Experimental test of the robustness of the non-classicality of single photons

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INVESTMENTS IN EDUCATION DEVELOPMENT

Motivation

- quantum dots are sources of single photons [1]
- they could be used as sources for:
  - quantum cryptography
  - long distance quantum communication
- we are interested in the behaviour of single photons in a noisy and lossy channel

Experimental Setup

Sample:

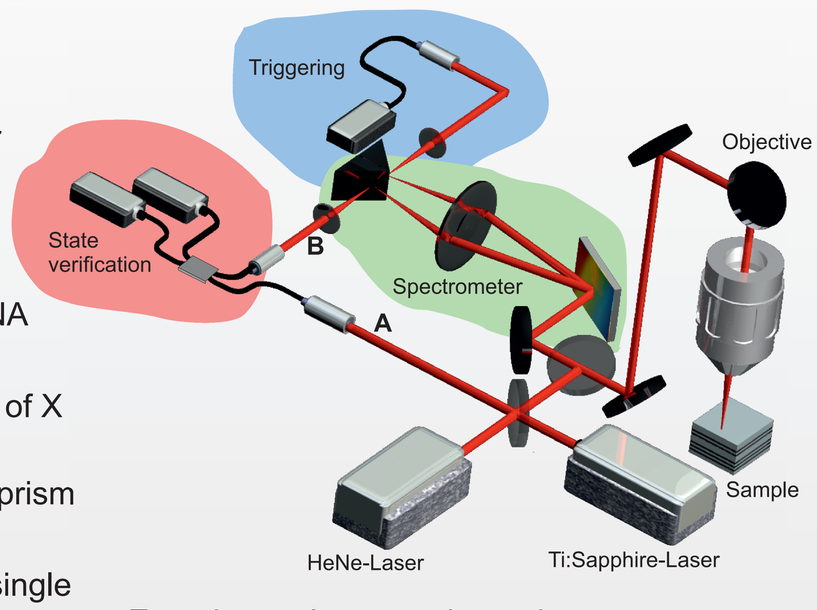
- InAs quantum dots as solid state single photon emitter

Excitation:

- HeNe laser in co-linear configuration

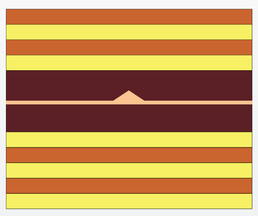
Collection:

- from top using a high NA objective
- wavelength separation of X and XX photons
  - ⇒ using a grating and prism mirrors
- coupling photons into single mode fibers
- photon attenuation at point B
- possibility to mix noise at point A



Experimental setup schematics

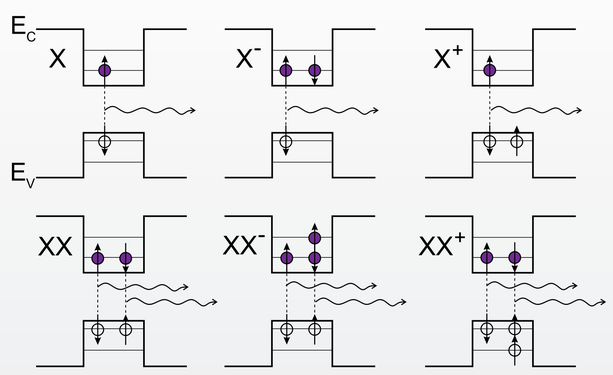
Sample design



Schematics of the sample

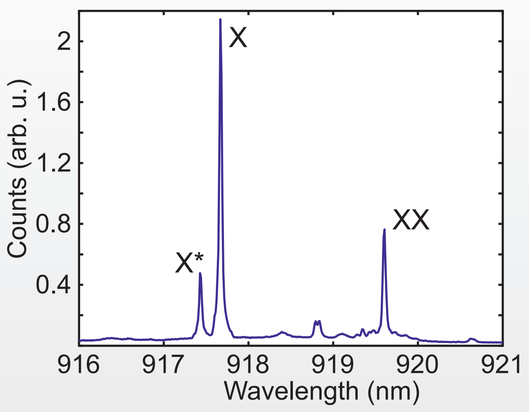
- self-assembled InAs quantum dots
- low quantum dot density (~ 10 μm^{-2})
- embedded in a 4λ cavity
- cavity consists of 15.5 lower and 10 upper DBR mirrors

Electronic Structure

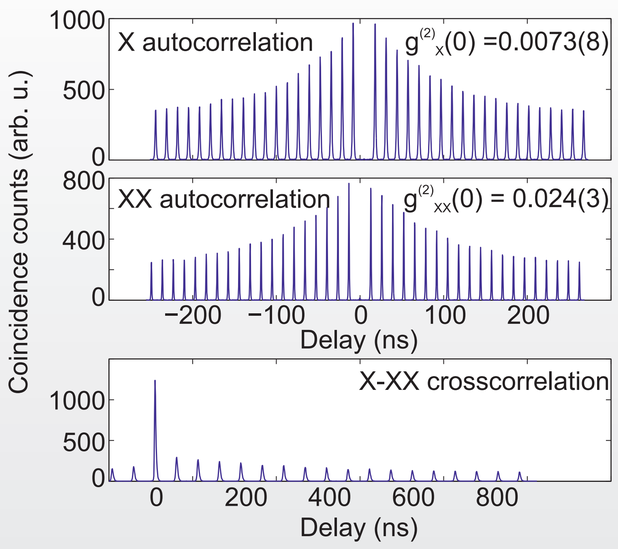


X ... exciton
XX ... biexciton
$X^{-(+)}$ ... charged exciton or trion
$XX^{-(+)}$ ... charged biexciton

Spectrum



Photon statistic measurements [2]

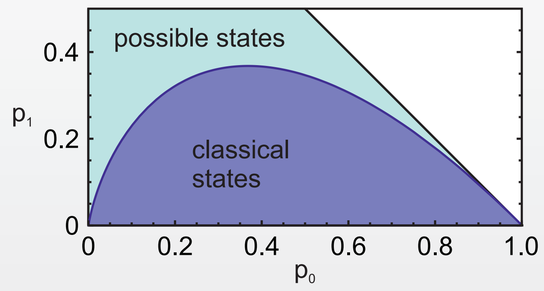


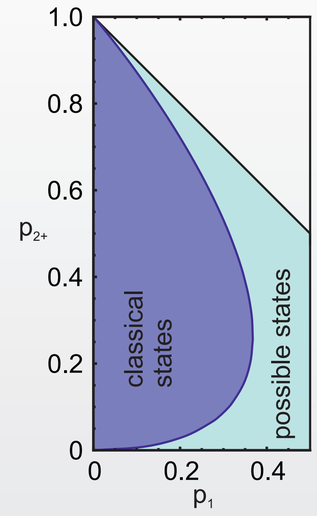
Theory [3]

Definition nonclassical:

- states that cannot be expressed as mixture of coherent states $|\alpha\rangle$

$p_0 = e^{-\bar{n}}$
$p_1 = \bar{n}e^{-\bar{n}}$
$p_{2+} = 1 - (p_0 + p_1)$



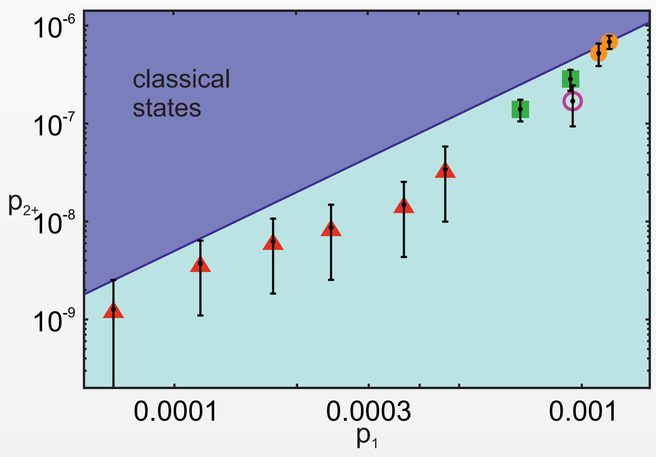


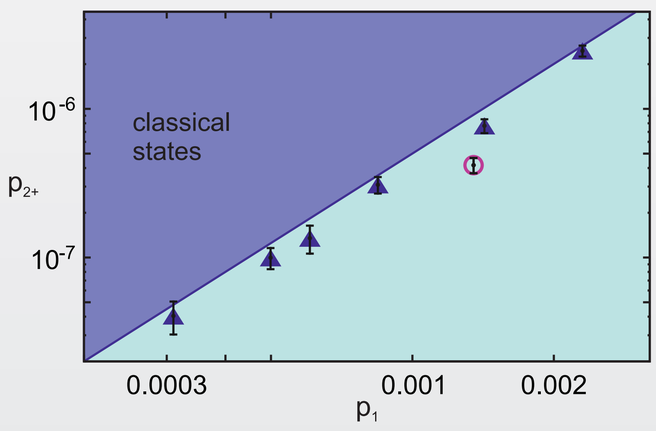
$\bar{n}$ ... mean photon number
p_0 ... vacuum probability
p_1 ... probability for one photon
p_{2+} ... probability for two or more photons

Measurements

Different measurements:

- Reference points (no artificial noise, no attenuation) (○)
- Lossy transmission channel:
  - above-band excitation with various levels of attenuation (▲)
- Noisy transmission channel:
  - mixing above-band excitation and resonant excitation without filtering the resonant excitation laser (■)
  - above-band excitation with mixing laser directly to the detected signal (●)
- Lossy and noisy transmission channel:
  - above-band excitation with mixing laser directly to the detected signal (50/50) with various levels of attenuation of the whole signal (▲)





Conclusions

- attenuated signal stays non-classical until reaching detector noise level
  - ⇒ moves parallel to the bound before
- noisy signal moves towards the bound
- noise only reaches exaclty the bound since the noise source is a laser
- noisy & attenuated signal moves parallel to the bound

References

[1] P. Michler, „Nonclassical light from single semiconductor quantum dots," Topics Appl. Phys., Springer-Verlag, 2003, **90**, 315-347

[2] A. Predojević, M. Ježek, T. Huber, H. Jayakumar, T. Kauten, G. S. Solomon, R. Filip, and G. Weihs, „A quantum non-Gaussian Fock state from a semiconductor quantum dot," arXiv:1211.2993

[3] M. Ježek, A. Tipsmark, R. Dong, J. Fiurášek, L. Mišta, Jr., R. Filip, and U. L. Andersen, „Experimental test of the strongly nonclassical character of a noisy squeezed single-photon state," Phys. Rev. A **86**, 043813 (2012)

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