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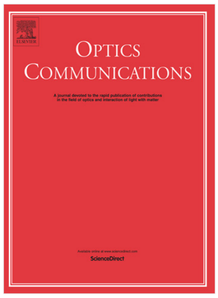

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Optomechanical state transfer in the presence of non-Markovian environments

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Quantum state transfer is one of the most prominent protocols in quantum information. In the context of optomechanics, it is still an important task, as it allows us to reliably convert an optical pulse into a mechanical excitation. In this paper, the quantum state transfer between a moveable mirror and cavity field is studied when the system is surrounded by non-Markovian environments, which has been recently realized in experiment. Utilizing the experimental spectrum density, we find that the transition from weak non-Markovianity to strong non-Markovianity happens when choosing a suitable optomechanical coupling strength. We also show that quantum state transfer can be implemented with high fidelity in the non-Markovian environment, and the non-Markovian memory effect is helpful for state transfer both in the short-time and long-time scales.

Keywords: optomechanical systems; non-Markovian effect; quantum state transfer.

PACS numbers: 03.65.Yz, 03.65.Ud, 42.50.Dv

I. INTRODUCTION

As a promising candidate for quantum information procession, cavity optomechanical systems come as a well-developed tool and have received a lot of attentions [1–5]. But, almost all of the theoretical research of optomechanical system [6] are focussing on the scenario of memoryless environment, thus the corresponding Markov approximation is used to derive the quantum Langevin equations [7]. However, recent experimental evidence clearly reveals that the dynamics of microresonators are non-Markovian [8]. Therefore the present understanding of radiation-pressure dynamic backaction processes is incomplete, and it is necessary to explore the non-Markovian effect in optomechanical systems.

Some progress have been made in this field, and it is proved that the backflow of information from the environments into the system known as the memory effect [9] is helpful for entanglement protection [10, 11], ground state cooling [12, 13] and force detection [14] in optomechanical system. In Ref. [10], we provide an analytical approach fully taking into account the non-Markovian memory effect, and put forward a scheme to protect optomechanical thermal entanglement. In Ref. [11], the quantum state diffusion approach [15–20] is used to investigate entanglement generation and duration. In our resent work [13], the non-Markovian memory effect also show huge advantages for breaking the conventional cooling limit in Markovian regime by utilizing the recent experimental spectrum density [8]. More interestingly, a novel sideband cooling scheme is proposed [12] by exploring the interplay between time-dependent external fields and structured environments. In addition, we also found that the non-Markovian effect can improve the mechanical sensitivity of weak-force by reducing the noise [14].

The strong coupling between mechanical resonators and microwave or optical cavities open up great avenues in efficiently transferring a quantum state with the help of optomechanical frequency conversion [21–24]. Throughout this process, the mechanical oscillator with small decay rate serves as a potential quantum network node for quantum information storage and processing [25, 26]. Such state transfer could allow us to combine the complimentary advantages of photon and phonon. As the flying qubit, the light field is hard to localize and store quantum information, in sharp contrast, the mechanical oscillator can be regarded as an intermediary medium receiving quantum state from one cavity field and transfers it to the other one. Therefore state transfer in optomechanics is an important task, and it has been studied extensively [27–31].

However, it is still unknown whether the non-Markovian memory effect is helpful for state transfer, although, the non-Markovian environments appear to be beneficial to quantum state transfer [32]. In this paper, we investigate the optomechanical state transfer in non-Markovian regime. The experimental mechanical spectral density [8] is used and the exact fidelity is derived based on the modified Laplace transformation [33]. We show that, in this case, quantum state transfer can be implemented with high fidelity. We further discuss the modulation of the non-Markovianity , which can be realized by adjusting the coupling strength. This article is organized as follows. Section II describes the model and gives the theoretical description of the dynamics. In section III, we investigate in detail the numerical results of quantum state transfer. Finally the conclusion is given in section IV.

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