Strongly coupled nanomechanical resonator modes: Coherent control and nonlinear dynamics

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Doubly-clamped pre-stressed silicon nitride string resonators excel as high Q nanomechanical systems enabling room temperature quality factors of several 100,000 in the 10 MHz eigenfrequency range. They are complemented by electrically induced gradient fields to implement dielectric transduction as an ideal platform for actuation, displacement detection and frequency tuning. The two orthogonal fundamental flexural modes of a single string vibrating in- and out-of-plane with respect to the sample surface can be engineered to tune reversely. This allows bringing both modes into resonance where a pronounced avoided crossing is observed, indicating strong mechanical coupling [1].
The resulting two-mode system can be coherently controlled via radio frequency pulses, and is shown to be an ideal testbed for the dynamics of two-level systems. The phenomena which can be explored range from Landau-Zener transitions [1] and Stückelberg interference [2] to Rabi- or Ramsey type experiments [3], and allow interesting insights into the coherence of the nanomechanical system.
Even more, the nonlinear response of the two-mode system becomes apparent under strong (parametric) actuation. It is reminiscent of second- and third order nonlinear processes in optical media [4]: Subject to a common parametric drive both modes start self-oscillating as a consequence of signal-idler generation via nondegenerate parametric two-mode oscillation. Dielectric tuning of the signal and idler resonances allows to control their frequency difference. Depending on the strength of the parametric pump tone, partial injection locking, injection pulling, and complete injection locking occurs. Furthermore, symmetric satellite resonances are observed which are attributed to degenerate four-wave mixing in the highly nonlinear mechanical oscillations.

[1] T. Faust et al., Nonadiabatic dynamics of two strongly coupled nanomechanical resonator modes, Phys. Rev. Lett. **109**, 037205 (2012).

[2] M. J. Seitner et al., Classical Stückelberg interferometry of a nanomechanical two-mode system, Phys. Rev. B **94**, 245406 (2016); M. J. Seitner et al., Finite time Stückelberg interferometry with nanomechanical modes, New. J. Phys. **19**, 033011 (2017).

[3] T. Faust et al., Coherent control of a classical nanomechanical two-level system, Nature Physics **9**, 485 (2013).

[4] M. Seitner et al., Parametric oscillation, frequency mixing, and injection locking of strongly coupled nanomechanical resonator modes, Phys. Rev. Lett. **118**, 254301 (2017).