



Enhanced optomechanically induced transparency via atomic ensemble in optomechanical system

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Abstract

We investigate the optomechanically induced transparency phenomena assisted through cavity optomechanical system. The system consists of an optical cavity system filled with the two-level atomic ensemble and driven by a weak probe laser as well as a strong coupling fields. Under different driving conditions, the system can exhibit the phenomena of optomechanical induced transparency dip. Specifically, the width of the transparency window increases with an increase in the coupling constant, while decreasing with an increase in atomic decay rate. Furthermore, the induced transparency phenomena are strongly affected by the number of atoms, coupling, and the decay rate. It is found that the larger the number of atoms, the wider the window of induced transparency, and therefore enhance the depth of transparency window. These results may have spectacular applications for slowing and on-chip storage of light pulses by the use of a micro-fabricated optomechanical array.

Keywords Optomechanical system · Atomic ensemble · Optomechanically induced transparency · Quantum Langevin equation · Input–output relation

1 Introduction

Cavity optomechanical systems have recently a rapidly growing research field and describe as an excellent candidate to coupled photons and phonons through the radiation pressure force [1,2]. In recent years, there has been significant progress in both theoretical and experimental studies of optomechanical systems, for instance, sympathetic cooling of a membrane oscillator [3], quantum interference [4], optomechanical force-sensing [5] as well as to create squeezed light [6,7]. Further progress also has been achieved for various features of the quantum effect and perform quantum applications [8–10]. This permits us to observe the implementation of various optomechanical

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devices can apply to modern optical networks and essential ingredient for quantum information processing. Substantial progress on the concept of optomechanically induced transparency (OMIT) was proposed theoretically [11] and then demonstrated experimentally [12]. Thus, OMIT offers significant progress in several aspects such as OMIT under the influence of spin ensemble system [13], membrane-in-the-middle configurations [14] and considerable applications in achieving on-chip optical signal processing [15]. Besides, introducing the idea of the atomic ensemble into optomechanical systems has an interesting platform for the novel OMIT phenomenon [17–20]. Thus, atomic ensembles play an important role in the field of optomechanical systems, and showed that these atoms effectively enhance the nonlinearities [21,22].

Recently, many researchers studied the optical properties of an optomechanical system coupled to a two-level or three-level system through the cavity field. For instance, [23] theoretically studied the two-level atomic ensemble that is coupled to the cavity field of an optomechanical system. It showed that atoms effectively enhance the radiation pressure of the cavity field, and suggested the larger the number of atoms, the wider the window of transparency. Furthermore, [24] demonstrated that the multiple OMIT with and without atomic media and showed that the number of OMIT windows is influenced by the coupling cavities and the atom, i.e., the OMIT is arising from the quantum destructive interference between different absorption of probe photons [25]. However, relatively few studies have addressed the effect of the coupling field induced on the probe response and the depth of the transparency window. This shows when a cavity optomechanical system is filed with an atomic ensemble is still a subject of active research.

In this paper, we investigate the OMIT window assisted with atomic ensembles coupled to the cavity optomechanical system. Specifically, the system consists of a Fabry–Pérot cavity with a two-level atom, where the cavity mode is driven simultaneously by a strong classical external and a weak probe field. Under this regime, we explore the ability of the system to generate OMIT. Instinctively, one can raise the question of how a two-level atom system enhances the OMIT phenomenon through an optomechanical system. Furthermore, does the depth of transparency window increase with the coupling of an optical cavity? Another aspect of interest does the coupling of the atomic ensemble to the mechanical resonator affect the OMIT is discussed in detail. To this aim, we utilized the Heisenberg–Langevin equations for the dynamics of the system, while we employed the input–output relation for the output transmission, and realized the cavity transmission.

The paper is organized as follows. In Sect. 2, we illustrate the physical model that describes the OMIT phenomenon by using a generic optomechanical system. In Sect. 3, we present the dynamics of the system using the Heisenberg–Langevin equation of motion and utilized the linearization approach by linearizing the operators, while in Sect. 4, we explicitly discuss the experimental feasibility of the behavior of OMIT phenomena using analytical expressions. The conclusion is summarized in Sect. 5

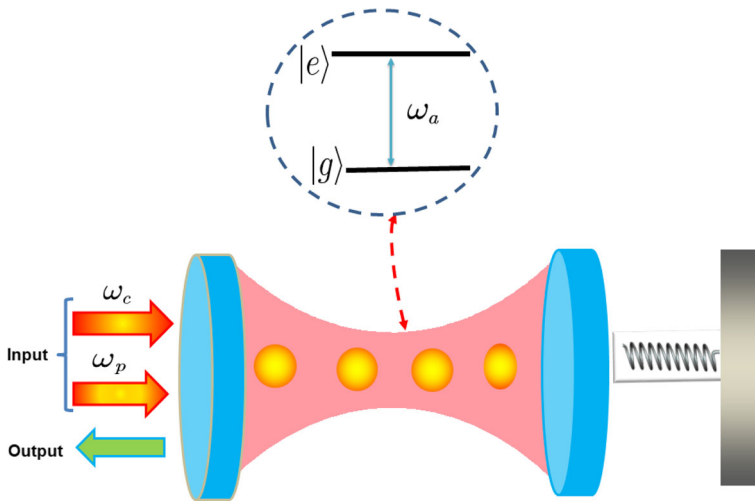


Fig. 1 Schematic of a Fabry–Perot cavity with atoms. $|g\rangle(|e\rangle)$ represents the ground (excited) of atoms trapped inside the optical cavity. The optical cavity is driven by a classical control field with frequency ω_c and laser frequency ω_p probes

2 Model and hamiltonian

As shown in Fig. 1, we consider a theoretical model of a hybrid optomechanical system. The system we study here consists of a Fabry–Perot cavity with one fixed mirror and one moving-end mirror with frequency ω_m , and the two level of atom trapped inside the cavity. The optical cavity is driven by a classical control field with frequency ω_c , and another laser with frequency ω_p probes the response of this driven optomechanical system but is much weaker than the control field. Furthermore, we assume that the atoms have the same transition frequency ω_a . Experiments have shown that both a cavity field and a mechanical resonator can be coupled to two-level atomic systems; thus, hybrid optomechanical systems are important ingredients to use the atomic medium as a potential quantum resource [15,26–28], on-chip storage of light pulses [16] and significantly enhanced the performance of lasing and quantum sensing [29,30]. The Hamiltonian of the whole system is the sum of four terms

$$\hat{H}_{tot} = \hat{H}_0 + \hat{H}_{at} + \hat{H}_{in} + \hat{H}_d,$$

where

$$\hat{H}_0 = \hbar\omega_0\hat{c}^\dagger\hat{c} + \left(\frac{\hat{p}^2}{2m} + \frac{1}{2}m\omega_m^2\hat{q}^2\right), \quad (1a)$$

$$\hat{H}_{at} = \frac{\hbar\omega_a}{2} \sum_{k=1}^N \hat{\sigma}_z^k, \quad (1b)$$

$$\hat{H}_{in} = \sum_{k=1}^N \hbar G \hat{c} (\hat{\sigma}_+^k + H.c) + \hbar\Omega e^{-i\omega_c t} \sum_{k=1}^N (\hat{\sigma}_+^k + H.c) + \hbar g_o \hat{c}^\dagger \hat{c} \hat{q}, \quad (1c)$$

$$\hat{H}_d = i\hbar\varepsilon_c\left(\hat{c}^\dagger e^{-i\omega_c t} - H.c\right) + i\hbar\left(\varepsilon_p\hat{c}^\dagger e^{-i\omega_p t} - H.c\right). \quad (1d)$$

The first term (\hat{H}_0) represents the sum of free Hamiltonian corresponding to the cavity field and oscillating mirror, in which $\hat{c}(\hat{c}^\dagger)$ is the annihilation (creation) operators with ω_0 denoting the frequency of the optical cavity. The momentum and position operators of the oscillating mirror frequency ω_m with an effective mass m are represented by \hat{p} and \hat{q} . The second term (\hat{H}_{at}) accounts for the free Hamiltonian of atomic ensemble arranged as $\hat{\sigma}_z^k$ and $\hat{\sigma}_+^k$ characterize the Pauli matrices for the two-level atoms in the system. The third term (\hat{H}_{in}) describes the interaction Hamiltonian between the atomic ensemble and the cavity field with coupling strength $G = -\mu\sqrt{\omega/2V_0\epsilon_0}$, where μ is the electric dipole between the two levels, and V_0 is the cavity mode volume and ϵ_0 describes the permittivity of vacuum [31] with g_0 the single-photon coupling rate. The last term \hat{H}_d describes the Hamiltonian of classical fields interacting with the cavity field [11]. While $\varepsilon_c = \sqrt{2\kappa\wp/\hbar\omega_c}$ and $\varepsilon_p = \sqrt{2\kappa\wp/\hbar\omega_p}$ are amplitudes of the driving and the probe fields, κ is the decay rate of the cavity field and \wp is the power probe of the field.

In the large N limit, we can see the atoms in the cavity as a whole which absorbs and emits the photons repeatedly. Therefore, we assume that all the atoms have the same transition frequency ω_a and the atoms that fill the optical cavity as a whole. To study the optomechanical system, we will simplify the problem by applying the Holstein–Primakoff approximation to describe the collective spin degrees of freedom [32]. Since the interaction between the photons and the atoms can be described by a type of collective low-energy excitations of the ensemble of atoms, we can define the collective quasi-spin operator of the atomic ensemble as: $\hat{a}^\dagger = \frac{1}{\sqrt{N}} \sum_{k=1}^N \hat{\sigma}_+^k$. They behave as bosons which satisfy the bosonic commutation relation $[\hat{a}, \hat{a}^\dagger] = 1$. Thus, with the help of the above and the interaction picture concerning $\hat{H}_0 = \hbar\omega_c(\hat{c}^\dagger\hat{c} + \hat{a}^\dagger\hat{a})$, the resulting effective interaction Hamiltonian of the whole system of Eq. (1) can then be written as:

$$\begin{aligned} \hat{H}_{eff} = & \hbar\Delta_c\hat{c}^\dagger\hat{c} + \left(\frac{\hat{p}^2}{2m} + \frac{1}{2}m\omega_m\hat{q}^2\right) + \hbar\Delta_a\hat{a}^\dagger\hat{a} + \hbar\left(g\hat{c}\hat{a}^\dagger + \chi\hat{a}^\dagger + H.c\right) \\ & - \hbar g_0\hat{c}^\dagger\hat{c}\hat{q} + i\hbar\varepsilon_c\left(\hat{c}^\dagger - H.c\right) + i\hbar\left(\varepsilon_p\hat{c}^\dagger e^{-i\delta t} - H.c\right). \end{aligned} \quad (2)$$

Here, $\Delta_c = \omega_0 - \omega_c$ characterize the detunings between the control and cavity field and $\Delta_a = \omega_a - \omega_c$ represents the detuning between the two levels of atoms and cavity field, and $\delta = \omega_p - \omega_c$ is the detunings between the control and probe field. $g = \sqrt{N}G$ is the effective coupling strength between the cavity field and the atomic ensemble. While $\chi = \sqrt{N}\Omega$ describes the effective coupling strength between the atomic ensemble and the external driving field, g and χ describe the coupling coefficients are enhanced via \sqrt{N} times [33].

3 Dynamics of the system

In this section, we examine the dynamics of our system; one should consider the full quantum treatment of the system. Thus, apply the standard approach of Heisenberg–Langevin equation of motion, and take the corresponding damping and noise effects of the mechanical, optical as well as atomic modes, i.e., $i\hbar\dot{\hat{Q}} = [\hat{Q}, \hat{H}_{eff}] + \hat{R}_{dis}$, (where \hat{Q} is an arbitrary operator for \hat{q} , \hat{p} , \hat{a} , and \hat{c}). \hat{R}_{dis} is the dissipation term. The nonlinear quantum Langevin equation can be extracted

$$\dot{\hat{q}} = \frac{\hat{p}}{m}, \quad (3a)$$

$$\dot{\hat{p}} = -m\omega_m^2\hat{q} + \hbar g_0\hat{c}^\dagger\hat{c} - \gamma_m\hat{p} + \xi, \quad (3b)$$

$$\dot{\hat{a}} = -[i\Delta_a + \gamma]\hat{a} - ig\hat{c} - i\chi + \sqrt{2\kappa}\hat{a}_{in}, \quad (3c)$$

$$\dot{\hat{c}} = -i[\Delta_c - g_0\hat{q} - i\kappa]\hat{c} - ig\hat{a} + \varepsilon_c + \varepsilon_p e^{-i\delta t} + \sqrt{2\kappa}\hat{c}_{in}, \quad (3d)$$

where κ denotes the leakage of cavity, γ (γ_m) describes the damping rate of the atomic (mechanical oscillator), respectively. Furthermore, \hat{c}_{in} and \hat{a}_{in} are the input vacuum noise operators with zero mean value, and their only nonzero correlation functions. We note that the nonzero correlation function for the \hat{c}_{in} and \hat{a}_{in} vacuum input noise operators, and the Hermitian Brownian noise operator of the mechanical mode ξ satisfy the correlation function [34,35]

$$\begin{aligned} \langle \hat{a}_{in}(t)\hat{a}_{in}^\dagger(t') \rangle &= \delta(t-t'), \quad \langle \hat{c}_{in}(t)\hat{c}_{in}^\dagger(t') \rangle = \delta(t-t'), \\ \langle \hat{\xi}(t)\hat{\xi}(t') \rangle &= m\hbar\gamma_m \int \frac{d\omega}{2\pi} e^{-i\omega(t-t')} \omega \left[\coth\left(\frac{\hbar\omega}{2k_B T}\right) + 1 \right], \end{aligned} \quad (4)$$

this can be understood as k_B is the Boltzmann constant and T is the temperature of the reservoir of the mechanical oscillator [36].

3.1 Linearization of quantum langevin equations

Recently, most experimental works of induced transparency confirm that the quantum interference effect can be observed in atoms and molecules [12]. Thus, the optical response to an atomic medium is controlled by an electromagnetic field realized under weak coupling with strong driving conditions [37]. This shows that for high-finesse cavities and enough driving power, the system is characterized by a semiclassical steady state with the cavity mode in a coherent states [38]. Under this condition, we can utilize the linearization approach by linearizing the operators of Eq.(3) as a sum of its steady-state mean values and an additional small fluctuation around the steady-state mean values, that is, $\hat{p} = \hat{p}_s + \delta\hat{p}$, $\hat{q} = \hat{q}_s + \delta\hat{q}$, $\hat{a} = \hat{a}_s + \delta\hat{a}$ and $\hat{c} = \hat{c}_s + \delta\hat{c}$, where \hat{p}_s , \hat{q}_s , \hat{a}_s and \hat{c}_s represent the amplitudes of the system, whereas $\delta\hat{p}$, $\delta\hat{q}$, $\delta\hat{a}$ and $\delta\hat{c}$

are the fluctuations with zero-mean values. The steady-state equations are given by

$$\hat{p}_s = 0, \quad (5a)$$

$$\hat{q}_s = \frac{\hbar g_0 |\hat{c}_s|^2}{m \omega_m^2}, \quad (5b)$$

$$\hat{a}_s = \frac{-i(g\hat{c}_s + \chi)}{i\Delta_a + \gamma}, \quad (5c)$$

$$\hat{c}_s = \frac{\varepsilon_c - M\chi}{i(\Delta_c - |\hat{M}|^2 \Delta_a - g_0 \hat{q}_s) + (\kappa + \gamma |\hat{M}|^2)}, \quad (5d)$$

where $M = g/(i\Delta_a + \gamma_a)$. Thus, parameter regimes are relevant for generating OMIT with a very large input power. In this case, one can safely neglect the nonlinear terms and gets the linearized Langevin equations for the fluctuations

$$\delta \dot{\hat{q}} = \frac{\delta \hat{p}}{m}, \quad (6a)$$

$$\delta \dot{\hat{p}} = -m\omega_m^2 \delta \hat{q} + \hbar g_0 \hat{c}_s (\delta \hat{c} + \delta \hat{c}^\dagger) - \gamma_m \delta \hat{p} + \xi, \quad (6b)$$

$$\delta \dot{\hat{a}} = -[i\Delta_a + \gamma] \delta \hat{a} - ig \delta \hat{c} + \sqrt{2\kappa} \hat{a}_{in}, \quad (6c)$$

$$\delta \dot{\hat{c}} = -[i\Delta + \kappa] \delta \hat{c} - ig \delta \hat{a} + g_0 \hat{c}_s \delta \hat{q} + \varepsilon_p e^{-i\delta t} + \sqrt{2\kappa} \hat{c}_{in}, \quad (6d)$$

where $\Delta = \Delta_c - g_0 \hat{q}_s$. These equations represent the equations of motion for the fluctuations of the mechanical, atomic system, and the optical cavity operators, respectively. The necessary condition for obtaining an available OMIT phenomenon is that there should exist an asymptotic steady state and the corresponding system will keep the state for a long evolution time. As we all know, the probe field in OMIT typically has a small amplitude and it would not influence the stability of the system [39]. In the limit of the weak probe field, the steady-state solution of Eq. (5) can be expanded

$$\hat{Q} = \hat{Q} + \delta \hat{Q}(t) \Rightarrow \hat{Q} + \hat{Q}^+ e^{i\delta t} + \hat{Q}^- e^{-i\delta t}, \quad (7)$$

for any operator $\hat{Q}(t)$ with \hat{Q} denoting the steady-state value and $\delta \hat{Q}(t) = \hat{Q}^+ e^{i\delta t} + \hat{Q}^- e^{-i\delta t}$ induced by the weak probing field. Substituting Eqs.(7) in (3), one can obtain the first-order steady-state equation

$$\hat{c}_+ = \frac{\Xi (\kappa - i(\Delta + \delta) + \Lambda) + i\hbar(g_0 \hat{c}_s)^2 \varepsilon_p}{\Xi (\kappa + i(\Delta + \delta) + C) (\kappa - i(\Delta + \delta) + \Lambda) + i\hbar(g_0 \hat{c}_s)^2 (2i\Delta - \Lambda + C)} \quad (8)$$

where $\Xi = m[\omega_m^2 - \delta^2 - i\delta\gamma_m]$, $\Lambda = (2g^2)/(\gamma - i(\delta + \Delta_a))$ and $C = (2g^2)/(\gamma - i(\delta - \Delta_a))$. These equations provide the fundamental description of the dynamics of the model considered here. Specifically, from these sets of equations, one can easily deduce that the atomic ensemble plays a prominent role. Even in the case of a steady state, the cavity decay is enhanced by the additional term, i.e., contribution of the atomic decay. Thus, one can easily notice that the atomic ensemble system plays an effective role, particularly the coupling and atomic decoherence. In this paper, we

focus on these parameters and discuss the influence on the overall properties of the optomechanical system.

3.2 Input–output relation

To study the phenomenon of OMIT behavior, we have to find out the response of the system to the probing frequency, which can be detected by the output field. Specifically, we consider that the output field oscillates with probe frequency. By using the well-known input–output relation [41], one obtains

$$\begin{aligned}\hat{c}^{out}(t) &= \hat{c}^{in}(t) - 2\kappa\hat{c}(t) \\ &= \{\epsilon_c - 2\kappa\hat{c}_s\} e^{-i\omega_c t} + \{\epsilon_p + 2\kappa\hat{c}_+\} e^{-i(\delta+\omega_c)t} - 2\kappa\hat{c}_- e^{i(\delta-\omega_c)t},\end{aligned}\quad (9)$$

and after a straightforward calculation, one can obtain the response phenomena of the total output field. The result of such a calculation is that ε_T is now given by

$$\varepsilon_T = 1 - 2\kappa \left\{ \frac{\Xi(\kappa - i(\Delta + \delta) + \Lambda) + i\hbar(g_0\hat{c}_s)^2\epsilon_p}{\Xi(\kappa + i(\Delta + \delta) + C)(\kappa - i(\Delta + \delta) + \Lambda) + i\hbar(g_0\hat{c}_s)^2(2i\Delta - \Lambda + C)} \right\}. \quad (10)$$

In particular, we apply in the sideband resolved limit $\omega_m \gg \kappa$. Since the coupling between the cavity field and the oscillating mirror is strong enough whenever $\delta = \pm\omega_m$ is considered in this paper. Moreover, results of these calculations are plotted in Figs. 2, 3.

4 OMIT phenomena in the optomechanical system

In this section, we numerically study the behavior of OMIT phenomena based on the above analytical expressions. Specifically, for numerical work, we use parameters from a recent experiment on the observation of the optomechanically induced transparency [10,16,40], and summarized in Table 1. Further, we consider that the coupling field is resonant with atoms transmission frequency $\Delta_a = 0$. The driving power $p_s = 11\text{ mW}$, while the coupling between the cavity field and the oscillating mirror is $g_o = 2\pi \times 325\text{ kHz}$. Besides, the mechanical frequency is much greater than the decay, i.e., $\omega_m \gg \kappa$, and therefore, the system is in the resolved sideband regime, also termed as the good-cavity limit [11].

To understand the coupling field induced on the probe response ε_T , we make reasonable approximations. To this aim, we first discuss the OMIT behavior through fixing the decay rate of the atomic ensembles as well as varying the coupling between the cavity field-atomic ensembles. We specifically plot Figs. 2 and 3.

In Fig. 2a, we plot the absorption $Re(\varepsilon_T)$ of the output field as a function of z/ω_m , where $z = \delta - \omega_m$, while the other experimental parameters are the same as Table 1. The figure reveals that by fixing the value of the decay rate of the atomic

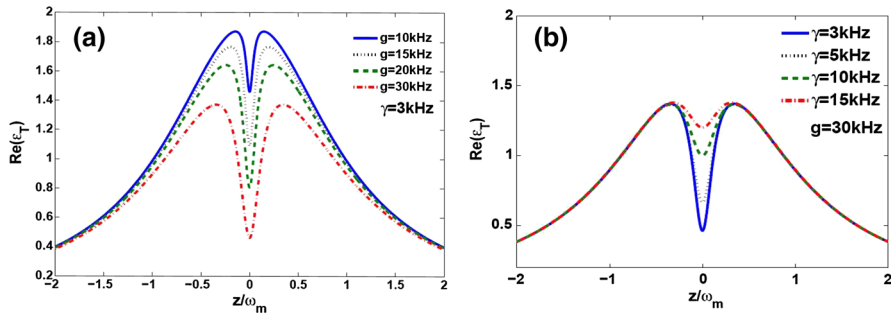


Fig. 2 Absorption of $\text{Re}(\varepsilon_T)$ as the function of z/ω_m , **a** the decay rate of atomic ensembles is fixing $\gamma = 3 \text{ kHz}$, while the coupling between cavity field-atomic ensemble is varied. **b** The coupling between the cavity field-atomic ensemble is fixed $g = 30 \text{ kHz}$, while the decay rate of the atomic ensembles is varying. The other parameters are the same as Table 1

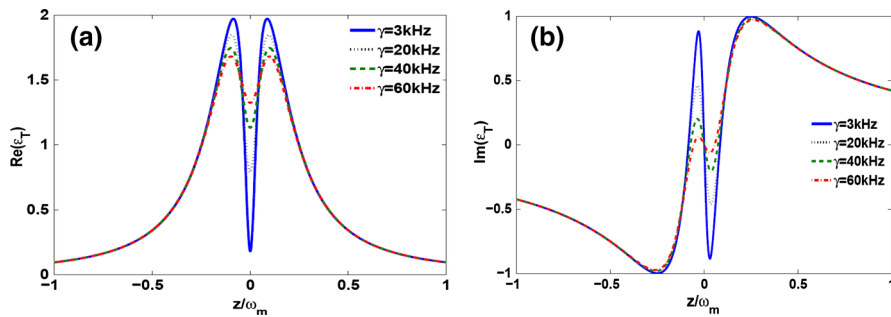


Fig. 3 The real and imaginary part of ε_T as the function of z/ω_m . **a** Real part ε_T as a function of z/ω_m ; **b** imaginary part of ε_T as a function of z/ω_m . The coupling between cavity field-atomic ensemble kept constant $g/2 = 80 \text{ kHz}$, while changing the decay rate of atomic ensembles. All other parameters are the same as Fig. 2

Table 1 List of possible experimental parameters [10,40]

Parameters	Symbol	Value
The length of the optical cavity	L	25 mm
The wavelength of the laser	λ_c	1064 nm
The mass of the oscillating mirror	m	145 ng
The frequency of the oscillating mirror	ω_m	$2\pi \times 947 \text{ kHz}$
The optical cavity decay rate	κ	$2\pi \times 215 \text{ kHz}$
The mechanical quality factor	$Q = \omega_m/\gamma_m$	6700
The damping rate of the oscillating mirror	γ_m	141 Hz

ensembles and changing the coupling between the cavity and atomic ensemble, one can observe that the system becomes transparent when $z/\omega_m = 0$. This shows that the transparency width increases as the coupling constant increases, while in Fig. 2b we fixed the value of coupling between the cavity and atomic ensemble, at the same time change the decay rate of the atomic ensemble. We have observed that the OMIT dip characteristic property and the depth of the transparency window decrease as the decay rate increases. The process is reversed in the case of coupling between the cavity field and atomic ensembles, as it is shown in Fig. 2a. We note that for the specific value of the atomic decay rate and increasing the coupling between the cavity field-atomic ensemble, the window of transparency broadens, which confirms that the coupling constant for the particular value of decay enhances the radiation pressure. This shows that the possibility of OMIT dip can be generated in the system, and the atoms coupled to the cavity system enhance the OMIT phenomenon.

Hence, introducing the atomic freedom into OMS can not only strengthen the coupling but also allow rich physics through enhanced nonlinearities [42–44]. These results are consistent with early studies as reported in [40], and electromagnetically induced transparency in mechanical effects of light [11]. However, it is quite different from [45], in which the researchers control the transparency window only in the presence of two nonlinearities optomechanical system with two movable mirrors. Thus, the possibility of OMIT could therefore provide a center of many important developments in optical physics [46] and led to a variety of applications, such as in the context of slow light, light storage, enhancement of nonlinear process [47,48], and many platforms developed to date experimental observation of the OMIT effect [16,49].

To bring out prominently the effect of atomic ensemble, we specifically change the decay rate of atomic ensembles and fixed the coupling. Specifically, in Fig. 3 we plot using these realistic possible parameters of Refs. [10,40]. In Fig. 3, the real part represents the absorption, and the imaginary part represents the dispersion of the output field at the probe frequency, respectively. This can be measured through homodyne techniques [50]. Moreover, the OMIT can be directly described by $|\varepsilon_T|^2$ of Eq.(10). To realize the coupling field-induced correction of the probe response ε_T , we utilize a reasonable approximations and take $g = 2\pi \times 80\text{ k Hz}$, while the decay rate of atomic ensembles changes from 3 kHz to 60 kHz . We can see that with the increase in the decay rate of atomic ensembles, the depth of transparency window become smaller, and the presence of identical or non-identical decay rate of atomic ensembles simplifies the OMIT window shrink. Specifically, we note that the decay of the atomic ensemble can be enhanced and the transparency window becomes shrunk in our model. The sweep of the photon from the cavity will cause a decrease in the transparency window. This behavior is similar to the one found in the context of atom-assisted optomechanical devices [40,51]. These results are an important phenomenon that displays a conspicuous dip in the absorption spectrum of a weak probe field when multi-level atoms or molecules appropriately couple to a strong control field [51], and provide a platform to study multiple coupling effects in hybrid systems [24].

In the present paper, we noticed a new publication work on the effect of atomic ensemble enhanced optomechanically induced transparency in a cavity optomechanical system. Our system is different from the recent work reported in Ref. [17], which is a hybrid nano-mechanical system in which a superconducting qubit is coupled with

the mechanical model, and [52] propose the quadratically coupled optomechanical system, where the movable membrane is located inside an optical cavity with two fixed mirrors. Furthermore, our scheme is different from Ref. [39] who proposed and analyzed a scheme to enhance OMIT based on parity-time-symmetric optomechanical system. Therefore, we believed that these results may be used to improve optomechanically induced transparency in multi-cavity optomechanical system with two-level atom.

5 Conclusions

In conclusion, we have studied the optical response behavior of the output field in an optomechanical cavity, which contains a Fabry–Pérot cavity with one fixed-mirror, one moving-end mirror, and two-level atomic medium trapped inside the optical cavity. We have shown that the system can exhibit optomechanical induced transparency phenomena. Furthermore, the width of the transparency window increases with an increase in the coupling constant, while decreases with the increase in the atomic decay rate. Particularly, we have presented the behavior of induced transparency is strongly affected by coupling between atomic and optical cavity as well as the atomic decay rate. The larger number of atoms can lead to the wider window of induced transparency. This shows that the mechanism of OMIT could have been well understood and even one could have known that an atomic ensemble could broaden the width of OMIT window. Our results provide a realistic route toward control light propagation and light manipulation, which further have potential applications in quantum optical devices and quantum information processing.

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