Exciton-Phonon Effects in the Coherently Driven Two Quantum Dots-Photonic Microcavity System Showing Cooperative Two-photon Lasing

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We show cooperative two-photon lasing in the coherently driven quantum dots coupled to single mode photonic crystal cavity system. We study the effect of exciton-phonon interaction present in the system in non-perturbative approach by making a polaron transformation[1] and shown results for T=5K and 20K. Here, we consider two separate quantum dots (QDs) coupled to a single mode photonic-crystal (PhC) cavity. The Hamiltonian for the system in rotating frame of cavity frequency is given by,

$$H = \hbar\Delta_1\sigma_1^+\sigma_1^- + \hbar\Delta_2\sigma_2^+\sigma_2^- + \hbar(g_1\sigma_1^+ a + g_2\sigma_2^+ a + H.C) + H_{ph}.$$

where, the detuning $\Delta_i = \omega_i - \omega_c$, ω_i, ω_c are the transition frequency between ground state $|g_i\rangle$ and excitonic state $|e_i\rangle$ for i^{th} QD, cavity mode frequency respectively. The lowering and raising operators for QDs are given by $\sigma_i^+ = |e_i\rangle\langle g_i|$, $\sigma_i^- = |g_i\rangle\langle e_i|$ and g_i is the exciton-cavity mode coupling constant, a is cavity field operator. The last term in Hamiltonian, H, represents the exciton and longitudinal acoustic phonon interaction , $H_{ph} = \hbar\Sigma_k\omega_k b_k^\dagger b_k + \hbar\Sigma_i\lambda_k^i|e_i\rangle\langle e_i|(b_k + b_k^\dagger)$. Here, $b_k(b_k^\dagger)$ is the annihilation(creation) operator of k^{th} phonon-bath mode of frequency ω_k. Here, λ_k^i is the coupling strength of exciton $|e_i\rangle$ to k^{th} mode of the phonon bath. We perform polaron transformation for the Hamiltonian, H using $H' = e^S H e^{-S}$, where $S = \Sigma_i\sigma_i^+\sigma_i - \Sigma_k\frac{\lambda_k^{e_i}}{\omega_k}(b_k^\dagger - b_k)$. Similar methods used to treat exciton-phonon interaction effect in other works [2]. We derive the time-convolutionless master equation for the system treating the phonon bath interaction terms after polaron transformation perturbatively using Born-Markov approximation. We have also included the incoherent processes present in the system such as spontaneous emission of excitons (γ_i), pure dephasing, (γ_i') and cavity decay (κ) phenomena.

$$\dot{\rho}_s = -\frac{i}{\hbar}[H_s, \rho_s] - L_{ph}\rho_s - \frac{\kappa}{2}L[a]\rho_s - \Sigma_{i=1,2}(\frac{\gamma_i}{2}L[\sigma_i^-] + \frac{\gamma_i'}{2}L[\sigma_i^+\sigma_i^-])\rho_s.$$

Here $L[\hat{O}]$ represents Lindblad super operator. L_{ph} corresponds to phonon induced processes. We further make approximations, $\Delta_i >> g_i, \eta_i$ to obtain a simplified master equation (SME). We use this SME to write the density matrix elements rate equations and by using Scully-Lamb theory [3], performing trace over collective QD states, the rate equation for probability of having ‘n’ photons in the cavity mode is obtained. Thereby, single and multi-photon emission and absorption rates are caluculated numerically.

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