QD-cavity feeding scenario: A Theoretical model

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Experiments


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Overview

The cavity feeding mechanism

Cavity feeding through LA-phonon sidebands

Cavity feeding through multiexciton cascade

Conclusion

Single photons from coupled quantum modes
The cavity feeding phenomenon

- Strong PL at the cavity mode wavelength even at $\delta \sim 100\gamma_{x,c}$
- What is the emission mechanism that feeds PL at the cavity wavelength?

Winger et al., PRL 103, 207403 (2009)

1) K. Hennessy et al., Nature 445, 896
5) Ota et al., arxiv:0908.0788

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QD-cavity feeding scenario: a theoretical model
Features of cavity feeding (1)

Power dependence

- Superlinear at large powers
- Linear at small powers

Features of cavity feeding (2)

Photon correlations

(i) the emission from the cavity-like peak is **poissonian** (large detuning) **antibunched** (small detuning)

(i) the emission from the exciton-like peak is **antibunched**

(i) photons emitted from the two peaks are **anticorrelated**
2L system+LA phonons


- Only works for $\delta \sim $meV
- Linear power dependence at all powers

- PL originates from a single 2L
- Photon antibunching


1) Y. Ota et al., arxiv:0908.0788
Multiexciton emission

- Multiple excitons (N>1) allow for emission at $\lambda_{cav}$
- Non-linear power dependence
- Poissonian statistics

**BUT**

- Non trivial competition between radiative and relaxation dynamics = spin is important

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$E_{cav}$

- Single particle e/h levels

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QD-cavity feeding scenario: a theoretical model
Multiexciton emission

\( M. \text{ Winger et al.}, \text{Phys. Rev. Lett.} \ 103, \ 207403 (2009) \)

\[
H_{c-c} = \sum_i \epsilon_i \hat{c}_i \hat{c}_i + \sum_j \epsilon_j \hat{d}_j \hat{d}_j + \frac{1}{2} \sum_{i_1,i_2,i_3,i_4} V_{i_1,i_2,i_3,i_4} \hat{c}_{i_1} \hat{c}_{i_2} \hat{c}_{i_3} \hat{c}_{i_4}
\]
\[
+ \frac{1}{2} \sum_{j_1,j_2,j_3,j_4} V_{j_1,j_2,j_3,j_4} \hat{d}_{j_1} \hat{d}_{j_2} \hat{d}_{j_3} \hat{d}_{j_4} - \sum_{i_1,i_2,j_1,j_2} V_{i_1,j_1,j_2,i_2} \hat{c}_{i_1} \hat{d}_{j_1} \hat{d}_{j_2} \hat{c}_{i_2}
\]

- Diagonalize \( H_{c-c} \) on a truncated set of N-e-h configurations
- 18 electrons levels, 32 holes levels
- \( N=1,2,3,4 \)
- Binding energies: \( X0 \sim 20 \text{ meV} \), \( XX0 \sim 4 \text{ meV} \) (~2nm)

Dynamics simulation


- Monte-Carlo simulation

- Excitation

- Emission

- Relaxation

- Spin flip
Phonons relaxation rates


- Taken from literature (1,2)
- Includes polaron effect
- Fast decay, even for mismatch > 10meV
- No phonon bottleneck

Radiative + Capture rates


- Radiative lifetimes: Purcell effect

\[ P(\omega) = I_{ij} \mu_{cv}^2 \frac{\hbar \omega}{n^2} \frac{4\pi}{V} \Delta^2 + (\gamma_m/2)^2 \]

\[ H_{rad} = P(\omega)(\hat{c}_\alpha^\dagger \hat{d}_\beta^\dagger + h.c.) \]

- Absorption of an e-/h pair: modeling relaxation from highly excited e-h states to N-exc states considered here

\[ H_{abs} = \gamma_{abs}(\hat{c}_\alpha^\dagger \hat{d}_\beta^\dagger + h.c.) \]

\[ \gamma_{abs} \sim 1/10 \text{ of ns} \]
Monte Carlo run


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QD-cavity feeding scenario: a theoretical model
Calculated emission spectrum


- Cavity peak naturally superlinear
Simulation of HBT experiment


Computed time correlations

Measured time correlations
Simulation of HBT experiment (2)


Computed time correlations

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QD-cavity feeding scenario: a theoretical model
‘Temporal monitoring’


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QD-cavity feeding scenario: a theoretical model
Removing of WL carriers

- Application of an electric field
- Removes WL carriers
- Closer to an ideal 2L system

Shake-up process

- MX cascade is equivalent to shake-up

Conclusion

- mechanism extending over 10meV
- many independent cavity emission event
- superlinear power dependence

- Two level approach: small detunings
  - not for large detunings
  - gives antibunched cavity photon correlations
  - linear power dependence

- MX cascade ‘shake-up’
  - excellent agreement with measurements
  - qualitative emission spectrum
  - correlation curves
  - superlinear
Single photons from coupled quantum modes:

T. C. H. Liew and V. Savona


Noise correlations between coupled quantum modes can deliver enhanced single photon statistics that survive in the presence of dephasing.

Devices based on [1]coupled semiconductor microcavity mesas or [2]photonic crystal cavities are proposed as single photon sources.