Optical Techniques Group - Department of Science and Technology - University of Twente

Towards quantum dot luminescence enhancement

An investigation of radiative properties of single quantum emitters near a nanometer sized metal object

Bastiaan van Gils – May, 13th 2004

Commission:

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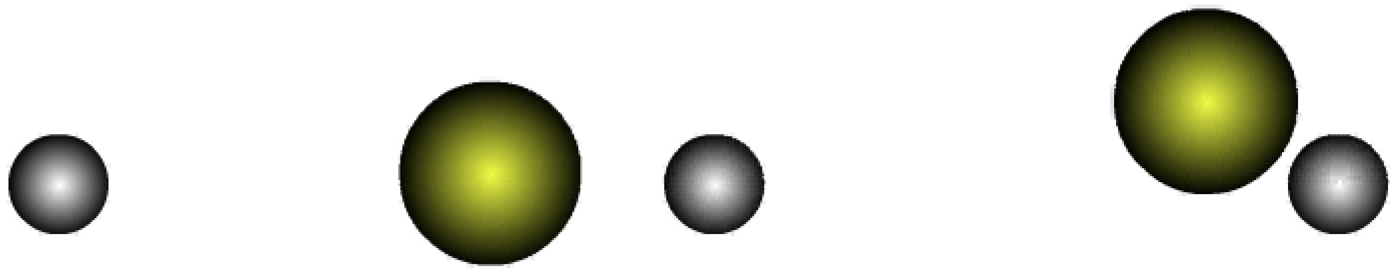
Presentation outline

- Project goal
- Theory
- Experiment
- Results
- Conclusions
- Recommendations

Project goal

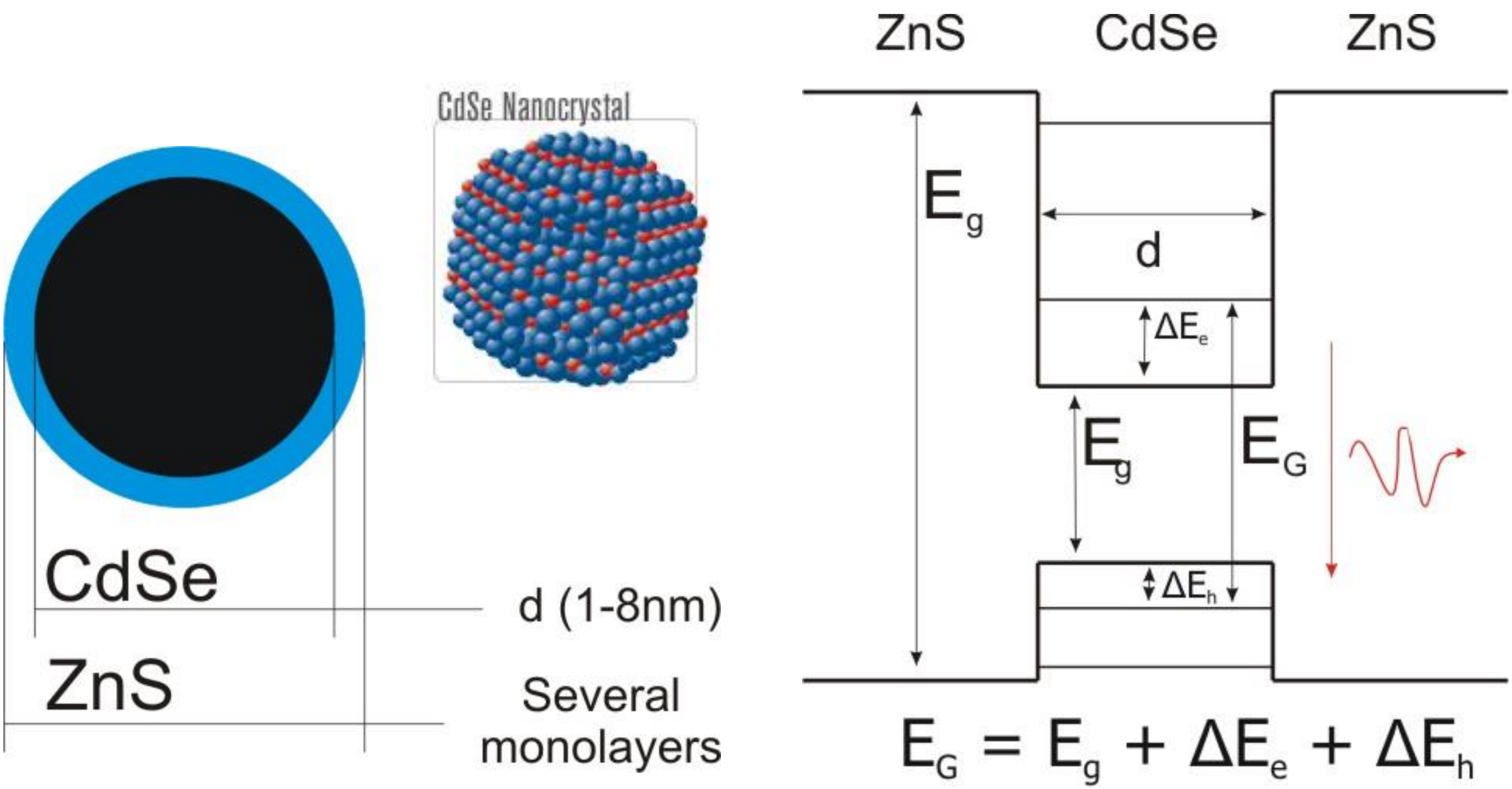
- Study the distance dependent radiative properties of single quantum emitters in close proximity to a metal nanometer sized object



More light from same emitter

Quantum dots – solid state physics

Effective bandgap is dependent on material and size



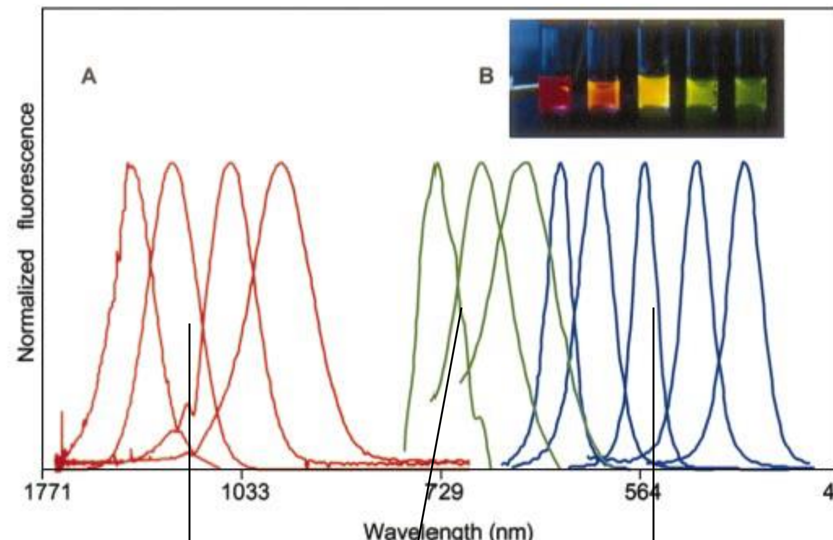
Quantum dots – luminescence

-Quantum confiment observable by luminescence

-Broad absorbtion spectrum

-Narrow emission spectrum

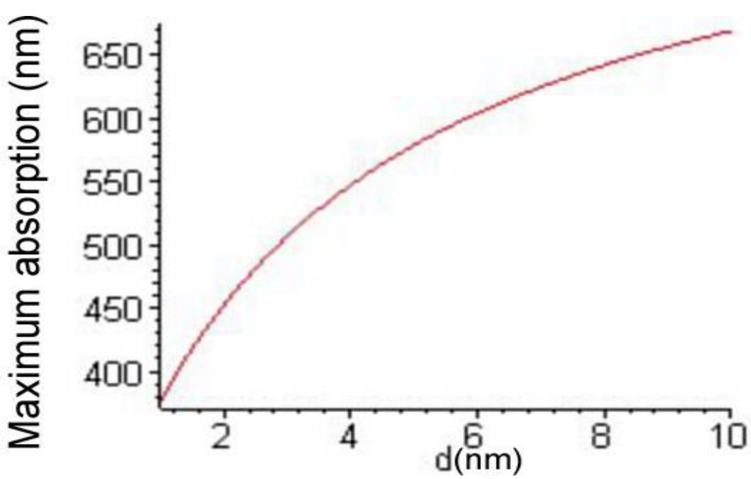
-Emission spectrum tunable by size



InAs
2.8-3.6-4.6-6.0nm

CdSe
2.1-2.4-3.1-3.6-4.6nm

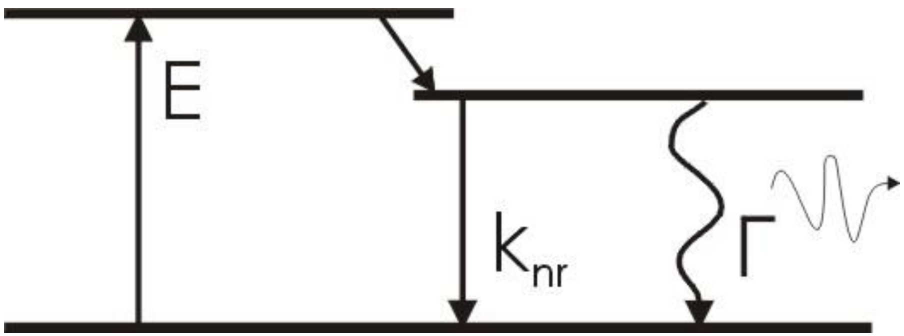
InP
3.0-3.5-4.6nm



Radiative properties - parameters

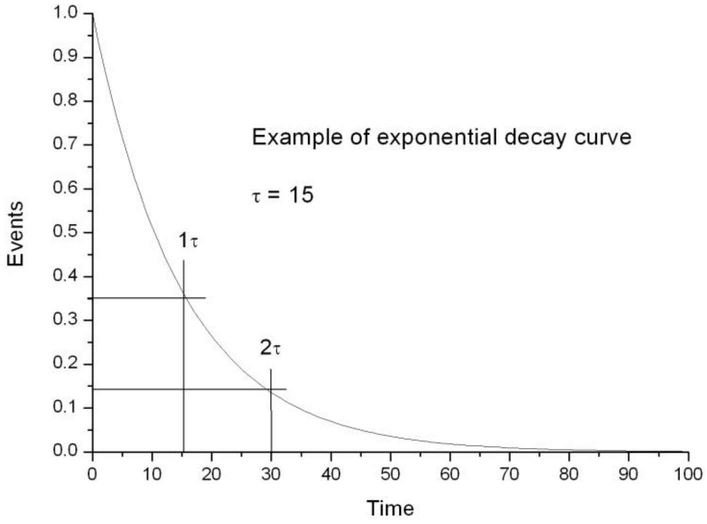
Lifetime

$$\tau_0 = \frac{1}{\Gamma + k_{nr}}$$



Quantum yield

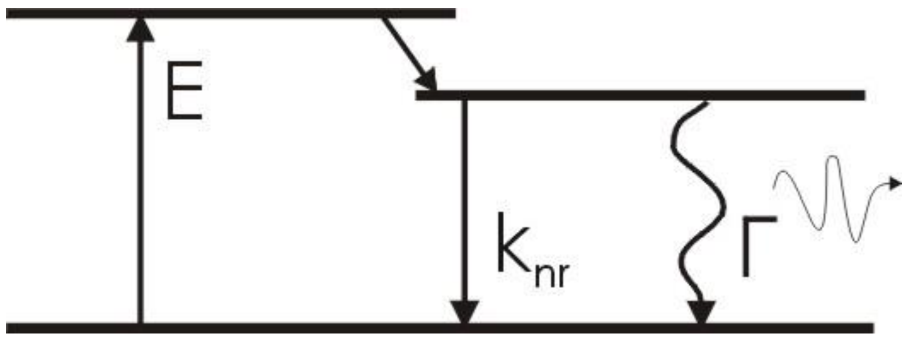
$$Q_0 = \frac{\Gamma}{\Gamma + k_{nr}}$$



Radiative properties - manipulation

Local field effects

-Effect: higher excitation intensity E



Quenching

-Effect: increased k_{nr}: shorter τ, lower Q.

-Dominating from 0 -10 nm

Radiative decay enhancement

-Effect: increased rate Γ: shorter τ, higher Q

-Dominating from 10 – 50nm

$$\tau_0 = \frac{1}{\Gamma + k_{nr}}$$

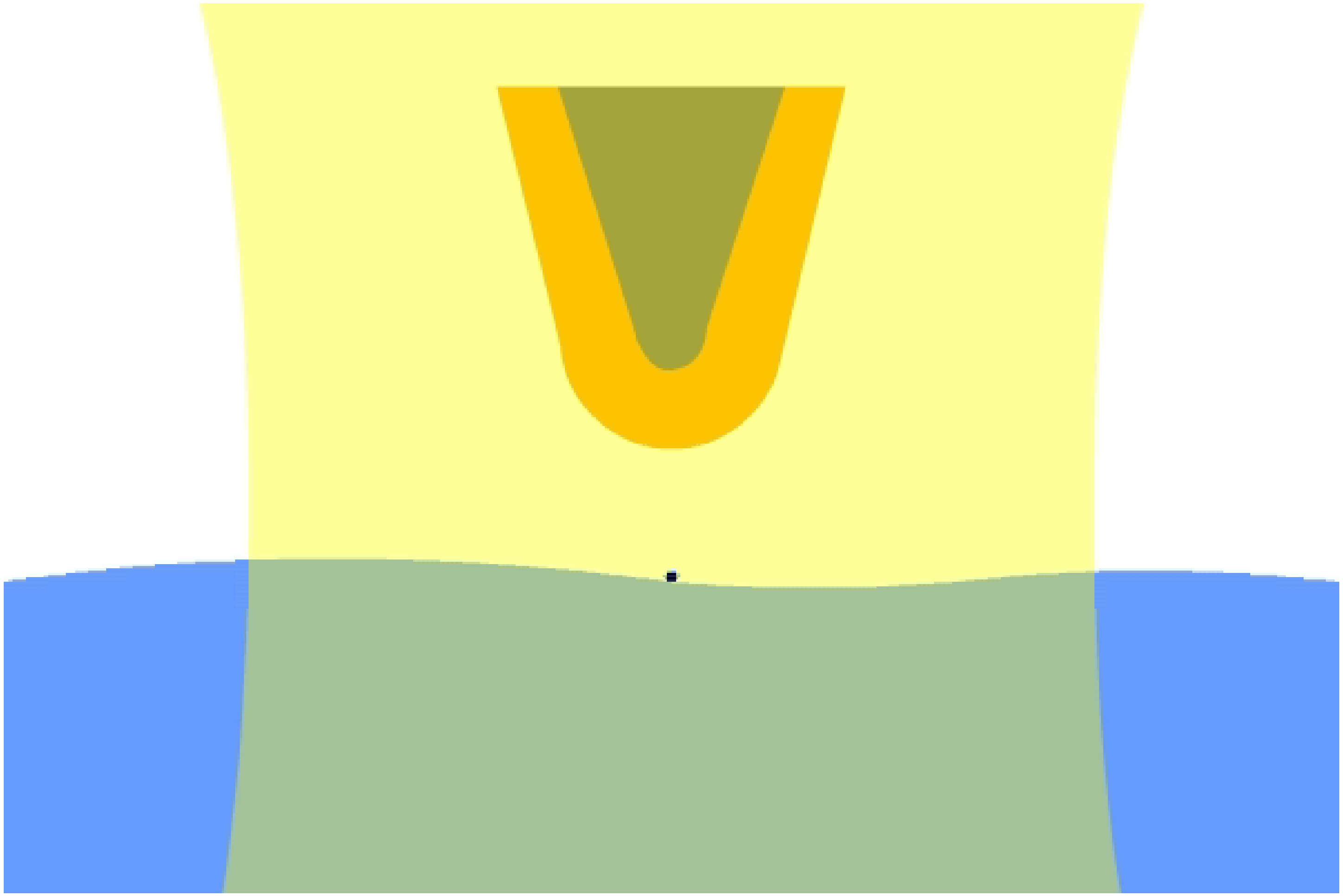
Photonic mode coupling

-Effect: coupling to environment, oscillating radiative rate Γ: oscillating τ and Q

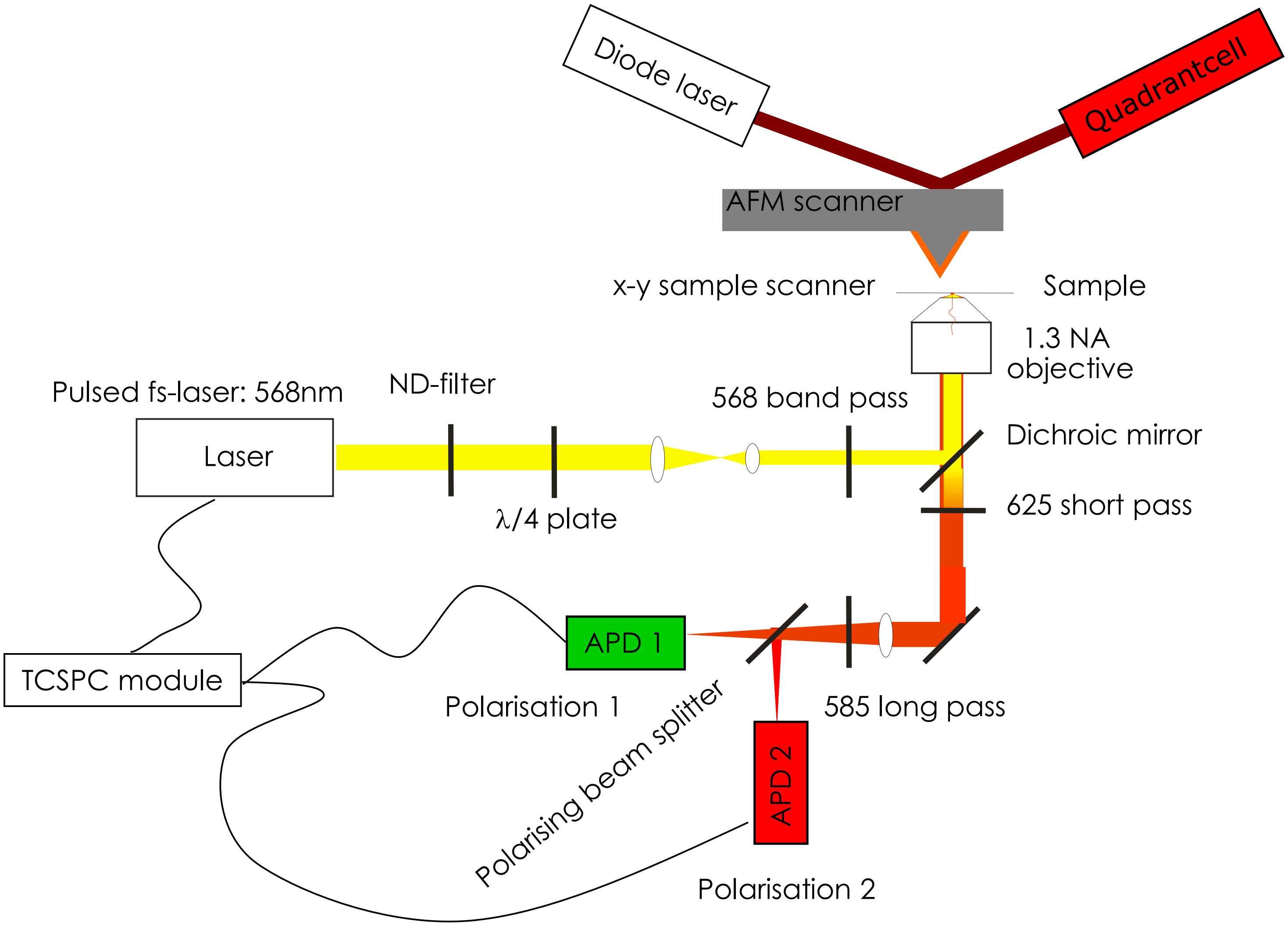
-Dominating from 50 – 1000nm

$$Q_0 = \frac{\Gamma}{\Gamma + k_{nr}}$$

Measurement method

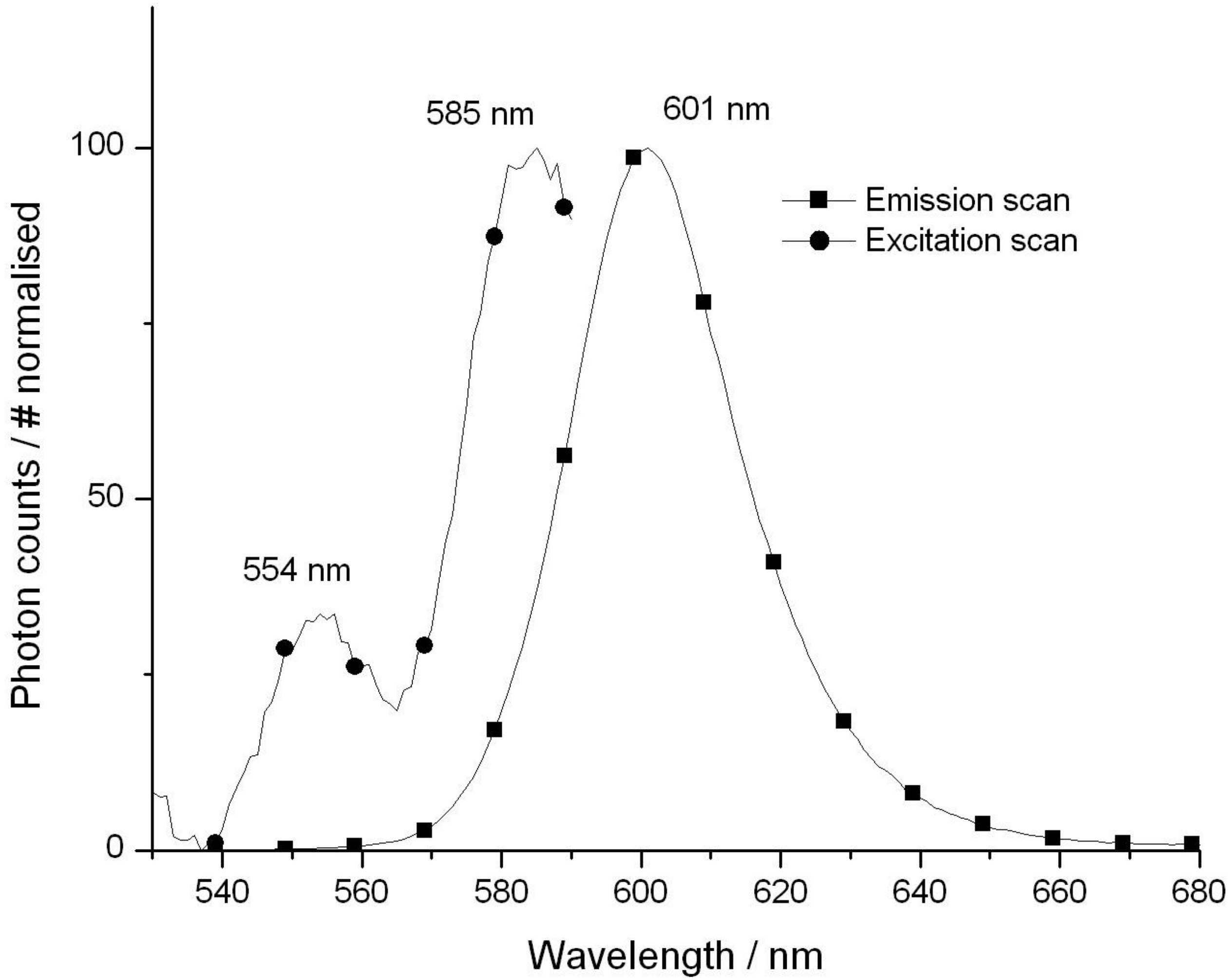


Measurement set-up

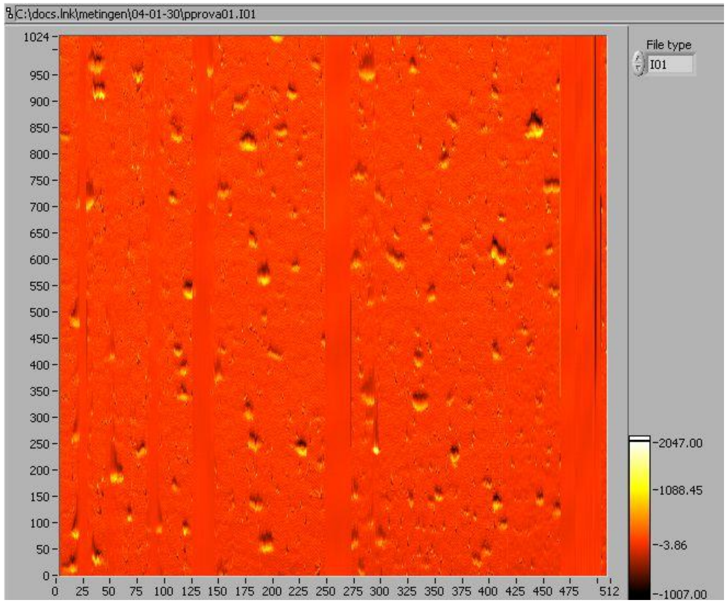


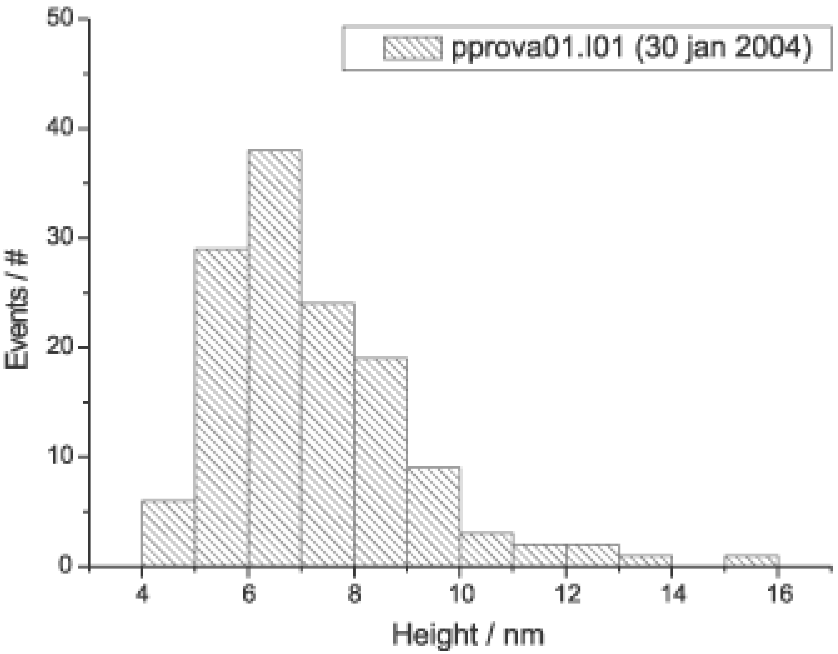
Bulk spectrum

Assigned size
5.4nm



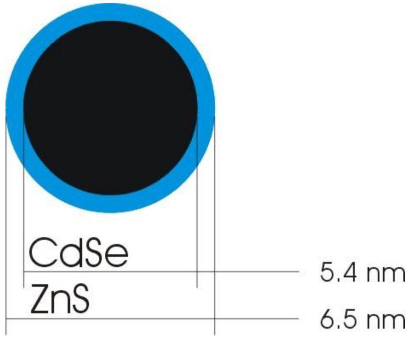
AFM size measurements





Assigned size: 6~7nm

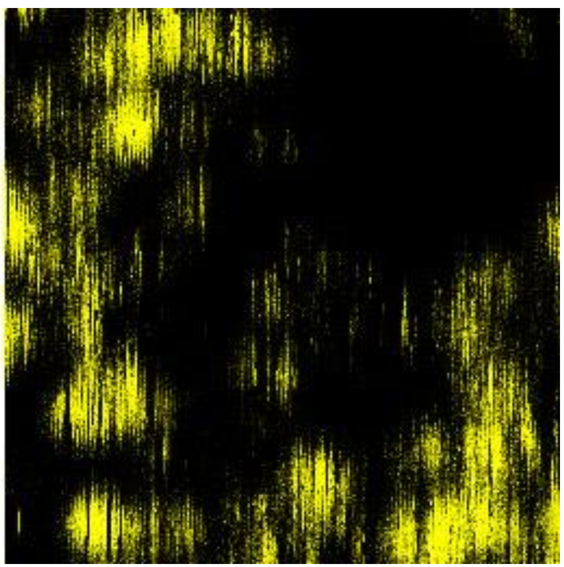
Explained by ZnS shell,
not accounted for in theory



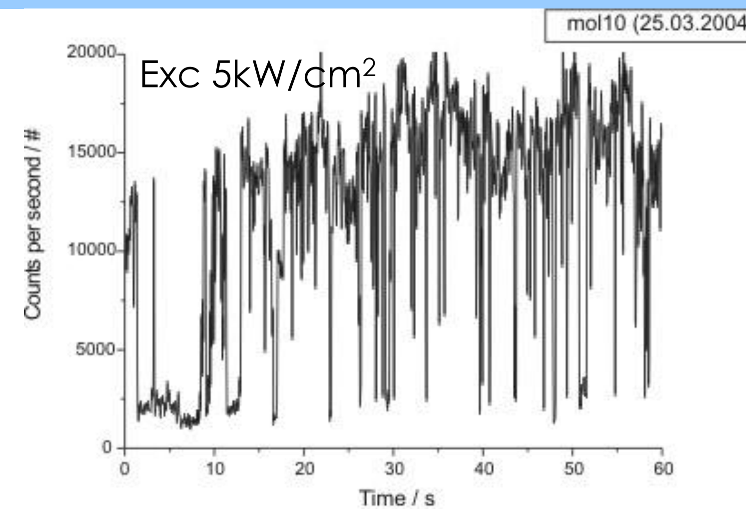
Confocal imaging – Blinking behaviour

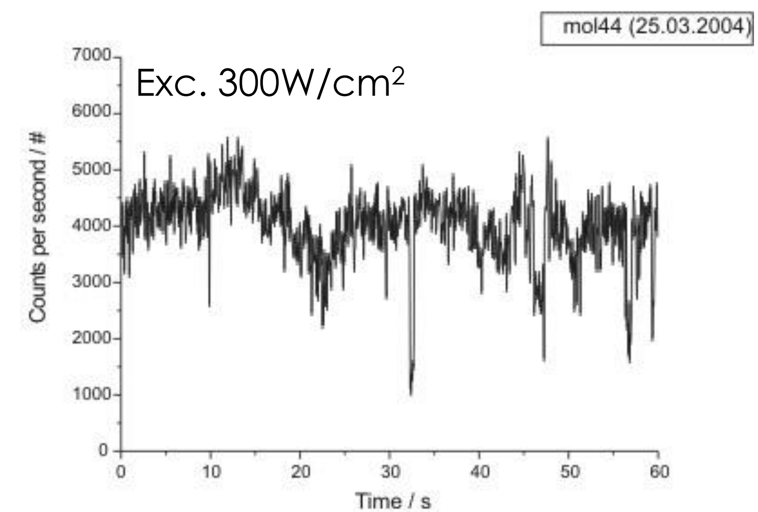
-On-off behaviour: single emitters

-Blinking behaviour pronounced for high excitation powers



Exc 5kW/cm², 1ms int. time
Scan 5x5um, 256x256px

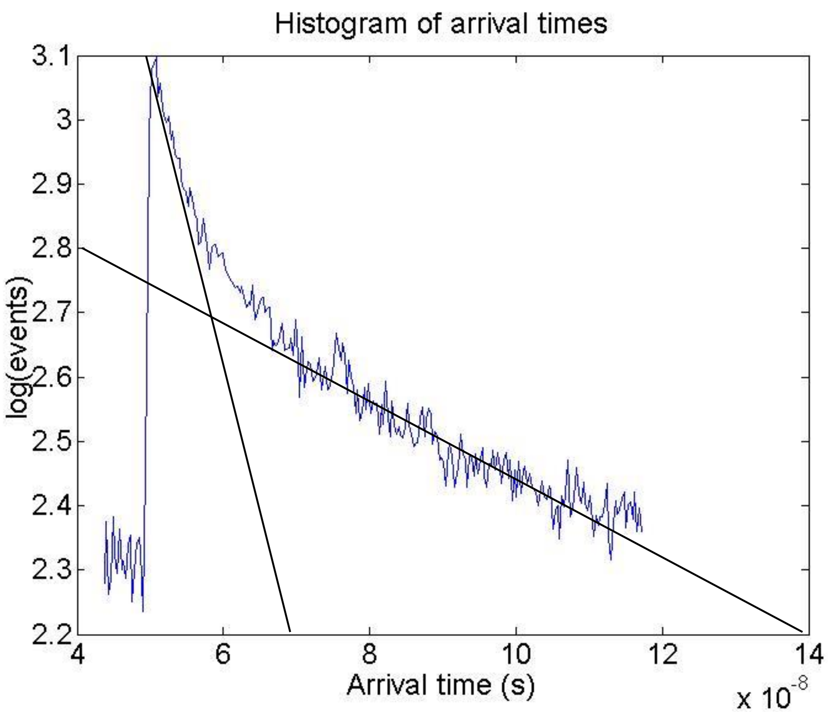


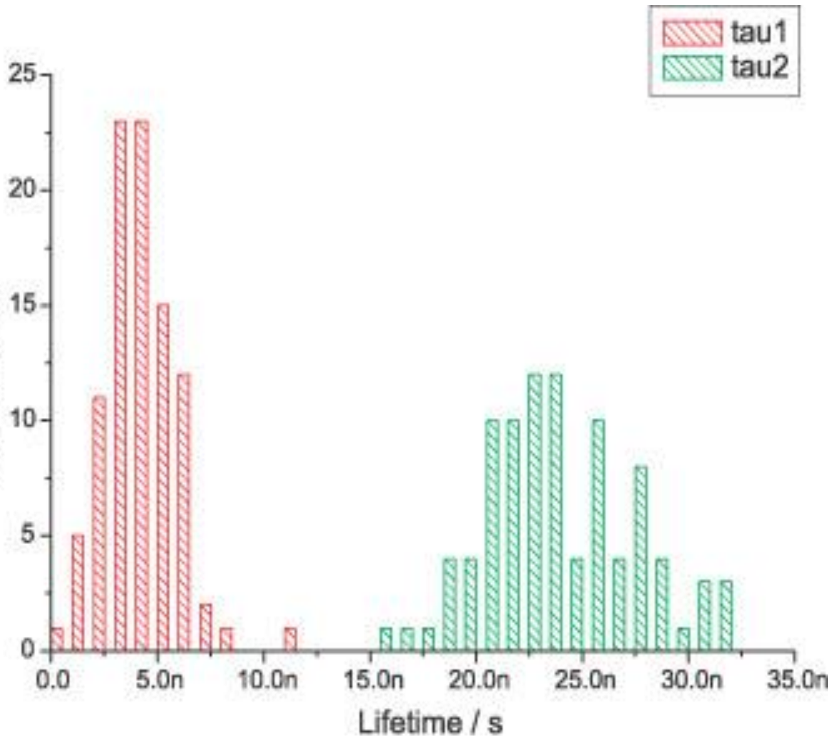


Confocal imaging – lifetime

-Lifetime histograms consist of fast (~5ns) and slow component (~20ns)

-Lifetimes are hardly influenced by excitation power



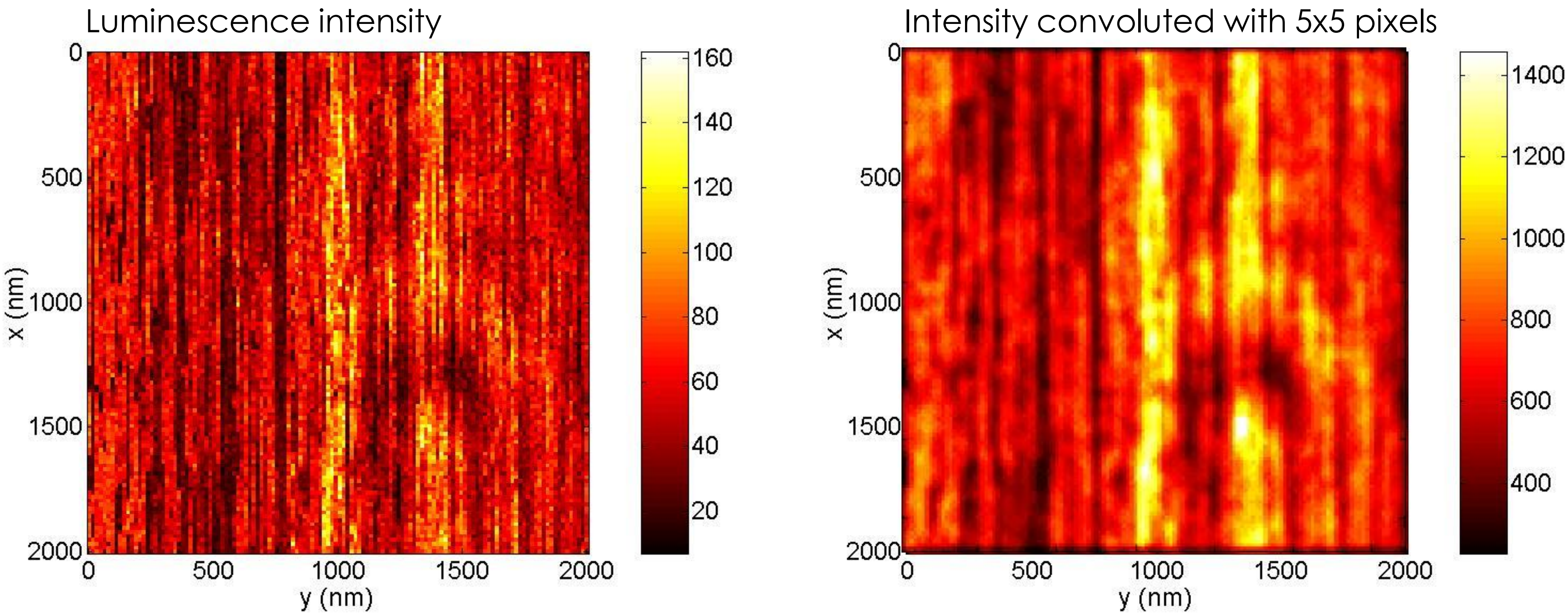


Gold coated tip – QD (1)

Radiative decay

-Tip creates a circular pattern in luminescence intensity

-Emitter is QD: blinking, lifetime according to previous measurements



Gold coated tip – QD (2)

Radiative decay

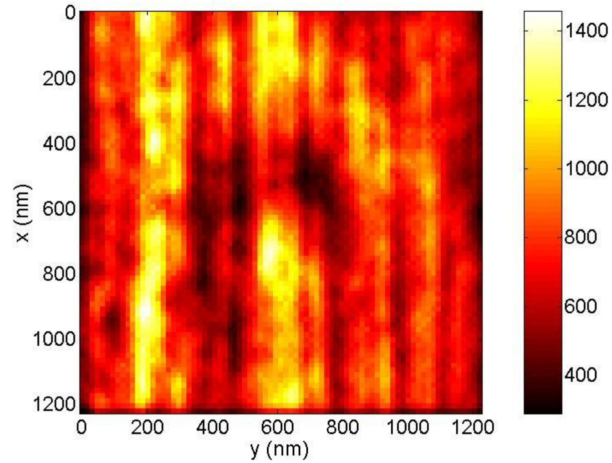
-Correlation between intensity and lifetime in radial integral

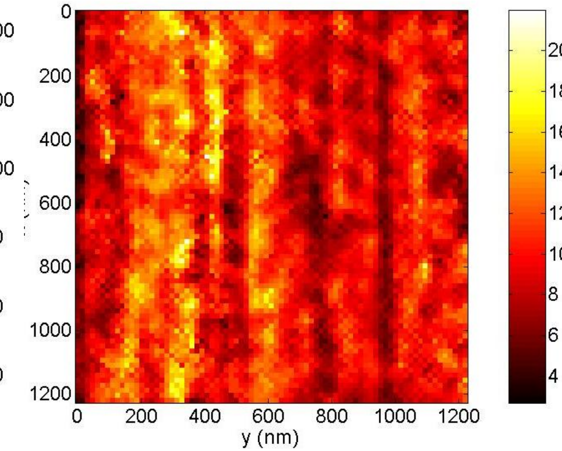
-Long range oscillation can be assigned to photonic mode coupling

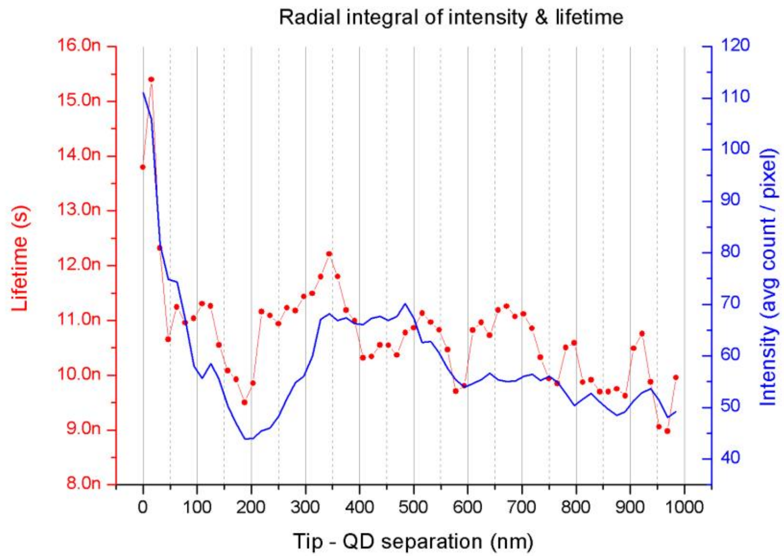
-Short range lifetime intensity suggests enhanced radiative rate

-Short range lifetime decrease supports suggestion

-Possible contribution by excitation interference







Conclusion

Quantum dots

-Quantum dot properties are in agreement with literature

Manipulation of radiative properties

-Clear influence on radiative properties by tip

-Long-range oscillations can be assigned to oscillating coupling to photonic modes

-Short range intensity enhancement and lifetime reduction suggests radiative rate enhancement

Recommendations

Improvements

-Use higher quality quantum dots

-Better suited filter set

-Improve manual alignment of AFM

-Ability to perform time-gated experiments

-Additional measurements

-Reduce tapping amplitude of AFM if possible

-Increase integration time per pixel

-Measurements at specific points

-Increase spatial resolution

QUESTIONS?

Borrel

Kleintje Vestingbar