Surface acoustic waves controlled optomechanically induced transparency in a hybrid piezo-optomechanical planar distributed Bragg reflectors cavity system

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We propose a scheme that can generate tunable optomechanical induced transparency (OMIT) in a hybrid piezo-optomechanical cavity system. The system is constituted of a high quality planar distributed Bragg reflectors (DBR) cavity, which the quality is improved by an embedded submicrometer three-dimensional Gaussian-shaped defect. Moreover, the interdigitated transducers (IDTs) are fabricated on the surface of the cavity to generate the surface acoustic waves (SAW). Here, the DBR cavity structure modified with the embedded Gaussian-shaped defect is proposed by F.Ding et al., relative to the traditional DBR structures with the same number of mirror pairs, the quality factor of this design can be effectively improved by nearly two orders, which can exceed $10^7$ [1]. We show that when a strong pump optical field and a weak probe optical field are applied to the hybrid cavity system simultaneously, at the presence of the SAW, a transmission window can be obtained in the weak output probe field. This phenomenon arises because that under the actuation of the SAW, the upper Bragg mirrors is vibrated as a bulk acoustic resonator (BAR). Then the two-level system formed by the energy levels of the DBR cavity is turned into a standard three-level optomechanical cavity system, which is formed by the energy levels of the DBR cavity and the BAR. Under the quantum interference between different energy-level pathways, the optomechanically induced transparency (OMIT) occurs, as a result, the transmission window is observed in the weak output probe field. Inversely, without the actuation of the SAW, the transmission window disappears. Our scheme can be applied in the fields of optical switches and quantum information processing in solid-state quantum systems.

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I. INTRODUCTION

In the field of quantum information, many types of artificial atomic systems are proposed to regulate and manipulate the processing of the optical or microwave information, including superconducting quantum circuits [2, 3], N-V centers [4, 5], semiconductor quantum dots [6, 7], and distributed Bragg reflectors (DBR) cavities [8, 9]. Furthermore, as most of these artificial atomic systems can be coupled with both photon and phonon modes, the operation of the optical or microwave information can also be realized by modulating the phonon modes. There are many ways to control the phonon modes, commonly, the phonon modes can be driven by the radiation pressure of the optical or microwave fields [10, 11]. Moreover, in recent experiments, the phonon modes can also be driven by different types of external mechanical fields, such as the Lorentz force and piezoelectric force [12, 13]. And a representative one of the mechanical fields is the surface acoustic wave (SAW), which is generated by the piezoelectric effect [14–22].

SAW is a type of phonon-like excitations containing mechanical vibration modes [14–19]. It is generated electrically on the surface of the piezoelectric substrate with the use of interdigital transducers (IDTs), and the IDTs are driven by the radio frequency voltage source (RF).

Furthermore, SAW contains both the transverse and longitudinal vibration modes, when it propagates along the surface of the substrate, it also propagates downward simultaneously. The velocity of the SAW propagating along the surface is determined by the material performance of the substrate. When the SAW propagates downward, the vibration frequency of it can be adjusted by the design of the IDTs, and the extension depth below the surface is approximately one wavelength of the SAW. Under the actuation of the SAW, the surface of the substrate in vertical direction is vibrated as a bulk acoustic resonator (BAR), which can be regarded as a standard mechanical resonator [5]. In the related researches, the quality factor of BAR has exhibited the order of $10^5$, and the frequency of it can exceed the order of GHz [21–23].

As the piezoelectric materials are widely used in the optical DBR cavity systems, SAW can also be applied to modulate the optical properties of the DBR cavity systems through controlling the phonon modes [15]. In the related experiment, the light-sound interacting has been realized in high-quality DBR micropillar cavity system [24]. Generally, the quality of the DBR cavities can be improved by increasing the number of mirror pairs or optimizing design of the structure [1, 25, 26]. Recently, F.Ding et al. proposed a representative high quality planar DBR cavity structure, in which the quality of it is improved by the embedded submicrometer three-dimensional Gaussian-shaped defect [1]. Concretely, in this DBR cavity structure, when the three-dimensional
Gaussian-shaped defect is sandwiched between the upper and the lower Bragg mirrors, due to the local change in the cavity length and the deformation of the photonic defect band, the photons can be confined in a small modal volume in the vertical direction. Moreover, the light scattering induced by the lateral dielectric discontinuities is also minimized. As a result, the quality of this structure is improved dramatically, relative to the traditional DBR structures with the same number of mirror pairs, the quality factor of it can be effectively improved by nearly two orders. Based on the finite difference time domain (FDTD) calculation, the quality factors $Q$ of the designed DRR cavity can exceed the order of $10^5$ [1].

Here we propose a hybrid planar distributed Bragg reflectors (DBR) cavity system, in which the interdigitated transducers (IDTs) are fabricated on the surface to generate the surface acoustic waves (SAW). Moreover, the quality factor of the DBR cavity is optimized by the embedded three-dimensional Gaussian-shaped defect. And the DBR cavity is composed of AlAs and GaAs alternating layers, which are both the piezoelectric materials to support the generation of the SAW. When the SAW is applied to the system, we can estimate that the thickness of the upper Bragg mirrors is within a wavelength scope of the SAW. As a result, the upper Bragg mirrors in vertical direction is vibrated as a bulk acoustic resonator (BAR), which can be regarded as a mechanical resonator. Accordingly, our system is turned into a standard three-level optomechanical cavity system [27, 28], which is formed by the energy levels of the DBR cavity and the BAR.

The traditional three-level optomechanical cavity system is composed of an optical cavity and a mechanical resonator, it has been applied in many fields, and a representative one is the optomechanically induced transparency (OMIT) [29–39]. OMIT is a special nonlinear-optical phenomenon, when it occurs, the susceptibility of the optomechanical cavity system is changed, then the resonance optical field can be modulated from opacity to transparency. Physically, it arises from the quantum interference between different energy-level pathways [40–43]. Similar to the electromagnetically induced transparency (EIT) observed in the three-level atomic systems [44, 45], OMIT also has many applications, including fast and slow light [35], quantum information processing [31] and quantum optical storage [46].

In our system, we show that when a strong pump optical field and a weak probe optical field are applied to the hybrid optomechanical cavity system simultaneously, at the presence of the SAW, a transmission window can be obtained in the weak output probe field. This phenomenon arises because under the driving of the SAW, the upper Bragg mirrors is vibrated as a BAR, then the two-level DBR cavity system is turned into a lambda-type three-level optomechanical system. Under the quantum interference between different energy-level pathways, the OMIT occurs, as a result, the transmission window is observed in the weak output probe field. Inversely, without the actuation of the SAW, the transmission window disappears. Our scheme can be applied in the fields of optical switches and quantum information processing in solid-state quantum systems.

The paper is organized as follows. In Sec. II we describe the proposed model and derive the system Hamiltonian. In Sec. III we present the dynamical process of the system. In Sec. IV we discuss the detailed physical mechanism of the OMIT and study the variation of output field controlled by the SAW. Finally we make a brief conclusion in Sec. V.

II. MODEL AND HAMILTONIAN OF THE SYSTEM

The hybrid piezo-optomechanical planar distributed Bragg reflectors (DBR) cavity system we proposed is illustrated in Fig. 1, in which the interdigitated transducers (IDTs) are fabricated on the surface of cavity to generate the surface acoustic waves (SAW). The IDTs is driven by the radio-frequency voltage source (RF), it can
convert the RF voltage signal to SAW via the piezoelectric effect. The high-Q planar DBR cavity is modified with the embedded three-dimensional Gaussian-shaped defect, which is proposed by F. Ding et al. to improve the quality factor of the cavity [1]. The optomechanical cavity is driven by a strong optical pump field and a weak optical probe field, respectively.

In our system, the quarter-wavelength design for the DBR mirrors is used to maximize the photons confinement. The DBR cavity is composed of AlAs and GaAs alternating layers. The GaAs spacer is sandwiched between the upper (10 pairs) and the lower (15 pairs) Bragg mirrors, and the same cavity structure is applied in the recent experiment [15]. In detail, the thicknesses of GaAs and AlAs layers are $\lambda/4n_{GaAs} \sim 64.8$ nm (refractive index $n_{GaAs} = 3.57$) and $\lambda/4n_{AlAs} \sim 77.6$ nm (refractive index $n_{AlAs} = 2.98$), respectively. For the DBR cavity, the optical thickness of GaAs spacer is $\lambda = 925$ nm, which corresponding to the frequency $\omega_n = 324$ THz, and the actual thickness is $L = \lambda/n_{GaAs} = 259.1$ nm. Moreover, the thickness and half-width of the three-dimensional Gaussian-shaped defect are indicated as $\Delta L$ and $W$, and the shape of the defect is defined by the Gaussian function. Referring to same structure proposed by F. Ding et al. [1], we assume that the thickness and the half-width of the Gaussian-shaped defect are $\Delta L = L/10 = 25.9$ nm and $W = L = 259.1$ nm, respectively.

Correspondingly, in the high-Q DBR cavity, the photons are confined in a small modal volume with the order of $(\lambda/n)^3$ ($\lambda$ is the spacer optical thickness and $n$ is the refractive index of the spacer material) and the light scattering induced by the lateral dielectric discontinuities is also minimized. As a result, the quality factor is improved nearly two orders relative to the traditional DBR cavity structure [1]. Based on the relevant experiment, we can estimate that the quality factor of the our system is increased to $10^9$ and the corresponding cavity linewidth is approximated to 3.5 GHz [15].

Moreover, in our system, the frequency of the SAW we choose is $\omega_s/2\pi = 1.05$ GHz, which is used in the recent experiment [1]. In this situation, the IDT electrode period is $2.9 \mu m$ and the wavelength is $\lambda_s = 2.9 \mu m$. Correspondingly, in the high-Q DBR cavity, the thickness of the upper 10 pairs Bragg mirrors is approximated to 1.42 $\mu m$, which is within a wavelength scope of the SAW. As a result, under the driving of the SAW, the upper Bragg mirrors is vibrated as a bulk acoustic resonator (BAR). Moreover, as the material densities of them are $\rho_{GaAs} = 5.37$ g/cm$^3$ and $\rho_{AlAs} = 3.72$ g/cm$^3$, we can estimate that the effective motional mass of the BAR is $m = 0.33$ pg. Based on the related researches, the quality factor of BAR has exhibited the order of $10^5$ [21–23]. Accordingly, in our system, we can estimate that the intrinsic damping rate of the BAR is $\gamma_b/2\pi = 10.5$ KHz and the BAR has a high quality factor with $\omega_b \gg \gamma_b$.

Now we consider the situation that when only a pump optical field and a probe optical field are applied to the DBR cavity simultaneously, and the frequencies of them are referred to as $\omega_{pu}$ and $\omega_{pr}$, respectively. In this situation, the DBR cavity is a standard two-level energy system, the Hamiltonian of it is given as

$$H_I = \omega_a \hat{a}^\dagger \hat{a} + i\hbar \varepsilon_{pu}(\hat{a}^\dagger e^{-i\omega_{pu}t} - \hat{a} e^{i\omega_{pu}t}) + i\hbar \varepsilon_{pr}(\hat{a}^\dagger e^{-i\omega_{pr}t} - \hat{a} e^{i\omega_{pr}t}).$$  \hspace{1cm} (1)

Here, the first term of $H_I$ describes the energy of the cavity mode, which $\hat{a}^\dagger$ and $\hat{a}$ are the creation and annihilation operators of the cavity mode, respectively. The second and third terms describe the energy of the input optical fields, $\varepsilon_{pu} = \sqrt{P_{pu}/\hbar \omega_{pu}}$ and $\varepsilon_{pr} = \sqrt{P_{pr}/\hbar \omega_{pr}}$ are the amplitudes of the optical pump field and probe field, respectively. $P_{pu}$ and $P_{pr}$ are the input powers of the optical pump field and optical probe field, respectively. $\kappa_a$ is the decay rate of the optical DBR cavity.

Furthermore, when the RF is also applied to the system, under the driving of the SAW, the upper Bragg mirrors is vibrated as a bulk acoustic resonator (BAR). Referring to the relevant research [5], the vibration amplitude of the BAR is determined by

$$q_o = \sqrt{\frac{P_{RF}}{4\pi I_{IDT} s v_{SAW}^3 \rho_o \omega_b}},$$  \hspace{1cm} (2)

where $P_{RF}$ is the power of the RF, $I_{IDT}$ is the length of the IDT fingers and $v_{SAW}$ is the velocity of the SAW. $\rho_o$ is the average density of the BAR. Based on the recent experiment [15], the amplitude of the BAR in our system can exceed $q_o = 1$ pm.

As a result, the initial two-level energy cavity system is turned into a standard three-level energy optomechanical system, and the Hamiltonian of the system becomes

$$H_O = (\omega_a - G\hat{q})\hat{a}^\dagger \hat{a} + i\hbar \varepsilon_{pu}(\hat{a}^\dagger e^{-i\omega_{pu}t} - \hat{a} e^{i\omega_{pu}t}) + i\hbar \varepsilon_{pr}(\hat{a}^\dagger e^{-i\omega_{pr}t} - \hat{a} e^{i\omega_{pr}t}) + \frac{\hat{p}^2}{2m} + \frac{1}{2}m \omega_b^2 q_o^2,$$  \hspace{1cm} (3)

where $G = \frac{\omega_s}{\lambda}$ is the cavity coupling strength, $\hat{q}$ and $\hat{p}$ are the position and momentum operators of the BAR, respectively. $m$ and $\omega_b$ are the mass and the frequency of the BAR, respectively.

Now quantizing the Hamiltonian of the system with

$$\hat{q} = \sqrt{\frac{\hbar}{2\omega_m m}}(\hat{b} + \hat{b}^\dagger),$$  \hspace{1cm} (4)

$$\hat{p} = i\sqrt{\frac{\hbar \omega_b m}{2}}(\hat{b} - \hat{b}^\dagger),$$

where $\hat{b}^\dagger$ and $\hat{b}$ are the creation and annihilation operators of the BAR, respectively. Then the Hamiltonian is rewritten as

$$H_O = \hbar \omega_a \hat{a}^\dagger \hat{a} + \hbar \omega_b \hat{b}^\dagger \hat{b} - \hbar g_{om} \hat{a}^\dagger \hat{b} (\hat{b} + \hat{b}^\dagger) + i\hbar \varepsilon_{pu}(\hat{a}^\dagger e^{-i\omega_{pu}t} - \hat{a} e^{i\omega_{pu}t}) + i\hbar \varepsilon_{pr}(\hat{a}^\dagger e^{-i\omega_{pr}t} - \hat{a} e^{i\omega_{pr}t}),$$  \hspace{1cm} (5)
where $g_{om} = G\sqrt{\frac{\hbar}{2\omega_{om} m}}$, it is referred to as the single-photon coupling strength.

In the frame rotating at the frequency of the pump field, which respect to $H' = \hbar \omega_{pu} \hat{a}^\dagger \hat{a}$, the total Hamiltonian of equation (4) is turned into

$$H_\text{c} = \hbar \Delta_\text{a} \hat{a}^\dagger \hat{a} + \hbar \omega_\text{pb} \hat{b}^\dagger \hat{b} - \hbar g_{om} \hat{a}^\dagger \hat{b} (\hat{b}^\dagger + \hat{b})$$

$$+ i\hbar \varepsilon_{pu} (\hat{a}^\dagger - \hat{a}) + i\hbar \varepsilon_{pr} (\hat{a}^\dagger e^{i\delta t} - \hat{a} e^{i\delta t}),$$

(6)

where $\Delta_\text{a} = \omega_\text{a} - \omega_{pu}$ is the frequency detuning of the optical cavity from the pump field, and $\delta = \omega_{pr} - \omega_{pu}$ is the frequency detuning of the optical probe field from the pump field.

### III. DYNAMICS PROCESS OF THE SYSTEM

In our system, we consider the situation that the intensities of the optical pump field and the probe field satisfy the condition $\varepsilon_{pr} \ll \varepsilon_{pu}$. Moreover, the system is operated in a resolved sideband regime, which meets the condition $\omega_b \sim \kappa_b$. Now we adopt the quantum Langevin equations (QLEs) for the operators, in which the damping and noise terms are supplemented [11, 43]. Then the Heisenberg-Langevin equations of the cavity mode and BAR mode can be obtained as

$$\dot{\hat{a}} = -(i\Delta_\text{a} + \frac{\kappa_b}{2}) \hat{a} + i g_{om} \hat{a} (\hat{b}^\dagger + \hat{b}) + \varepsilon_{pu} + \varepsilon_{pr} e^{-i\delta t} + \hat{f},$$

(7)

$$\dot{\hat{b}} = -(i\omega_b + \frac{\gamma_b}{2}) \hat{b} + i g_{om} \hat{a}^\dagger \hat{a} + \hat{\xi}.$$

Here $\hat{f}$ and $\hat{\xi}$ are the quantum and thermal noise operators, respectively [11]. $\gamma_b$ is the intrinsic damping rate of the BAR. For simplicity, the hat symbols of the operators are omitted in the following description.

Then we linearize the dynamical equations of the operators by assuming $a = a_s + \delta a, b = b_s + \delta b$, which are both composed of an average amplitude and a fluctuation term. Here $a_s$ and $b_s$ are the steady-state values of the operators when only the strong driving field is applied to the system. Assuming $\varepsilon_{pr} \rightarrow 0$ and setting all the time derivatives to zero, we can get

$$a_s = \frac{\varepsilon_{pu}}{i\Delta_\text{a} + \frac{\kappa_b}{2}},$$

$$b_s = \frac{i g_{om} |a_s|^2}{i\omega_b + \frac{\gamma_b}{2}},$$

(8)

where $\Delta'_s = \Delta_s - g_{om} (b_s^2 + b_s)$, it denotes the effective frequency detuning of the optical pump field from the optical cavity, including the frequency shift caused by the mechanical motion. In our system, we assume that the cavity is driven by the optical pump field at the red sideband, which meets the condition $\Delta'_s = \omega_b$.

Next, by substituting the assumptions $a = a_s + \delta a$ and $b = b_s + \delta b$ into the nonlinear QLEs and dropping the small nonlinear terms, we can obtain the linearized QLEs, which are

$$\dot{\delta a} = -(i\Delta'_s + \frac{\kappa_b}{2}) \delta a + i G_{om} (\delta b^\dagger + \delta b) + \varepsilon_{pe} e^{-i\delta t} + \hat{f},$$

$$\dot{\delta b} = -(i\omega_b + \frac{\gamma_b}{2}) \delta b + i (G_0^2 \delta a + G_0 \delta a^\dagger) + \delta \xi,$$

(9)

where $G_{om} = g_{om} a_s$ is the total coupling strength between the optical mode and BAR mode.

Furthermore, the fluctuation terms can be rewritten as

$$\delta a = \delta a_+ e^{-i\delta t} + \delta a_- e^{i\delta t},$$

$$\delta b = \delta b_+ e^{-i\delta t} + \delta b_- e^{i\delta t},$$

$$f = f_+ e^{-i\delta t} + f_- e^{i\delta t},$$

$$\xi = \xi_+ e^{-i\delta t} + \xi_- e^{i\delta t},$$

(10)

where $O_+$ and $O_-$ (with $O = a, b, f, \xi$) correspond to the components at the original frequencies of $\omega_{pr}$ and $2\omega_{pu} - \omega_{pr}$, respectively [47, 48]. Next we substitute Eq. (10) into Eq. (9) and ignore the second-order small terms, by equating coefficients of terms with the same frequency, the components at the frequencies $\omega_{pr}$ can be obtained as

$$\langle \delta a_+ \rangle = \langle \delta b_+ \rangle = 0,$$

$$\langle \delta a_+ \rangle = \frac{(\frac{\kappa_b}{2} - i\lambda_b) \varepsilon_{pr}}{(\frac{\kappa_b}{2} - i\lambda_b)(\frac{\kappa_b}{2} - i\lambda_b) + G_{om}^2}. $$

(12)

Based on the input-output relation, the output field at the probe frequency $\omega_{pr}$ can be expressed as [40, 48]

$$\varepsilon_{out} = \kappa_a \langle \delta a_+ \rangle - \varepsilon_{pr}. $$

(13)

Then the transmission coefficient $T_{pr}$ of the probe field is given by [43, 50]

$$T_{pr} = \frac{\varepsilon_{out}}{\varepsilon_{pr}} = \frac{\kappa_a \langle \delta a_+ \rangle}{\varepsilon_{pr}} - 1. $$

(14)

Defining $\varepsilon_T = \frac{\kappa_a \langle \delta a_+ \rangle}{\varepsilon_{pr}}$, we can obtain the quadrature $\varepsilon_T$ of the output field at the frequency $\omega_{pr}$, which is

$$\varepsilon_T = \frac{\kappa_a (\frac{\kappa_b}{2} - i\lambda_b)}{(\frac{\kappa_b}{2} - i\lambda_b)(\frac{\kappa_b}{2} - i\lambda_b) + G_{om}^2}. $$

(15)

For simplicity, in the following discussion, we consider the situation that $\lambda_a = \lambda_b = \lambda$, then $\varepsilon_T$ can be rewritten as

$$\varepsilon_T = \frac{\kappa_a (\frac{\kappa_b}{2} - i\lambda)}{(\frac{\kappa_b}{2} - i\lambda)(\frac{\kappa_b}{2} - i\lambda) + G_{om}^2}. $$

(16)
The real part $\text{Re} [\varepsilon_T]$ and imaginary part $\text{Im} [\varepsilon_T]$ of optical probe field as function of $(\delta - \omega_b) / \omega_b$, respectively. The blue-solid line and the black-dotted line represent the situations that the SAW is applied or not, respectively. The other parameters we used are $\omega_a / 2\pi = 324$ THz, $\kappa_a / 2\pi = 3.5$ GHz, $\omega_b / 2\pi = 1.05$ GHz, $\gamma_b / 2\pi = 10.5$ KHz, $g_{\text{om}} / 2\pi = 1.54 \times 10^7$ Hz, $P_{\text{pu}} = 0.01 \mu W$.

The real part $\text{Re} [\varepsilon_T]$ and imaginary part $\text{Im} [\varepsilon_T]$ describe the absorptive and dispersive behaviors of the system, respectively.

Moreover, the phase $\phi_T$ of the output field can be given as

$$
\phi_T = \text{arg} [\varepsilon_T] = \frac{1}{2i} \text{Im} \left( \frac{\varepsilon_T}{\varepsilon_T^*} \right).
$$

This phenomenon arises from that in the situation of OMIT, the width $\Gamma$ of the transmission window meets the relation $\Gamma = \gamma_b + 4G_{\text{om}}^2 / \kappa_a$. As a result, the width $\Gamma$ is proportional to the optical pump field power, and the relevant mechanisms have also been studied extensively [27, 35]. This phenomenon can be applied in the fields of optical switches [35] and the optical quantum information process [31].

To further explore the characteristics of our system, when the OMIT occurs, the phase $\phi_T$ as functions of $(\delta - \omega_b) / \omega_b$ and the phase $\phi_T$ as functions of $(\delta - \omega_b) / \omega_b$. The other parameters we used are $\omega_a / 2\pi = 324$ THz, $\kappa_a / 2\pi = 3.5$ GHz, $\omega_b / 2\pi = 1.05$ GHz, $\gamma_b / 2\pi = 10.5$ KHz, $g_{\text{om}} / 2\pi = 1.54 \times 10^7$ Hz, $P_{\text{pu}} = 0.01 \mu W$.

The real part $\text{Re} [\varepsilon_T]$ and imaginary part $\text{Im} [\varepsilon_T]$ of optical probe field as function of $(\delta - \omega_b) / \omega_b$ are plotted in Fig. 2, the blue-solid line and the black-dotted line represent the situations that the SAW is applied or not, respectively. It is shown that when there is no SAW applied, there is no transparency window can be obtained in the transmission spectrum curve. But when the SAW is applied, a transparency window can be obtained in the transmission spectrum curve, and the center position of the window is determined by the frequency point $\delta - \omega_b = 0$. As a result, our system can be applied in the fields of optical switches, high-resolution spectroscopy and quantum information processing [39, 52].
FIG. 4. (color online) The real part $\text{Re}[\varepsilon_T]$ of optical probe field as functions of $(\delta - \omega_b)/\omega_b$ and pump field power strength $P_{pu}$, the range of $P_{pu}$ is from $1 \times 10^{-8}$ W to $3 \times 10^{-8}$ W, the other parameters are the same as those in Fig. 2.

FIG. 5. (a) The phase $\phi_T$ of optical probe field as functions of $(\delta - \omega_b)/\omega_b$. (b) The group-delay $\tau_T$ as functions of pump field power strength $P_{pu}$. The other parameters are the same as those in Fig. 2.

are plotted in Fig. 5. Fig. 5 (a) shows that when the OMIT occurs, the phase at the frequency position $\delta = \omega_b$ is modulated excessively, it indicates that the group-velocity of the probe field is altered. In this situation, it leads to the generation of slow-light effect [35]. Fig.5 (b) shows that with the increasing of the pump field power, the group delay of the probe field is decreased. And when the power of the pump field is weak enough, the magnitude of the group delay can be obtained as much as 0.03 ms. As a result, our system can be applied in the field of optical quantum information memory in solid-state systems.

V. CONCLUSION

In conclusion, we propose a scheme that can generate tunable optomechanical induced transparency (OMIT) in a hybrid piezo-optomechanical cavity system, the system is constituted of a high quality planar distributed Bragg reflectors (DBR) cavity, it is modified with an embedded three-dimensional Gaussian-shaped defect. Moreover, the interdigitated transducers (IDTs) are fabricated on the surface of the cavity to generate the SAW. We show that when a strong pump optical field and a weak probe optical field are applied to the hybrid optomechanical cavity system simultaneously, at the presence of the SAW, a transmission window can be obtained in the weak output probe field. This phenomenon arises because that under the actuation of the SAW, the upper Bragg mirrors is vibrated as a bulk acoustic resonator(BAR). Then the two-level system formed by the DBRs cavity is turned into a lambda-type three-level optomechanical system, which is constituted by the DBR cavity and the BAR. As a result, the destructive quantum interference between different energy level pathways generates the OMIT, which induces the occurrence of transmission window in the weak output probe field. Inversely, without the actuation of the SAW, the transmission window disappears. Our scheme can be applied in the fields of optical switches, quantum information memory and quantum information processing in solid-state systems.

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