; tests at $T = 4.2$ K)

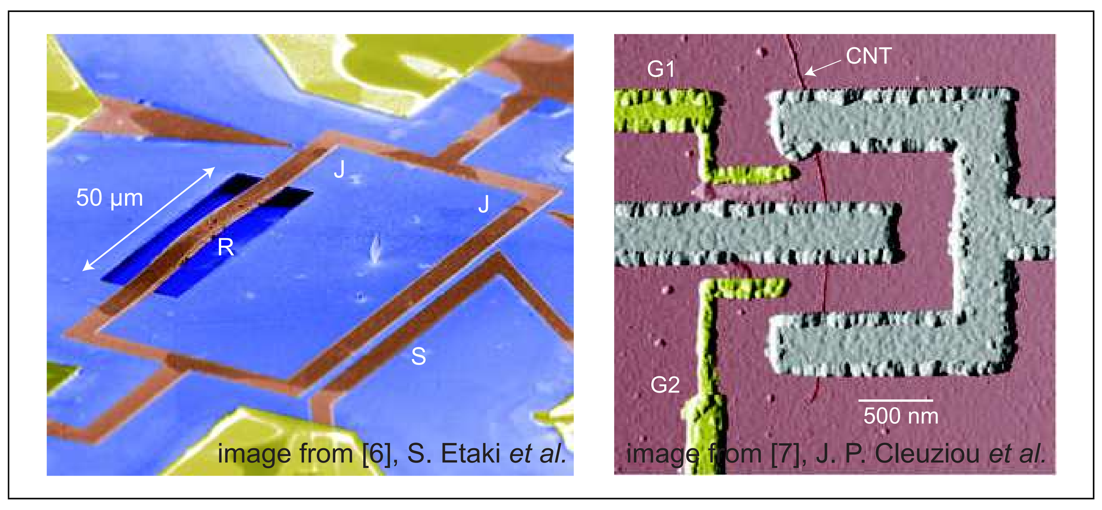


- successful nanotube growth across superconductor layers and trenches
- metal $T_c \simeq 800$ mK after CVD process
- fabrication and testing ongoing



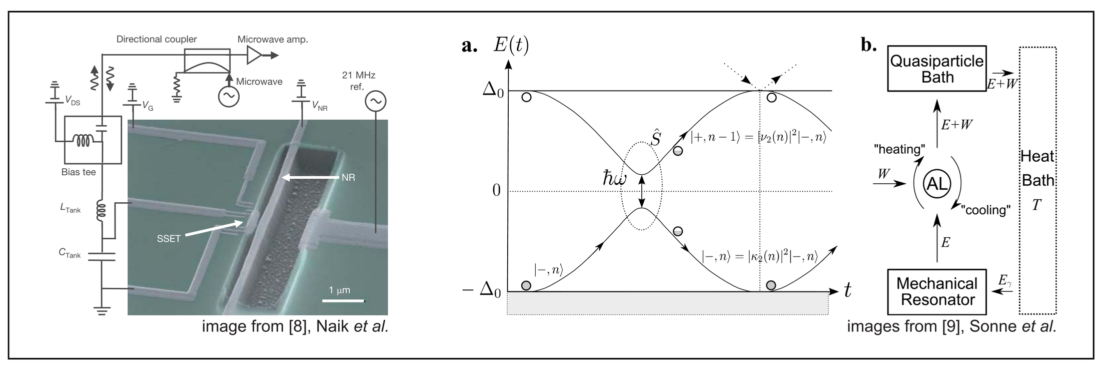


Plans and outlook: NEMS & superconductivity



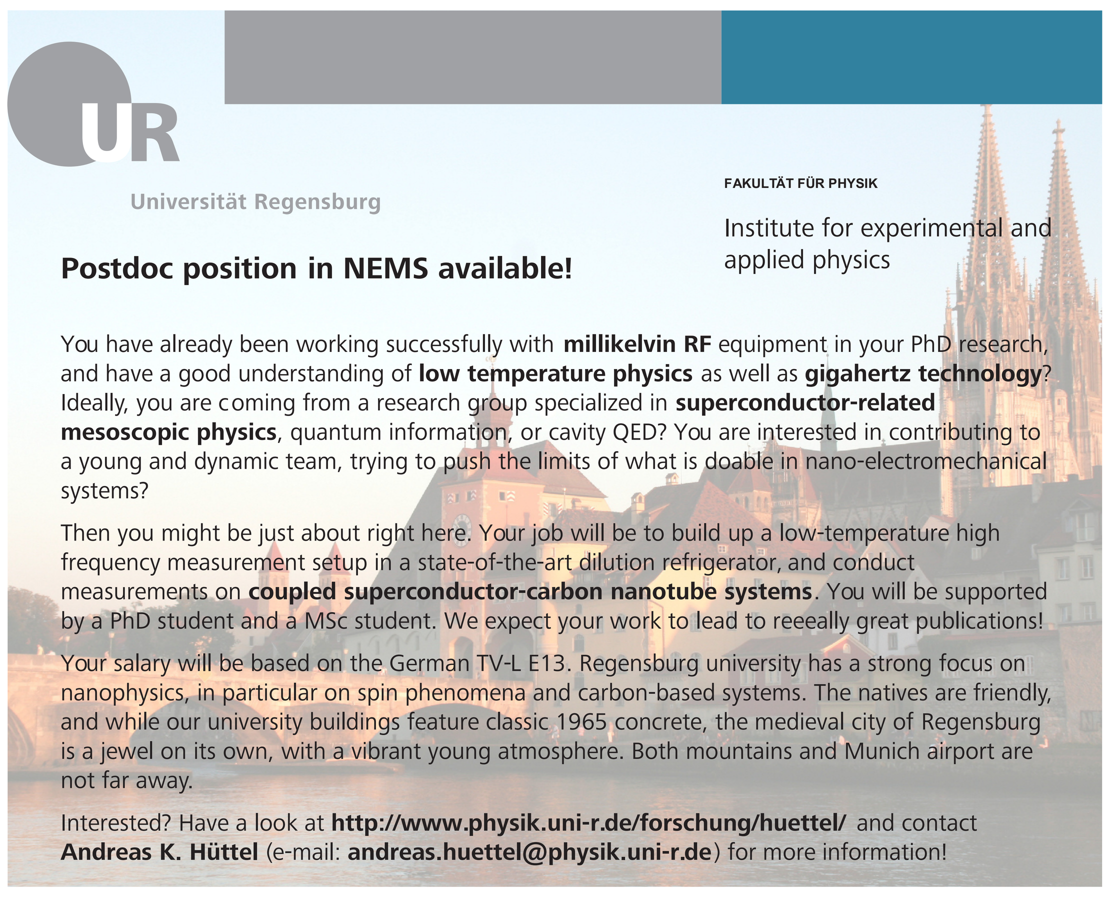
- a SQUID can be used to detect the mechanical motion of a beam integrated in its arm [6]
- a single nanotube can form the weak links of a SQUID [7]
- combine these techniques?
- open questions e.g. interplay of mechanical motion with ac Josephson effect, localized electronic states, Kondo effect?

Self-cooling resonators



- a nanotube mechanical resonator can be already close to quantum limit at $T \simeq 50$ mK
- back-action / sideband cooling [8]?
- use also ac Josephson effect, see [9]?
- other specific properties of systems with superconducting leads?

Bright postdoc wanted!


Universität Regensburg

FAKULTÄT FÜR PHYSIK

Institute for experimental and applied physics

Postdoc position in NEMS available!

You have already been working successfully with **millikelvin RF** equipment in your PhD research, and have a good understanding of **low temperature physics** as well as **gigahertz technology**? Ideally, you are coming from a research group specialized in **superconductor-related mesoscopic physics**, quantum information, or cavity QED? You are interested in contributing to a young and dynamic team, trying to push the limits of what is doable in nano-electromechanical systems?

Then you might be just about right here. Your job will be to build up a low-temperature high frequency measurement setup in a state-of-the-art dilution refrigerator, and conduct measurements on **coupled superconductor-carbon nanotube systems**. You will be supported by a PhD student and a MSc student. We expect your work to lead to reeeally great publications!

Your salary will be based on the German TV-L E13. Regensburg university has a strong focus on nanophysics, in particular on spin phenomena and carbon-based systems. The natives are friendly, and while our university buildings feature classic 1965 concrete, the medieval city of Regensburg is a jewel on its own, with a vibrant young atmosphere. Both mountains and Munich airport are not far away.

Interested? Have a look at **http://www.physik.uni-r.de/forschung/huettel/** and contact **Andreas K. Hüttel** (e-mail: **andreas.huettel@physik.uni-r.de**) for more information!

References

[1] J. Cao *et al.*, Nature Materials **4**, 745 (2005).
[2] V. V. Deshpande *et al.*, Science **323**, 106 (2009).
[3] G. A. Steele *et al.*, Nature Nanotech. **4**, 363 (2009).
[4] A. K. Hüttel *et al.*, Nano Letters **9**, 2547 (2009).
[5] G. A. Steele, A. K. Hüttel *et al.*, Science **325**, 1103 (2009).
[6] S. Etaki *et al.*, Nature Physics **4**, 785 (2008).
[7] J.-P. Cleuziou *et al.*, Nature Nanotech. **1**, 53 (2006).
[8] A. Naik *et al.*, Nature **443**, 193 (2006).
[9] G. Sonne *et al.*, Phys. Rev. Lett. **104**, 226802 (2010).

We gratefully acknowlegde funding by the DFG via the Emmy Noether grant Hu1808/1-1
"Carbon nanotubes as electronical and nano-electromechanical hybrid systems in the quantum limit".