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Ground state cooling of a carbon nano-mechanical resonator using spin-polarized current

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We study the non-equilibrium regime of a mechanical resonator at low temperature realized with a suspended carbon nanotube quantum dot contacted to two ferromagnets. Due to spin-orbit interaction [1,2] and/or an external magnetic gradient [3], the spin on the dot couples directly to the flexural eigenmodes, see Fig. 1. Owing to this interaction, the nanomechanical motion induces spin-flips of the electrons passing through the nanotube. When a finite voltage is applied, a spin-polarized current causes either heating or active cooling of the mechanical modes, depending on the gate voltage. Optimal cooling is achieved at resonance transport realized when the energy splitting between two dot levels of opposite spin equals the resonator frequency. We show that weak interaction coupling strength and moderate polarization can achieve ground state cooling.[4].

In a realistic setup, taking into account the intrinsic damping of the mechanical oscillator also increases the minimum phonon occupation. Remarkably, a phonon occupation of $n_{min} \simeq 0.5$ is still achieved for $Q \simeq 10^4$, small coupling $\lambda/\omega = 0.05$ and polarizations $p > 0.48$. The minimal phonon occupation reduces to $n_{min} = 0.2$ at $p = 1$. An occupation of $n_{min} \simeq 0.5$ is also obtained for $Q \simeq 10^5$ and $p > 0.3$ ($n_{min} = 0.05$ at $p = 1$). Motivated by a recent experiment which reported large spin-orbit interaction coupling Δ_{SO} [12], one can also consider coupling constants of order $\lambda/\omega = 0.2$ which implies a strong reduction of the polarization required for cooling. As example, we find $n_{min} \simeq 0.5$ for $Q \simeq 10^4$ and $p > 0.3$. Therefore we conclude that even for modest polarizations, which appears feasible in promising experiments with carbonnanotube quantum dots, quantum ground state cooling is achievable.

References

[1] M. S. Rudner and E. I. Rashba, PRB 81, 125426 (2010).
[2] A. Pályi, P. R. Struck, M. Rudner, K. Flensberg and G. Burkard, PRL 108, 206811 (2012)
[3] D. Rugar, R. Budakian, H. J. Mamin and B. W. Chui, Nature 430, 329 (2004)
[4] P. Stadler, W. Belzig and G. Rastelli, arXiv: 1404.0485.

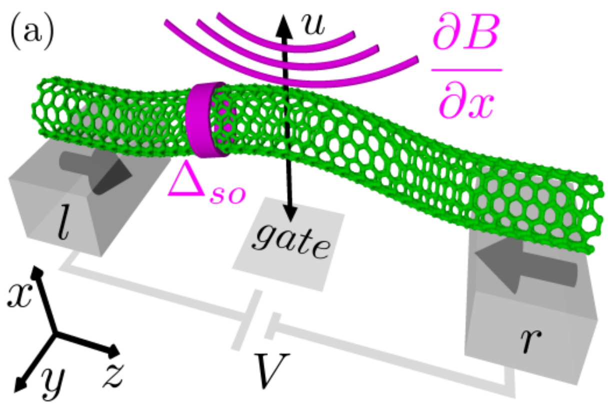

Figure 1. Schematic view of a carbon nanotube quantum dot suspended between two ferromagnetic leads. Due to the nanotube spin-orbit interaction and/or to a magnetic field gradient, the dot spin's component parallel to the mechanical displacement u is coupled to the flexural mode with a dimensionaless coupling constant λ/ω.

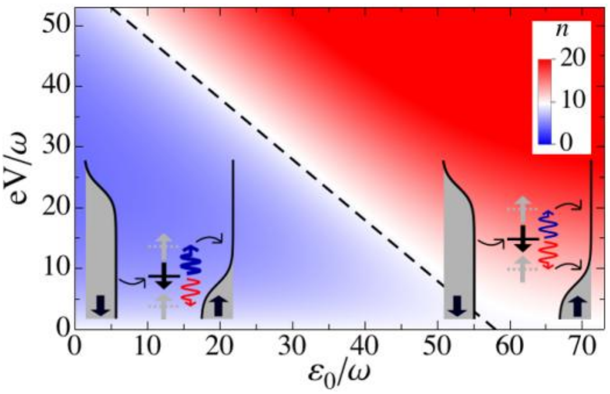

Figure 2. Non-equilibrium occupation n of the mechanical resonator as a function of source drain voltage and energy level of the dot ε_0 for fully polarized ferromagnetic leads with anti-parallel magnetization. The dashed line corresponds to the alignment of a spin-resolved energy level with the chemical potential on the left contact. The insets show the processes for cooling (I) and heating (II), respectively. The temperature of the mechanical resonator is set to $k_BT=10\omega$.

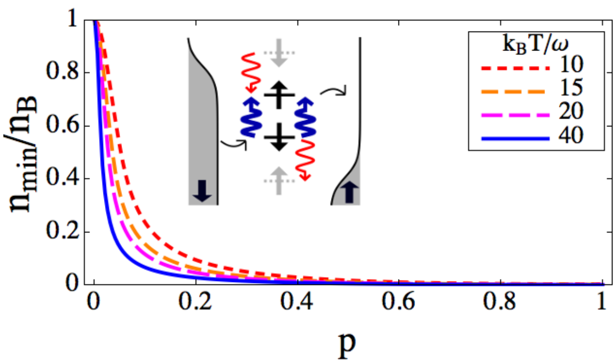

Figure 3. Minimal Phonon occupation along the vertical axis $\varepsilon_0=0$ of Fig. 1 as a function of polarization for different temperatures at resonance. The bosonic thermal occupation is denoted as n_B.