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Magnon Bistability for Photonic Magnonic system

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Abstract

We explore the Bistability 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 for both photonic and magnonic systemin presence of a driving source. Surprisingly we achieve Sharpe bistable frequency when the coupling strength between photon and magnon is tune. This study opens a new window to designing optical switches and optical flip-flops in quantum communication technology.

Keywords: Optical Gates, Optical Switches, Bistability

1 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, 4, 5, 6, 7, 8] related to quantum communication. The cavity system is coupled in a magnonic system strongly or ultrastrongly [9, 10, 11]. In recent several magnonic cavity systems demonstrate theoretically [12, 13] and experimentally [14, 15, 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.

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.

2 The Model

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

H=$\omega_a\, a^*\, a + \omega_m\, m^*\, m + \zeta\, m^*\, mm^*\, m + g_m\, (a^*\, m + am^*\,) + \Omega(m^*\, e^{-i\omega_d\, t} + me^{i\omega_d\, t})$——-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 $m^*(m)$ represents the creation (annihilation) operator of Magnons with frequency ω_m. 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 $\sqrt{\kappa P/\hbar\omega_c}$ 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 Hamilto-

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nian has the form
$H = \Delta_a a^* a + \Delta_m m^* m + \zeta m^* m m^* m + g(m a^* m + a m^*) + \Omega(m^* e^{-idt} + m e^{idt})$——2
Where $\Delta_a = \omega_a - \omega_c$, $\Delta_m = \omega_m - \omega_c$, $\Delta_d = \omega_d - \omega_c$ we derive the coupled equations for the macroscopic fields $\bar{a}$, $\bar{m}$. Using the corresponding damping and noise term, the Heisenberg equations are
$\dot{a} = -(\kappa_a + i\Delta_a)a + i g_m m + \sqrt{2\kappa_a a_{in}(t)}$—3
$\dot{m} = -(\kappa_m + i\Delta_m)m + i\zeta m^* m m + i g_m a + e^{-i\Delta_p t + \sqrt{2\kappa_m m_{in}(t)}}$———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. $< a_{in} > = < m_{in} > = 0$——-5 This nonlinear equation is linearized by using a steady-state classical mean value with fluctuating quantum part $a = \bar{a}_s + \delta\, a, m = \bar{m}_s + \delta\, m$

The steady-state solutions in absence of probe field of equations (3)-(6) give the following results
$a_s = g_m m_s / ({}_a + i\Delta_a)$———6
$m_s = \Omega + i g_m a_s / \kappa_m + i\Delta_m - i\zeta |m_s|^2$——7

Where a_s and m_s are the steady-state solution of a and m respectively. From these solutions, we can obtain steady-state magnon $|m_s|^2$ 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.

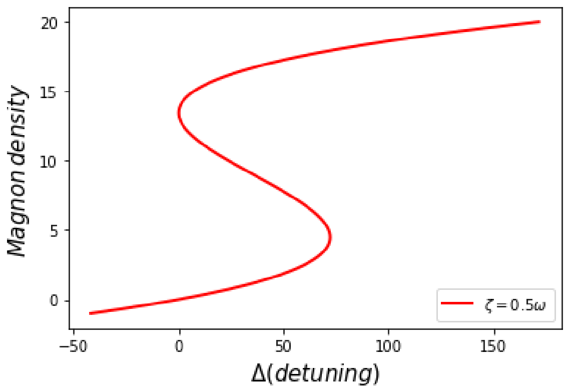

Figure 1: Magnon Density Profile

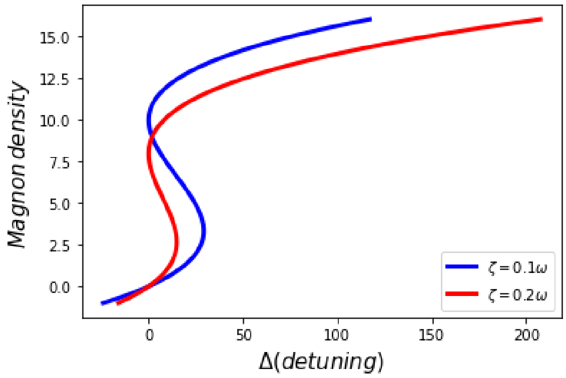

Figure 2: Magnon density Profile under multi nonlinear coupling

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

3 Conclusion

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.

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