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STUDIES ON SEMICONDUCTOR WAVEGUIDE-CAVITY SYSTEM CONTAINING A SINGLE QUANTUM DOT

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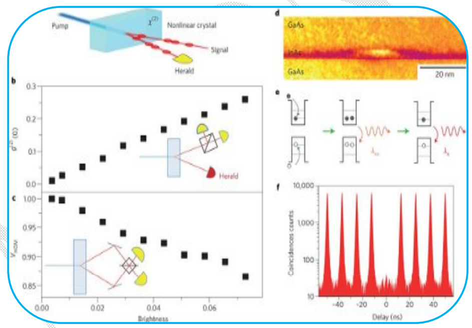

ABSTRACT:
This paper presents the coherent light propagation effects in various semiconductor systems, including planar photonic crystals and micropillars.

KEYWORDS: *Photonic crystals, Coherent light & Quantum dot*

INTRODUCTION :

The ability to couple waveguides and cavities offers exciting opportunities for integrated quantum optical devices using solids.[1-3] In particular, planar photonic crystals offer a technology platform, where quantum bits (qubits) can be manipulated from quantum dots (QDs) placed on field antinode positions within the cavity or waveguide.[4-6] Integrated semiconductor micropillar systems also show great promise for quantum optical applications [7-9]

METHODOLOGY

We want to describe light propagation for QD- cavity geometry, where the input and output fields are identified separately from the cavity region, in which QD is assumed as embedded. An example waveguide-cavity system is shown schematically in Fig. 1.(a,b,c) For a continuous wave (cw) waveguide mode of a photonic crystal system [10, 23]

$$r_{pc}(\omega)=\frac{i\omega\Gamma_c}{\omega_c^2-\omega^2-i\omega(\Gamma_c+\Gamma_0)-\omega\Sigma(\omega)}. \quad (1)$$

where the self-energy is $\omega(\omega) = \omega g^2 / (\omega_x - \omega^2 - I\omega$ $^{of}{}_{q)},$ *0 ≡ 2 κ 0 is the cavity* decay rate through vertical scattering (unloaded cavity broadening), $_{df} \equiv 2\kappa_c = 2(\kappa_l + \kappa_r)$ is the cavity-waveguide coupling rate coincides with the vacuum Rabi splitting which can be observed in transmission or reflection; this *normal mode* doublet can occur even if the dot is *not* in the strong-coupling regime,

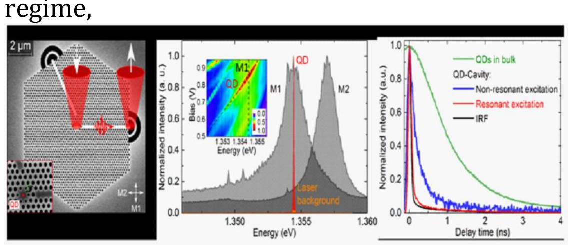

Fig -1 SEM image of the waveguide-coupled QD PhCC system

we will use a ME approach where exciton -photon interactions are easily included in all orders. Referring to Fig. 1 (a,b,c), we relate the left / right output operators to the cavity mode operator[24-27]

$$\langle a_{out}^{r}(t)\rangle = -\langle a_{in}(t)\rangle + \sqrt{2k_c}\langle a(t)\rangle, \qquad (2)$$

$$\langle a_{out}^{l}(t)\rangle = \sqrt{2k_c}\langle a(t)\rangle \qquad (3)$$

where , for a coherent cw input state, $\langle \alpha_{in}\rangle = i\eta_c/(2\sqrt{2k_c})$, with η_c the cavity pump rate Following the solution of the ME (discussed below), the *steady-state* transmissivity and reflectivity are obtained: $t \equiv |t|e^{i\varphi_t} = \langle a_{out}^{r}\rangle_{ss}/\langle a_{in}\rangle$ and $r \equiv |r|e^{i\phi_r} = \langle a_{out}^{l}\rangle_{ss}/\langle a_{in}\rangle$, where φ_t and φ_r are the phases Working in a frame rotating with respect to the laser pump frequency, ω_L, the model Hamiltonian can be written as

$$H = h\Delta_{xL}\sigma^{+}\sigma^{-} + h\Delta_{cL}a^{+}a + hg(\sigma^{+}a^{-} + a^{+}\sigma^{-}) + H_{drive}^{c} + \sigma^{+}\sigma^{-}\sum_q h\lambda_q(b_q + b_q^{+}) + \sum_q h\omega_q b_q^{+}b_q, \qquad ...(4)$$

where b_q (b^{+}_q) are the annihilation and creation operators of the phonons, a is the cavity mode annihilation operator , σ^{+} and σ^{-} are the Pauli operators of the electron-hole pair

$$\frac{\partial p}{\partial t} = \frac{1}{ih}\left[H_{sys,}^{+} p(t)\right] + L(p) + L_{ph}(p), \qquad ..... (5)$$

where the polaron -transformed system is Hamiltonian is

$$H_{sus}^{'} = h(\Delta_{xL} - \Delta p)\sigma^{+}\sigma^{-} + h\Delta_{cL}a^{+}a + \langle B\rangle X_g + H_{drove}^{c}, \quad \text{with} \quad \left[-\frac{1}{2}\int_0^{\infty} d\omega J(\omega)/\omega^2 \coth(\beta h\omega/2)\right]$$

$$(\beta = 1/k_b T), X_g = hg(a^{+}\sigma^{-} + \sigma^{+}a), \text{ and } \Delta_p = \int_0^{\infty} d\omega J(\omega)/\omega.$$

Using a Markov approximation, the incompatible phononscattering term is defined as

$$L_{ph}(\rho) = \frac{1}{h^2}\int_0^{\infty} d\tau \sum_{m=g,u}\left(G_m(\tau)\times\left[X_{m,}e^{-i}H_{sys}^{!\ \tau/h} X_m e^{-i}H_{sys}^{!\ \tau/h}\rho(t)\right] + H.c.\right), \qquad ......(6)$$

where $x_u = -ihg(a^{\dagger}\sigma^{-} - \sigma^{+}a)$, and $g_{g/u}(t)$ are the polaron green functions:[25-30]
Lindblad ME has been shown to yield very good agreement with the full polaron ME solution above. In this way , one defines the phonon-mediated incompatible scattering processes through

$$L_{ph}(\rho) = \frac{\Gamma_{ph}^{\sigma^{+}a}}{2}L(\sigma^{+}a) + \frac{\Gamma_{ph}^{\sigma^{+}a}}{2}L(a^{+}\sigma^{-}), \qquad ....(7)$$

where $G(D) = 2D i\rho di^{\dagger} - D^{\dagger}D\rho - \rho D^{\dagger}D$, and the scatteringates are obtained analytically,

$$\Gamma_{ph}^{\sigma^+ a/a^+\sigma^-} = 2\langle B\rangle^2 g^2 \,\mathrm{Re}\left[\int_0^\infty d\tau e^{\pm i\Delta_{cx}}\left(e^{\phi(t)}-1\right)\right], \quad \text{.......(8)}$$

The rate $\Gamma_{ph}^{\sigma^+\sigma^-}$ describes the process of cavity excitation and the emission of exaction, via phonon-induced scattering..

CONCLUSION

This paper presents the light propagation for QD- cavity geometry using Master equation.

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