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Enhanced vibrational quantum dynamics beyond the rotating wave approximation

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Optomechanical systems have promising properties with great impact in many fields. There is a significant variety of hybrid systems such as an oscillating mirror of an optical cavity, coupled optical and mechanical resonators or nanorods inside a cavity etc. [1]. These kinds of systems allow us to study the quantum behaviours of nanomechanical structures with potential application in ultra-weak signal detection, quantum informatics and bioengineering [2, 3]. Coupling mechanical, optical and artificial qubits may give more pronounced quantum properties in the strong-coupling limit, such that their analytical description would differ somehow from the standard ones and, respectively, novel effects are expected. For instance, optomechanical systems allow for high precision quantum optical measurements of the mechanical motion, optomechanical cooling or photon-phonon quantum correlations, etc. [1–5]. Usually combinations of simple quantum systems lead to complex dynamics whose proprieties are much more different from that of separate systems.

In this Letter, we investigate an ensemble of laser pumped two-level quantum dots placed on a vibrating quantum mechanical resonator (QMR). The QMR is treated as a single-mode quantum oscillator. Respectively, the vibronic modes of the QMR are quantified and the standard creation and annihilation operators, $\{b^\dagger, b\}$, describe their quantum behaviours. As an appropriate real system, can serve a carbon nanotube resonator, for instance, having a collection of two-level atoms or quantum dots fixed on it [4]. Usually, the nanotube has a diameter within a range up to few tens of nanometers, whereas its length can be thousands times larger. Nanomechanical resonators with lengths up to several micrometers exist and are good candidates as well [2].

Particularly, due to fast dynamic of qubits in comparison with the ones of mechanical resonator degree of freedoms, the variable of the artificial atoms can be eliminated in a standard way. The obtained master equation will characterize the QMR alone. An important ingredient here is that we keep those terms which usually are neglected in the secular approximation with respect to variables describing the phonon subsystem. Therefore, our model works for stronger qubit-phonon coupling strengths. Consequently, the equations of motion of the phonon subsystem operators were obtained. We have shown that the mean phonon number exhibits a peak due to the induced nonlinearities, see Fig. 1. Interestingly, this nonlinearity occurs because of the involved two-phonon emission or absorption processes beyond the secular approximation. Furthermore, the second-order phonon-phonon correlation function shows a peak structure as well. In principle, these behaviours may help to determine the Rabi frequency experienced by the quantum emitters or the vibrating frequency of the QMR, for instance.

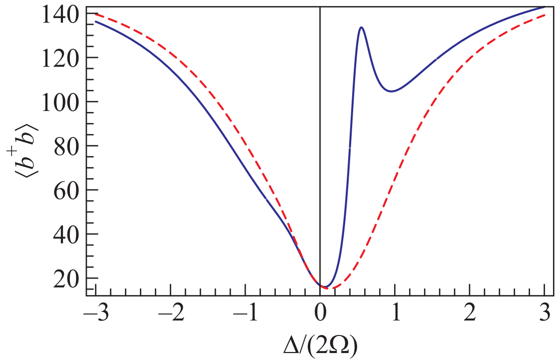

Fig. 1. (Color online) The steady-state behaviours of the mean phonon number $\langle b^\dagger, b\rangle$ versus the scaled detuning for certain parameters of interest. The solid/dashed line is obtained beyond/within the secular approximation with respect to phonon degrees of freedom

In summary, we have studied the dynamics of a quantum mechanical oscillator interacting with a laser-pumped ensemble consisting of two-level quantum emitters fixed on it. Beyond the secular approximation with respect to phonon subsystem, we have shown a peak structure of the mean phonon number as well as of

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the second-order phonon-phonon correlation function, respectively. We have shown that two-phonon processes are responsible for these specific behaviours.

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