Photonic Crystal Cavities (coupled with InAs Quantum Dots)

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Introduction

• Quantum Dots

• Photonic Crystal Cavities

• Current Research

• Future Research
What are Quantum Dots?

• Semi-conductor devices
• Artificial atom’s
• Resonance pumping results in s-shell population
• Quasi-resonant (off resonant) results in p-shell population

Quantum Memory Candidate
1us lifetime
What are Quantum Dots?

- InP/InAs/GaAs dots emit 1μm-1.55μm photons (telecom wavelength)
- We use AlInAs/InP dots grown through Molecular Beam Epitaxy
Why do we need photonic crystal cavities?

• Quantum Dots
  • Incredibly useful for quantum experiments but,
  • Spontaneous emission (SE) from QD can occur in any direction
  • Emission efficiency is low

• Introducing a cavity enhances the spontaneous emission of the QD through the Purcell effect.

\[ F_p \propto \frac{Q}{V} \]

Q: Quality Factor, V: mode volume of cavity
Photonic Crystal with 2D periodic structure

High index of refraction (n = ~3)

Low index of refraction (n=~1, air)
• Measuring photons in the vertical direction while changing the lattice spacing (a)
• When emission spectrum overlaps with PBG:
  • Vertical efficiency increases
  • SE can only occur vertically
  • Time of SE increases
A cavity can be created by removing three holes in the lattice, and shifting the holes on either side.

This combination of removing/shifting has resulted in a Q’s of 4000-45,000 while attempting to minimize V (to maximize Purcell effect).

Introducing this defect creates a cavity for wavelengths that fall within the PBG defined by the periodicity.
- L3 Defect cavity
- $a = 370\text{nm}$
- Hole radius = 0.27$a$
- Slab thickness = 280 nm

- Q-factor
- M1: 7000
- M2: 4300
- M3: 380
- M4: 2000
- M5: 1000
Quantum dot needs to be cooled to 4K in a cryostat.

The distance between the PC and lens at the entry of the cryostat can cause photons to spread.

M1 mode has the highest Q-factor, but a far field measurement of the electric field ($E_y$ and $E_x$) shows that most of the light would not couple with the lens.
Current Research: Investigation of Biexcitons

Applying a magnetic field can reduce Fine Structure Splitting (FSS)

\[ |\phi^+\rangle = \frac{1}{\sqrt{2}} (|R\rangle_{XX}|L\rangle_x + |L\rangle_{XX}|R\rangle_x) \]

\[ = \frac{1}{\sqrt{2}} (|H\rangle_{XX}|H\rangle_x + |V\rangle_{XX}|V\rangle_x) . \]
How to find Biexcitons?

![Graph showing PL intensity vs. energy with peaks at X and XX, and another graph showing integrated intensity vs. excitation power with linear and quadratic trends for X and XX.](image-url)
$X^2$ response
Future Work

Energy

GaAS (Conduction Band)

Wetting Layer

p-shell

s-shell

Resonance

s-shell

p-shell

Wetting Layer

GaAS (Valence Band)
Continuing Research

• On resonance pumping scheme
• Photoluminescence excitation (PLE) measurements
  • Vary the pump wavelength and take spectrum measurements
  • Graph Pump wavelength vs. spectrum to determine s-shell (resonance) or p-shell (quasi-resonant) behavior
• Find additional QD’s that are better candidates for find biexcitons
  • This is limited due to the constraint of photons that are telecom wavelength
Questions??