NONMONOTONIC NONLINEAR FRICTION IN SELF-SUSTAINED NANOTUBE OSCILLATORS

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Suspended carbon nanotubes (CNTs) are studied intensively as Nano-Electro-Mechanical Systems (NEMS) [1] since they represent a challenge for future industrial applications in the promising field of nanotechnology [2-4]. Owing to their ultrahigh frequencies and quality factors (i.e. low damping), they can bridge the gap between classical and quantum technologies, and enable high-performance nanomechanical sensors, mechanical quantum bits and double quantum dots. Furthermore, due to their extreme flexibility, they are commonly used for studying electron transport mechanisms at the nanoscale [5]. The hallmark of CNT NEMS is the coupling between the mechanical and the electrical degrees-of-freedom, which emerges from the effect of each single electron charge over the high mechanical compliance of the device. Electrons influence the mechanical response by creating electrostatic forces, yet at the same time, allocation of charges is modified as a reaction to the displacement. This combination of mechanical vibrations and electric transport of charges brings to light new possibilities for amplifying thermal fluctuations as in single-electronic shuttle devices, as well as cooling down CNTs to only a few quanta.

In this work, we analyse the intermittent motion in a carbon nanotube that arises from the combination of electron tunneling and thermal effects [6]. The electro-mechanical cross-talk leads to co-existence of large-amplitude self-sustained oscillations and thermal vibrations. An analytical model that accounts for a nonmonotonic variation of nonlinear friction shows that stable self-sustained oscillations lie on an isolated branch in the space of the parameters [7]. Such a dynamical scenario is commonly hidden behind the veil of Brownian noise, and is structurally different from the conventional self-oscillations activated via a Hopf bifurcation of an equilibrium state. We elaborate on the occurrence of these isolated bifurcations and discuss how the nonlinear friction forces depend on the applied source-drain voltage drive.

References

[1] Adrian Bachtold, Joel Moser, and M. I. Dykman. Mesoscopic physics of nanomechanical systems. *Rev. Mod. Phys.*, 94:045005, 2022.

[2] https://www.iberdrola.com/innovation/nanotechnology-applications

[3] https://en.wikipedia.org/wiki/Applications_of_nanotechnology

[4] https://www.nano.gov/about-nanotechnology/applications-nanotechnology

[5] G. A. Steele, A. K. Hüttel, B. Witkamp, M. Poot, H. B. Meerwaldt, L. P. Kouwenhoven, and H. S. J. van der Zant. Strong coupling between single-electron tunneling and nanomechanical motion. *Science*, 325(5944):1103–1107, 2009.

[6] C. Urgell, W. Yang, S. L. De Bonis, C. Samanta, M. J. Esplandiu, Q. Dong, Y. Jin, and A. Bachtold. Cooling and self-oscillation in a nanotube electromechanical resonator. *Nature Physics*, 16(1):32–37, 2020.

[7] P. Belardinelli, W. Yang, A. Bachtold, M. I. Dykman, and F. Alijani. Hidden mechanical oscillatory state in a carbon nanotube revealed by noise. *https://arxiv.org/abs/2312.14034*, 2023.