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Simultaneous suppression of spontaneous emission and thermal effect in two-level trapped ion system

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Abstract. We have proposed a method to suppress simultaneously decoherence induced by spontaneous emission and thermal effect in a single two-level trapped ion system based on bang-bang scheme. The basic idea of this method is that two kinds of decoherences are both suppressed by using a series of large detuned pulses to drive the ion in a precision-designed manner, thus best results can be obtained with minimal resources.

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Key words: decoherence, spontaneous emission, thermal effect, trapped ions

1 Introduction

Recently quantum dynamics of trapped ions system has investigated extensively not only because it is of fundamental interest in quantum optics [1, 2] but also because it plays very important role in quantum computation [3]. Quantum computers have powerful potential of parallel computation. However, an obvious obstacle of physical realization of quantum computer is decoherence. Docoherence of quantum systems generally results from their entanglement with environment. Due to decoherence, quantum linear superposition states will be degenerated into their mixed states. To overcome decoherence, many different strategies have been proposed such as. quantum error-correcting codes (QECC) [4–7], quantum error-avoiding codes (QEAC) [8–11], bang-bang control [12]. The bang-bang controlling scheme, which is also termed as dynamical decoupling scheme, is a very useful and effective method in inhibiting decoherence. So far many dynamical decoupling schemes have been proposed such as periodic dynamical decoupling(PDD) [13], concatenated dynamical decoupling (CDD) [14] and Uhrig dynamical decoupling(UDD) [15]. They can be applied to inhibit a variety of noises such as white noise [12], $1/f^{\alpha}$ noises [16], etc. However, the proposed

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bang-bang schemes have been only used to suppress decoherence induced by single noise resource. According to the authors' knowledge, it is not reported that the bang-bang scheme is used to simultaneously suppress decoherence induced by more noise resources.

In trapped ions system, decoherence induced by the environment seems to be father complex, but basic decoherence factors have spontaneous emission involving electric motion of ion and thermal effect involving vibrational motion of ion. In this paper, we propose a scheme to control simultaneously both decoherence factors by means of external controllable light fields. We find that both decoherence will be effectively suppressed.

Let us consider the interaction of a single two-level ion (the excited state $|e\rangle$ and ground state $|g\rangle$) trapped in a harmonic potential trap with the environment (thermal bath). The environment is modeled as a collection of quantized harmonic oscillators. With approximation of rotating wave, the total Hamiltonian is given by ($\hbar = 1$)

$$H = H_0 + H_i, \tag{1a}$$

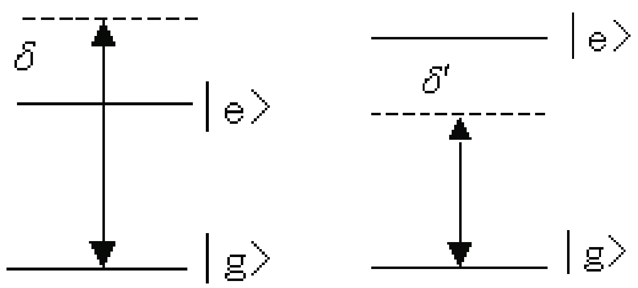
$$H_0 = \frac{1}{2}\omega_a \sigma_z + \nu a^+ a + \sum_k \omega_k b_k{}^+ b_k, \tag{1b}$$

$$H_i = \sum_k \gamma_k (a + b_k{}^+ + a^+ b_k) + \sum_k \lambda_k (\sigma_+ b_k + \sigma_- b_k{}^+), \tag{1c}$$

where $b_k{}^+$ and b_k are, respectively, creation and annihilation operator for the k-th field mode, γ_k and λ_k are coupling parameters, σ_z is Pauli operator, $\sigma_+ = |e\rangle\langle g|$ and $\sigma_- = |g\rangle\langle e|$ are up and down atomic operators, respectively. It is noted that the first term in Eq. 1c describes thermal effect of vibratioal motion of the ion, while the second term describes spontaneous emission of the ion. The evolution operator of the whole system is represented as

$$U(t, t_0) = e^{-i(t-t_0)(H_0+H_i)}. \tag{2}$$

In order to control decoherence induced by spontaneous emission and thermal effect in two-level trapped ion system, we apply bang-bang control scheme. For this goal we drive



(a) **(b)**

Figure 1: Schematic diagram of the trapped ion driven by optical pulses, (a) $\delta = \omega_L - \omega_a > 0$, (b) $\delta' = \omega_a - \omega'_L > 0$.