CONTROLLABLE MAGNONIC PROPERTIES IN DOUBLE CAVITY OPTOMECHANICAL SYSTEM

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Abstract: We controlled the Bistability and photon blockade effect of quantum states for a coupled cavity with the magnonic system in presence of Kerr-nonlinearity. The magnonic system is strongly coupled with the photonic cavity system. We observe the bistable behaviour as well as Photon Blockade for both photonic and magnonic system in presence of a driving source. Surprisingly we achieve Sharpe bistable frequency when the coupling strength between photon and magnon is tune. The blockade system is achieved by tuning different system parameters with the help of some recent experimental results. Perfect magnon blockade is achieved under a weak coupling regime. By solving the Master's equation numerically we determined the second-order correlation function of magnon coupling with different system parameters. We controlled the magnon blockade perfectly by tune different system parameters. This study opens a new window to designing optical switches and optical flip-flops in quantum communication technology.

Keywords: Optical Gates, Optical Switches, Bistability Photon Blockade.

Introduction

In applied quantum physics, Quantum communication is strongly correlated to quantum information processing and quantum telecommunication. Quantum communication is more secure to protect data and data transferring from one place to another. Quantum processing [1] and quantum internet [2] are needed to achieve quantum communication. The optomechanical cavity system is the only helpful tool to overcome quantum communication. Recently magnonic systems take a part to design many components [3-8] related to quantum communication. The cavity system is coupled in a magnonic system strongly or ultrastrongly [9-11]. In recent several magnonic cavity systems demonstrate theoretically [12-13] and experimentally [14-16]. Now a day's quantum information processing is developed by microwave Photons [17] Optical Photons [18] Phonons [19] under strong correlations between magnons and cavity photons in a Hybrid quantum system.

Single magnon source has many more applications in quantum optics, especially in quantum communication. In different experiments, it is clear the single magnon has basic tools for communication due to its extremely high spin density [20-24]. Optical cooling magnon [25] has important applications. In a cavity, a magnonic system to generate Bell states magnon photon phonon coupling [26] and magnon phonon squeezed states [27] is required. In recent, some nonlinear system photon phonon and magnon blockade effects is discussed [28-30]. To generate a Magnon-polariton system magnon blockade effect is a common phenomenon [31-32]. To design, a magnon emitter magnon blockade phenomena are used [33]. In recent magnon, the blockade effect mechanism is discussed theoretically and experimentally by using a YIG sphere in a cavity magnonic system [34-37].

To our knowledge, our work has many aspects to achieve bistability in Nonlinear Optics. Also, this study covers many parts to enhance nonlinear phenomena, Bistability is the fundamental study and it has many potential applications in optical switching devices and design memories.

This paper's design is as follows: in section 1 we discussed the model and different parts of our model. In section 2 we numerically solve our system Hamiltonian by using different decay or noise fluctuation. In this section, we also discussed the numerical results of Bistability. In section 3 we discussed our results with the help of different experimental results. At last, we discussed the Conclusion of this study.

Model

The cavity Magnonic system represented by the Hamiltonian (taking$\hbar = 1$) [9-10]

$$H = \omega_a a^* a + \omega_b b^* b + \zeta b^* b b^* b + g_b(a^* b + a b^*) + \Omega(b^* e^{-i\omega_d t} + b e^{i\omega_d t}) \quad (1)$$

The first part of this Hamiltonian represents cavity Photons and $a^*(a)$ represents the creation (annihilation) operator of photons with a frequency ω_a. The second part of this Hamiltonian represents the Magnonic system and $b^*(b)$ represents the creation (annihilation) operator of Magnons with frequency ω_b. The third term represents a magnon nonlinear term. Where $\zeta = \frac{\mu_o \gamma}{M^2 V_m}$ μ_o is magnetic permeability, γ gyromagnetic ratio, M saturation magnetization, V_m The volume of the magnetic cavity. The fourth term represents the coupling between photon with magnon, where g_m is the coupling strength. The last term represents as driving term, where Ω is the strength of the laser source, which is equal to $\sqrt{\frac{\kappa P}{\hbar \omega_c}}$ with P and κ being the drive laser power and the cavity damping rate, ω_c probe field frequency and ω_d drive field frequency.

. In the rotating frame with the drive frequency ω_c the interaction Hamiltonian has the form

$$H = \Delta_a a^* a + \Delta_b b^* b + \zeta b^* b b^* b + g_b(a^* b + a b^*) + \Omega(b^* e^{-i\Delta_d t} + b e^{i\Delta_d t}) \quad (2)$$

Where $\Delta_a = \omega_a - \omega_c$ $\Delta_b = \omega_b - \omega_c$ $\Delta_d = \omega_d - \omega_c$ we derive the coupled equations for the macroscopic fields $\bar{a}$, $\bar{m}$. Using the corresponding damping and noise term, the Heisenberg equations are

$$\dot{a} = -(\kappa_a + i\Delta_a)a + ig_m m + +\sqrt{2\kappa_a}\, a_{in}(t) \quad (3)$$

$$\dot{b} = -(\kappa_b + i\Delta_b)b + i\zeta b^* b b + ig_b a + \Omega e^{-i\Delta_p t} + \sqrt{2\kappa_b}\, b_{in}(t) \quad (4)$$

In the above equation κ_a , κ_m denote the decay rates of photon Magnon respectively. $a_{in}(t)$, $m_{in}(t)$, describe the corresponding environmental noise with zero mean values.

$$< a_{in} > = < b_{in} > = 0 \quad (5)$$

This nonlinear equation is linearized by using a steady-state classical mean value with fluctuating quantum part $a = \bar{a}_s + \delta a$, $b = \bar{b}_s + \delta b$

The steady-state solutions in absence of probe field of equations (3)-(6) give the following results

$$a_s = \frac{g_b b_s}{(\kappa_a + i\Delta_a)} \quad (6)$$

$$m_s = \frac{\Omega + i g_b a_s}{\kappa_b + i\Delta_b - i\zeta |b_s|^2} \quad (7)$$

Where a_s and b_s are the steady-state solution of a and m respectively. From these solutions, we can obtain steady-state magnon $|b_s|^2$ and Photon number $|a_s|^2$. Which are strongly coupled with each other. The stability conditions are solved by applying the Routh-Hurwitz criterion [20] and the eigenvalues of the Langevin equations have negative real parts. From these results, we observe that the magnon number and photon number for cavity mode are dependent on each other and they can generate a multistable state. Comparing equations (6) and (7) we get the non-linear equation that generates the bistable behavior of this system.

Master equation

To study the perfect magnon blockade effect we use a Classical field with a frequency ω_d and coupling between cavity field and driving field amplitude $\boldsymbol{\Omega}$ with zero pumping phase. Using the noise term from the environment, the master equation for the density operator in a double cavity optomechanical system

$$\dot{\rho} = \frac{\partial \rho}{\partial t} = -i[H, \rho] + \kappa_1 \mathcal{L}_{a1}(\rho) + \kappa_2 \mathcal{L}_{a2}(\rho) + \gamma_o(n_{th} + 1)\mathcal{L}_b(\rho) + \gamma_o n_{th} \mathcal{L}_{b^*}(\rho) \text{------------} (8)$$

The Lindblad dissipation for the phonons $\mathcal{L}_o(\rho) = o\rho o^* - o^* o\rho - \rho o^* o$ ------------------ (9)

Where $o = a_j (j = 1, 2)$ or b corresponds to the photon or magnon here κ_1, κ_2 , γ_o are the decay rates of photon and magnon respectively, $n_{th} = 1/e^{\frac{\hbar\omega}{kT}}$ where k is the Boltzman constant and T is the temperature. Now the second-order correlation function

$$g_2(0) = \frac{Tr(b^* b^* bb\rho)}{Tr[b^* b\rho)]^2} \quad \text{----------------------- (10)}$$

Results and Discussions

In our result, we demonstrate the nonlinear behavior in the cavity magnonic system by driving the laser source field. The hysteresis loop width decrees or increases in a different set of input laser power strength. We set the system parameters from different recent experimental results [21]. We analyze our results in presence of an off-resonance condition that is $\omega_b = \omega_c = \omega$, in this situation magnet coil current, becomes 4.5 A, and the crystallographic axis of the magnonic cavity parallel to the static magnetic field B_0.

To study the bistability of the magnonic system we plot the intracavity magnon number as a function of detuning in Fig. 1-2. The steady-state Magnon number is represented as $|b_s|^2$ and the nonlinear equation can exhibit bistability [21-20]. we set different experimental parameters [21] to investigate steady-state solutions of intracavity magnon numbers. The parameters used are as follows $\omega_b = 2\pi \times 10.5$ GHz, $\kappa_a = 6.5 \times 10^6 \omega_b$, $\kappa_b = 2.5\omega_b$,

Figure (1-2) shows the steady state magnon number as a function of normalized detuning normalized by magnon frequency. The initial intracavity magnon is in the ground state (smallest roots) and as detuning increases, it jumps to the upper state (largest root) for a fixed Kerr nonlinear term. The results represent that the intracavity magnon number has different values under variations in driving frequency. When the control field Kerr nonlinearity is 0.1ω and 0.2ω the width of the bistability shifted. This behavior applies to the optical switch, optical Flip-Flop, etc.

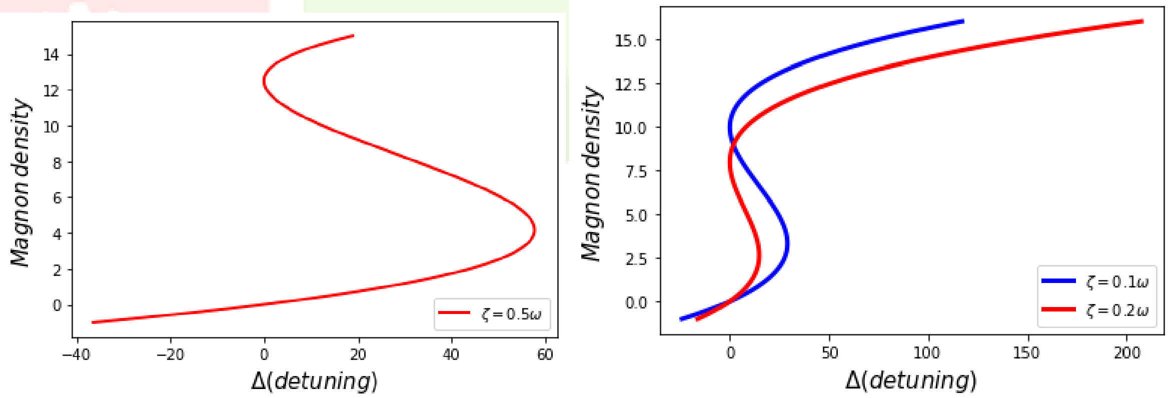

Fig (1-2) Plots of intracavity photon number as a function of normalized Detuning frequency. $\omega_m = 2\pi \times$ 10.5 GHz, $\kappa_a = 6.5 \times 10^6 \omega$, $\kappa_b = 2.5\omega$, $g_b = 5\omega$ $g = 1\omega$, Ω=10.65 MHz, $P = 2.0$ mW.

The magnon blockade effect depends on different system parameters like detuning, driving laser amplitude, coupling parameters, and also thermal magnon density states. Our theoretical study agrees with some experimental studies and this study is applicable to single magnon emitter.

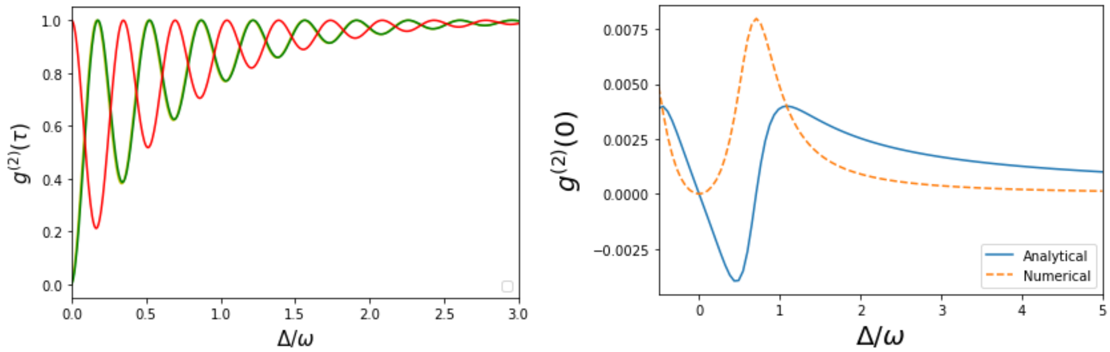

Fig (2-3) Plots of Second order corelation function as a function of normalized Detuning frequency. $\omega_m = 2\pi \times 10.5$ GHz, $\kappa_1 = 6.5 \times 10^6\omega$, $\kappa_2 = 2.5\omega$, $g_m = 5\omega$, Ω=10.65 MHz,$n_{th} = 200$ (a) $\kappa = 0.5$, Δ= 0.5, 0.8, 1.0 (red, yellow, green) (b) $\kappa = 0.5$, 1.0. Δ= 0.5.

Conclusions

The intracavity Magnon number shows the "S" shaped under variation of cavity detuning frequency. Controlling bistability behaviour have various practical applications like optical switches and optical flip-flop (Logic devices) for quantum communications and information processing. Bistability behaviour tune by Kerr-type nonlinear term. So by using a different set of Kerr terms Bistability behaviour can be achieved. To generate the perfect Magnon blockade in a weak coupling region we have predicted the distinguishable relationship with different system parameters. We have discussed the necessary condition for generating antibunched and sub-Poissonian Magnon sources. We have derived the steady state condition and have given the emission efficiency of generated single Magnon source. In presence of weak Kerr, nonlinearity is taken for the generation of the Magnon Blockade effect.

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