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Efficient sideband cooling of atom with the help of auxiliary transition

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We propose a cooling scheme for the V-type three-level atom tightly confined in a harmonic trap. Two excited levels are coupled to the ground state by a quadrupole transition with small dissipation rate and a dipole transition with large dissipation rate respectively. The quadrupole transition is strongly driven by a running-wave laser 1, which acts as the cooling channel in the Lamb-Dicke regime. The dipole one is weakly driven by another running-wave laser 2 as the auxiliary transition. The ground-state cooling with large rate can be achieved through the appropriate choice of the Rabi frequency of laser 1 and the detuning of the auxiliary transition.

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I. INTRODUCTION

Realization of the ions trapped within the vicinity of quantum ground state is the key ingredient in the emerging fields such as efficient quantum computation [1], quantum information processing [2], precision detection of mass [3] and investigations in precision spectral and time and frequency standards [4]. And different kinds of efficient laser cooling schemes for trapped atoms and ions are proposed to realize ground-state cooling. The sideband cooling scheme leads to the ground-state cooling for the two-level atoms confined in the harmonic trap through tuning the laser to the lower motional sideband to realize an optical pumping and efficient transfer into the vibrational ground state [5–7]. Sideband cooling scheme also works on some other dissipative two-level systems such as superconducting qubits [8–11], nitrogen-vacancy defects in diamond [12] and quantum dots [13–16]. Thereafter Raman sideband cooling [17–19] and electromagnetically-induced transparency (EIT) cooling schemes [20, 21] are proposed to realize the cooling for the three-level atoms and ions. Both the two-level and Raman sideband cooling schemes should fulfill the requirement that the linewidth of the internal transition and the Rabi frequencies of lasers are much smaller than the trap frequency, which makes the cooling process be finished on a long time scale. The EIT cooling scheme [20–22] is realized in the Λ -shaped arrangement of atomic levels by exploiting quantum interference, which removes the restrictions on the linewidth and eliminates the carrier transition to improve cooling performance. It is challenging to realize the exact calibration of laser intensity and the high intensities. The Stark-shift cooling realizes the elimination the carrier transition by a precisely tuned Rabi frequency of a pair of lasers [23]. Based on the EIT and Stark-shift cooling schemes, a fast and robust laser cooling scheme even under conditions of fluctuating laser intensity and frequency has been proposed [24].

In this paper, we propose an alternative approach based on the two-level system with an auxiliary transition, where carrier transition is eliminated by trapping the atom in the

non-dissipative lower dressed state. With respect to Stark-shift cooling in [23], we obtain the same form of cooling rate and replace the restriction of the pair on same Rabi frequency lasers with a single weak laser, which is easier to realize. The model is shown in Fig.1(a). The running-wave laser 1 strongly drives the quadrupole transition, which also acts as the sideband cooling channel. The auxiliary transition is dipole-allowed transition, which is weakly driven by another running-wave laser field 2. The auxiliary transition can result in the atomic population selectively trapped in one of dressed states formed by the strong coupling between the quadrupole transition and laser 1 even in the case of resonant interaction, which eliminates the carrier transition. Also, it acts as the dissipation channel to significantly increase the cooling rate. Through adjusting the detunings between the frequency of the laser 2 and the energy difference of dipole-transition levels and the Rabi frequency of laser 1, the efficient laser cooling can be realized in the system. The paper is organized as follows: In sec.II, the model is introduced and the master equation of the vibration mode is deduced. In sec.III, we present the numerical simulation and physical discussions on the cooling scheme. Finally, we give a summary.

II. BASIC DYNAMICS AND MASTER EQUATION

We consider a V-type three-level atom tightly confined in a harmonic potential field and driven by a couple of laser fields shown in Fig.1(a). The motion of the atom is described by the harmonically oscillating Hamiltonian $\nu a^\dagger a$, where a is the annihilation operator of vibration mode with frequency ν . The internal structure of the atom is constituted of two excited levels $|1\rangle, |2\rangle$ and the ground level $|3\rangle$, with the energy frequencies $\omega_1, \omega_2, \omega_3$ respectively. The quadrupole transition $|1\rangle \leftrightarrow |3\rangle$ is strongly pumped by the running-wave laser 1 with the Rabi frequency $2\Omega_1(x)$. The dipole-allowed transition $|2\rangle \leftrightarrow |3\rangle$ is weakly pumped by another running-wave laser 2 with the Rabi frequency $2\Omega_2$, which does not induce the coupling between internal and external degrees of freedom by adjusting the wave vector perpendicular to the ion trap [23].

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The Hamiltonian of the system is written as ($\hbar = 1$)

$$\begin{aligned} H &= H_L + H_{at} + H_{mec}, \\ H_L &= \Omega_1 \sigma_{31} e^{-ik_1 x} + \Omega_2 \sigma_{32} + h.c., \\ H_{at} &= \delta_2 \sigma_{22} + \delta_1 \sigma_{11}, H_{mec} = \nu a^\dagger a, \end{aligned} \quad (1)$$

where $\sigma_{kl} = |k\rangle\langle l|$ ($k, l = 1, 2, 3$) are atomic operators. The detunings $\delta_i = \omega_i - \omega_3 - \omega_{Li}$ ($i = 1, 2$), where ω_{Li} are frequencies of laser i . Ω_i is the Rabi frequencies and k_1 is the wave vector of the laser 1. x is the displacement of the atom and expressed as $x = (a + a^\dagger)/\sqrt{2m\nu}$, where m is the mass of atom.

FIG. 1: (a) The bare atomic configuration. The quadrupole transition $|1\rangle \leftrightarrow |3\rangle$ is strongly driven by the running-wave laser 1 with Rabi frequency $2\Omega_1(x)$, with the detuning δ_1 and dissipation rate γ_1 . The auxiliary dipole transition $|2\rangle \leftrightarrow |3\rangle$ is weakly driven by the laser 2 with Rabi frequency $2\Omega_2$, with the detuning δ_2 and dissipation rate γ_2 . (b) The dressed levels in representation of strongly driven atomic transition. (c) The cooling process based on the dressed states formed by quadrupole atomic transition with the strong-driving running-wave laser 1.

In the Lamb-Dicke limit, we keep terms up to the first order of Lamb-Dicke parameter η [1]. The Hamiltonian H_L can be simplified as

$$\begin{aligned} H_L &= H_{0L} + H_{1L}, \\ H_{0L} &= \Omega_1(\sigma_{31} + \sigma_{13}) + \Omega_2(\sigma_{32} + \sigma_{23}), \\ H_{1L} &= i\Omega_1\eta(\sigma_{13} - \sigma_{31})(a + a^\dagger). \end{aligned} \quad (2)$$

The master equation is described by

$$\dot{\rho} = -i[H_{at} + H_{0L} + H_{mec} + H_{1L}, \rho] + \mathcal{L}_1\rho + \mathcal{L}_2\rho, \quad (3)$$

where the atomic dissipation and damping of phonon are given by

$$\begin{aligned} \mathcal{L}_1\rho &= \sum_{l=1,2} \gamma_l(2\sigma_{3l}\tilde{\rho}\sigma_{l3} - \sigma_{ll}\rho - \rho\sigma_{ll}), \\ \mathcal{L}_2\rho &= \frac{\kappa}{2}(\bar{n}+1)(2a\rho a^\dagger - a^\dagger a\rho - \rho a^\dagger a) \\ &\quad + \kappa\bar{n}(2a^\dagger\rho a - aa^\dagger\rho - \rho aa^\dagger). \end{aligned} \quad (4)$$

Here $2\gamma_l$ ($l = 1, 2$) are the dissipation rates of excited atomic levels and κ is the damping rate of phonon with $\bar{n}$ being the mean number of phonon in the thermal reservoir. $\tilde{\rho}$ is related to the angular distribution $\mathcal{N}_l(\theta)$ by the expression [25]

$$\tilde{\rho} = \int_{-1}^1 \mathcal{N}_l(\theta) e^{ik_l x \cos \theta} \rho e^{-ik_l x \cos \theta} d \cos \theta. \quad (5)$$

Because of the quadrupole transition $|1\rangle \rightarrow |3\rangle$, i.e., $\gamma_1 \ll \gamma_2$, it is reasonable to ignore the diffusion heating caused by this spontaneous decay channel, thus we just take into the case $l = 2$. With the parameters $\kappa \ll \gamma_2$, the evolution equation of the phonon mode can be obtained through adiabatically eliminating the internal atomic variables with their stationary ones. By using the second order perturbation theory with respect to the phonon-atom coupling [26, 27], one can derive the rate equation for the occupation probability P_n of the phonon number state $|n\rangle$

$$\begin{aligned} \dot{P}_n &= [\kappa(\bar{n}+1) + A(-\nu) + \mathcal{D}][(n+1)P_{n+1} - nP_n] \\ &\quad + [\kappa\bar{n} + A(\nu) + \mathcal{D}][nP_{n-1} - (n+1)P_n], \end{aligned} \quad (6)$$

with $A(\pm\nu) = 2\text{Re}[S(\pm\nu)]$, where

$$\begin{aligned} S(\pm\nu) &= -\eta^2 \Omega_1^2 \int_0^\infty d\tau e^{\mp i\nu\tau} \\ &\quad \times \langle [\sigma_{13}(\tau) - \sigma_{31}(\tau)][\sigma_{13}(0) - \sigma_{31}(0)] \rangle \end{aligned} \quad (7)$$

are the spectra of the atomic correlation functions. $\mathcal{D}$ is the diffusion term with the expression

$$\mathcal{D} = \eta^2 \gamma_2 \rho_{22}^s \alpha, \quad (8)$$

where ρ_{22}^s is the steady-state atomic population on the state $|2\rangle$ with $\alpha = \int_{-1}^1 \mathcal{N}_2(\theta) \cos^2 \theta d \cos \theta$, which is $\frac{2}{5}$ for usual dipole transitions [28]. With the occupation probability equation in Eq.(6), the evolution of the mean value of phonon number $\langle n \rangle$ can be obtained as

$$\begin{aligned} \frac{d}{dt} \langle n \rangle &= -\{\kappa + A(-\nu) - A(\nu)\} \langle n \rangle \\ &\quad + \{\kappa\bar{n} + A(\nu) + \mathcal{D}\}. \end{aligned} \quad (9)$$

The steady-state phonon number $\langle n \rangle$ and effective cooling rate W are deduced to be

$$\begin{aligned} \langle n \rangle &= \{\kappa\bar{n} + A(\nu) + \mathcal{D}\}/W, \\ W &= \kappa + A(-\nu) - A(\nu), \end{aligned} \quad (10)$$

where $A(\nu)$ and $A(-\nu)$ are heating and cooling parameters respectively. Obviously the larger $A(-\nu) - A(\nu)$ is, the faster the cooling process is. The detailed expressions of $A(\pm\nu)$ are given in the following.

III. NUMERICAL SIMULATION AND PHYSICAL DISCUSSION

In the Lamb-Dicke regime, the spectrum $S(\pm\nu)$ in Eq.(7) can be numerically obtained from the master equation by ignoring the coupling between the external degrees of freedom

and internal ones and the quantum regression theory [27, 29]. In Fig.2, we numerically show the phonon number $\langle n \rangle$ and the cooling rate as functions of δ_2 and Ω_1 , with parameters $\delta_1 = 0, \nu = 12, \Omega_2 = 2, \gamma_1 = 10^{-3}, \kappa = 10^{-4}$, in units of γ_2 , and $\bar{n} = 20, \eta = 1/20$. Evidently, the small phonon number and the corresponding large cooling rate are achieved around $\Omega_1 = \nu/2, \delta_2 = \lambda_1$.

FIG. 2: The mean phonon number and the cooling rate as functions of δ_2 and Ω_1 with the parameters $\delta_1 = 0, \nu/\gamma_2 = 12, \Omega_2/\gamma_2 = 2, \gamma_1/\gamma_2 = 10^{-3}, \kappa/\gamma_2 = 10^{-4}, \bar{n} = 20, \eta = 1/20$.

In order to gain physical insight into the above result, with the relations $\Omega_1 \gg \Omega_2, \gamma_1, \gamma_2$ shown in Fig.2, we utilize the dressed states formed by the main part of interaction $H_0 = \delta_1 \sigma_{11} + \delta_2 \sigma_{22} + \Omega_1 (\sigma_{31} + \sigma_{13})$. The dressed states and corresponding eigenvalues of H_0 are

$$\begin{aligned} |\tilde{1}\rangle &= \sin \varphi |3\rangle + \cos \varphi |1\rangle, \lambda_1 = (\delta_1 + \bar{\Omega}_1)/2, \\ |\tilde{3}\rangle &= \cos \varphi |3\rangle - \sin \varphi |1\rangle, \lambda_3 = (\delta_1 - \bar{\Omega}_1)/2, \end{aligned} \quad (11)$$

where

$$\sin \varphi = \sqrt{1 - \delta_1/\Omega_1}/\sqrt{2}, \bar{\Omega}_1 = \sqrt{\delta_1^2 + 4\Omega_1^2}. \quad (12)$$

The bare state $|2\rangle$ remains unchanged and is denoted by $|\tilde{2}\rangle$ with eigenvalue $\lambda_2 = \delta_2$. We assume the Rabi frequency Ω_1 is large, which leads to simplifying the system with the adoption of secular approximation [29]. Without loss of generality, we assume the dressed state $|\tilde{2}\rangle$ is far detuned from $|\tilde{3}\rangle$ but may resonant with $|\tilde{1}\rangle$ as shown in Fig.1(b). Then the set of evolution equations for density operator elements of internal atomic variables in the dressed representation $\tilde{\rho}_{ij} = \langle \tilde{i} | \rho | \tilde{j} \rangle$ is given by

$$\begin{aligned} \dot{\tilde{\rho}}_{22} &= i\Omega_2 \sin \varphi (\tilde{\rho}_{21} - \tilde{\rho}_{12}) - 2\gamma_2 \tilde{\rho}_{22}, \\ \dot{\tilde{\rho}}_{33} &= 2\gamma_1 \cos^4 \varphi \tilde{\rho}_{11} + 2\gamma_2 \cos^2 \varphi \tilde{\rho}_{22} - 2\gamma_1 \sin^4 \varphi \tilde{\rho}_{33}, \\ \dot{\tilde{\rho}}_{12} &= -(b_1 + i(\lambda_1 - \lambda_3))\tilde{\rho}_{12} - i\Omega_2 \sin \varphi (\tilde{\rho}_{22} - \tilde{\rho}_{11}), \\ \dot{\tilde{\rho}}_{31} &= -b_2 \tilde{\rho}_{31} + i\Omega_2 \sin \varphi \tilde{\rho}_{32}, \\ \dot{\tilde{\rho}}_{32} &= -b_1 \tilde{\rho}_{32} + i\Omega_2 \sin \varphi \tilde{\rho}_{31}, \end{aligned} \quad (13)$$

where $b_1 = -i(\delta_2 - \lambda_3) + \gamma_1 \sin^2 \varphi + \gamma_2, b_2 = -i(\lambda_1 - \lambda_3) + \gamma_1(1 + 2\sin^2 \varphi \cos^2 \varphi)$. Making use of the quantum regression theory [29], $A(\nu)$ is obtained as

$$S(\nu) = \eta^2 \Omega_1^2 \left[\frac{(i\nu + b_1^*) \tilde{\rho}_{33}^s}{D(\nu, b_1^*, b_2^*)} + \frac{(i\nu + b_1) \tilde{\rho}_{11}^s + i\Omega_2 \sin \varphi \tilde{\rho}_{12}^s}{D(\nu, b_1, b_2)} \right], \quad (14)$$

where $D(\nu, b_1, b_2) = [\frac{b_1 + b_2}{2} + i(\nu - \bar{\Omega}_2)][\frac{b_1 + b_2}{2} + i(\nu + \bar{\Omega}_2)], \bar{\Omega}_2 = \sqrt{\Omega_2^2 \sin^2 \varphi - (b_2 - b_1)^2/4}$. And $\tilde{\rho}_{33}^s, \tilde{\rho}_{11}^s, \tilde{\rho}_{12}^s$ are the steady-state solutions of the elements of density operator in the dressed representation without considerations of the coupling to external degrees of freedom, which can be obtained from Eqs.(13) together with the normalization condition $\sum_{i=1}^3 \tilde{\rho}_{ii}^s = 1$.

In order to physically analyze the Fig.2, we will give detailed discussions at the parameters $\lambda_1 = \delta_2, \delta_1 = 0$ and $\nu = 2\Omega_1$, where the efficient cooling occurs. In order to obtain the major part of the cooling rate W , we keep the terms of the second order in Ω_1 and reach the result

$$W = \kappa + 2\eta^2 \Omega_1^2 \text{Re} \left[\frac{(-i\nu + b_1^*) (\tilde{\rho}_{33}^s - \tilde{\rho}_{11}^s) + i\Omega_2 \sin \varphi \tilde{\rho}_{21}^s}{D(-\nu, b_1^*, b_2^*)} \right]. \quad (15)$$

Obviously the cooling rate is closely concerned with the population difference $\tilde{\rho}_{33}^s - \tilde{\rho}_{11}^s$ between the dressed states $|\tilde{3}\rangle$ and $|\tilde{1}\rangle$. So if the atom can be set to the dressed state $|\tilde{3}\rangle$, the cooling rate can be significantly enhanced. Because of the quadrupole transition $|1\rangle \leftrightarrow |3\rangle$, i.e., $\gamma_1 \ll \gamma_2$, it is reasonable to take the parameters as given in Fig.2, the dressed-state populations $\tilde{\rho}_{33}^s, \tilde{\rho}_{11}^s$ and $\tilde{\rho}_{22}^s$ are numerically obtained as 0.9536, 0.02015 and 0.02625 respectively. Under this case, the atom is almost selectively populated in the dressed states $|\tilde{3}\rangle$. Little population in $|\tilde{2}\rangle$ allows one to ignore the heating process caused by the diffusion term $\mathcal{D}$. This selective population can be physically explained from Eqs.(13). The decay rate of $|\tilde{2}\rangle$ is $2\gamma_2$, while the decay rates of $|\tilde{1}\rangle$ and $|\tilde{3}\rangle$ are proportional to γ_1 . So the atom is hardly populated in $|\tilde{2}\rangle$. When the dressed level $|\tilde{2}\rangle$ is tuned to be resonant with $|\tilde{1}\rangle$, i.e., $\delta_2 = \lambda_1$, the transition between $|\tilde{1}\rangle$ and $|\tilde{2}\rangle$ driven by the auxiliary laser 2 is resonant, simultaneously the transition between $|\tilde{3}\rangle$ and $|\tilde{2}\rangle$ caused by the laser 2 is far-off-resonance and can be ignored because the detuning $\bar{\Omega}_1$ of this transition is much larger than the coupling coefficient $2\Omega_2$. So with the help of the auxiliary transition caused by the weak laser 2, an additional two-step channel is involved: $|\tilde{1}\rangle \rightarrow |\tilde{2}\rangle$ driven by laser 2 and $|\tilde{2}\rangle \rightarrow |\tilde{3}\rangle$ through the fast dipole-allowed spontaneous dissipation. This two-step channel guarantees the atom is trapped in the lowest dressed state $|\tilde{3}\rangle$. Therefore the population difference $\tilde{\rho}_{33}^s - \tilde{\rho}_{11}^s$ approaches unity.

Further we consider the condition of $\gamma_1/\gamma_2 = 0$. The evolution equation of $\tilde{\rho}_{33}$ in Eqs.(13) is simplified to $\dot{\tilde{\rho}}_{33} = 2\gamma_2 \cos^2 \varphi \tilde{\rho}_{22}$, and in steady state the atom is trapped in the state $|\tilde{3}\rangle$. It means that $\tilde{\rho}_{33}^s = 1$ and all the other elements of density operator are equal to 0. When the phonon field is resonant with transition between the dressed states $|\tilde{1}\rangle$ and $|\tilde{3}\rangle$ i.e., $\nu = 2\Omega_1$, the cooling rate and the steady-state phonon number is in the form

$$W = \kappa + 4\eta^2 \gamma_2 \Omega_1^2 / \Omega_2^2, \langle n \rangle = \kappa \bar{n} / W. \quad (16)$$

Eqs. (16) indicate that the cooling rate is proportional to the dissipation rate $2\gamma_2$ of level $|2\rangle$ and the steady-state phonon number is equal to the thermalization rate from the external reservoir $\kappa\bar{n}$ divided by the cooling rate W , which is consistent with the dynamical equilibrium. The cooling process can be also understood intuitively from Fig.1(c), based on the steady state of dressed atomic variables. When there occurs the transition $|\tilde{3}\rangle|n\rangle \rightarrow |\tilde{1}\rangle|n-1\rangle$, one phonon is absorbed. The reverse process is suppressed because of little atomic population in level $|\tilde{1}\rangle$. The laser 2 drives the transition $|\tilde{1}\rangle|n-1\rangle \rightarrow |\tilde{2}\rangle|n-1\rangle$. Then the phonon is removed by the dissipation channel from $|\tilde{2}\rangle|n-1\rangle$ to $|\tilde{3}\rangle|n-1\rangle$ due to spontaneous emission with the rate $2\gamma_2$.

It should be pointed out that Retzker *et.al.* [23] proposed a fast cooling scheme for trapped ion using the dynamical Stark shift, in which a Λ -type three-level ion is driven by a pair of lasers and one strong laser. The coupling between the two lower states driven by the strong running-wave field supplies the dynamical Stark shift and the channel for absorbing phonon, and the pair of lasers respectively driving the transitions from the two lower states to the upper state with precisely chosen intensities and frequencies lifts the ion to its excited state. If the ion dissipates to the antisymmetric superposition of lower states, cooling is achieved. In the Stark shift cooling scheme [23], the higher Rabi-frequency and the cancelation of the carrier transition promise increased cooling rates and lower final temperatures, on which is also our cooling scheme established. The cooling rate in Eqs.(16) the same form as obtained in [23]. But in Stark shift cooling scheme [23], the pair of lasers should possess the same Rabi-frequency, any fluctuation of the two weak laser intensities may reduce the cooling efficiency. However, here in our proposed scheme, only weak laser is utilized to drive the auxiliary transition for speeding up the cooling process, this decreases the experimental difficulty as compared with the Stark shift cooling scheme. Especially the above parameters adopted in Fig.2 can be found in atomic Barium [30, 31], in which the atom can be selectively trapped in the lowest dressed state [26].

If the auxiliary transition $|2\rangle \leftrightarrow |3\rangle$ does not exist, our discussion reduces to the standard two-level sideband cooling scheme, where the requirement for realizing ground-state cooling is $\nu > \Gamma$, with ν the trap frequency and Γ the decay rate [32]. When a classical running-wave laser interacts weakly with the atom and is tuned to the atom's lower vibrational sideband, cooling occurs [33]. For the strongly driven system, one has to consider the dynamic Stark shift and ν equal to energy difference of dressed states. For the model in Fig.1 without the auxiliary transition, with the secular approximation in the dressed representation the heating parameter is

$$A(\nu) = 2\eta^2\Omega_1^2\text{Re}\left[\frac{\tilde{\rho}_{33}^s}{i\nu + b_2^*} + \frac{\tilde{\rho}_{11}^s}{i\nu + b_2}\right], \quad (17)$$

which is consistent with the result obtained [28]. Obviously with the parameters given in Fig.2, the system can not lead to the occur of cooling because of half of the population in the upper dressed state which results in the heating mechanism competing with the cooling process when the detuning $\delta_1 = 0$. The cooling can only occurs for $\delta_1 < 0$ and $\Omega_1 \ll |\delta_1|$. Actually, in the tightly confinement limit [34], the cooling rate $A(-\nu) = 2\eta^2\Omega_1^2/\gamma_1$ (the decay rate $2\gamma_1$). It is numerically shown in [34] that the cooling rate is small. Experimentally sideband cooling is realized by the well-known cooling technique described in [5], where cooling is achieved by tuning the laser to the lower sideband of the quadrupole transition, emptying the population in the upper level with another dipole transition and dissipating to metastable level through the fast dipole channel. In our scheme, under the interaction with the strong running-wave field, the cooling process occurs between the dressed states $|\tilde{1}\rangle$ and $|\tilde{3}\rangle$ when the frequency ν of trap obeys $\nu = 2\Omega_1$. Therefore the strength of the sideband cooling process is greatly improved and the efficient and fast sideband cooling can be achieved in the present scheme.

IV. CONCLUSION

In summary, we have proposed a scheme with the help of an auxiliary atomic dipole transition to improve the efficiency of the two-level sideband cooling. Two excited states couples to the ground state by a strongly driven quadrupole transition and a weakly driven dipole transition respectively. In the dressed-state representation formed by the strongly driven atomic quadrupole transition, the transition $|\tilde{3}\rangle \leftrightarrow |\tilde{1}\rangle$ acts as the cooling channel. With the appropriate choice of the Rabi frequency of laser 1 to make the energy difference of these two dressed state be resonant with the phonon mode, the coupling between the phonon and the atomic variables is strengthened. Through tuning the detuning of auxiliary transition δ_2 to be degenerate to the dressed level $|\tilde{1}\rangle$ together with the large dipole dissipation rate with respect to the quadrupole one, the atom is selectively trapped in the lowest dressed state $|\tilde{3}\rangle$ resulting in the cancelation of the carrier transition. And phonons dissipated out of the system through the fast dipole dissipation, the fast cooling process is simultaneously realized.

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