Quantum Dots as Single Photon Emitters

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Outline

- What is a QD?
- Processing of QDs
- Populating the QD
- Spontaneous emission from a QD
- The QD as a single photon emitter
- The QD as a source of entangled photons
What is a QD?

Spatially restricted in 3D – a 0D structure → quantization of the energy levels in 3D

The quantization energies as well as the number of energy states in the QD are dependent on the size of the QD.
Processing of a QD

Self-assembly:
Stranski-Krastanow process
- Epitaxial growth
- Mismatched lattice constants

GaN quantum dots grown at 750°C and ripened in vacuum

[1], [2]
Energy levels in the QD

Square potential

Energy levels are confined in 3D.

The separation of the energy levels depends on the size of the QD.

Energy levels in the WL are only confined in 1D.

In the surrounding semiconductor layer there will be a continuum of states with higher energy than the energy levels in the dot.
Populating the QD

- Optical excitation
- Electrical excitation (the Coulomb blockade)
Optical Excitation

- Above band pumping
  → Can address an assembly of QDs.

- P-shell pumping
  → Ideal when having an assembly of QDs.

[4]
Spontaneous emission from a QD

Consider a QD, where only one exciton is created.

\[ I(t) = A_f \exp(-\gamma_f t) + A_s \exp(-\gamma_s t) \]
Measurement

Setup

Result

PBS1
HWP1
MIRA 900
Verdi
PBS2
HWP2
Polarizer
ND filter
Microscope
Low angle
Cryostat
Translation stages
Sample
Microscope objective
Fiber coupler

Counts
0 2 4 6 8 10 12 14

Norm. Residual [counts/s]
0 5 10 15 20 25
0 2 4 6 8 10 12 14
Electrical Excitation

Discrete charging energy $\frac{e}{C^2}$

[5], [1]
The QD as a Single Photon Emitter
QD as a Source of Entangled Photons

\[ |\psi^+\rangle = (|RL\rangle + |LR\rangle)/\sqrt{2} \]

Electroluminescence intensity (a.u.)

Energy (eV)

[7]
The Biexciton

\[ |\Psi\rangle = \frac{1}{\sqrt{2}} (|HH\rangle + |VV\rangle) \]
Density Matrix of the Bell State

Fidelity

$$F = \langle \Psi | \rho | \Psi \rangle = 0.702 \pm 0.022$$

[8]
Summary

- 0D confinement leads to quantized energy levels in 3D
- Self-assembly requires a mismatch of lattice constants and bandgap of the involved semiconductors.
- Optical excitation
- Double exponential decay for spontaneous emission due to the presence of a dark state of the exciton
- Electrical excitation uses the Coulomb blockade.
- Source of entangled photon pair. Creates photon pairs that are polarised entangled.
References

[1]: Reimann, Stephanie M. et al.: Electronic structure of quantum dots, Reviews of Modern Physics, Volume 74, October 2002
[2]:
[3]: Julsgaard, B. et al. : Decay dynamics of quantum dots influenced by the local density of optical states of 2-dimensional photonic crystal membranes, 2008,
http://arxiv.org/abs/0802.2947v1
[5]: http://www.sp.phy.cam.ac.uk/SPWeb/research/CB.html