Single photon sources for room temperature operation based on CdSe/ZnSSe/MgS quantum dots

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Outline

- Introduction and motivation
- CdSe/ZnSSe/MgS:
  Epitaxial quantum dots for room temperature applications
- Electrically driven single photon sources
- Summary

Operation temperature of single photon sources

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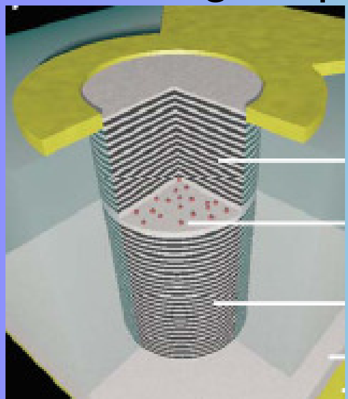
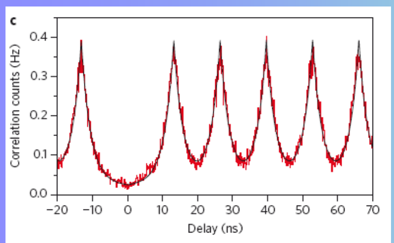
4 K - 100 K

Ga(In)As, Ga(Al,In)P QDs

- Sources of single and entangled photons

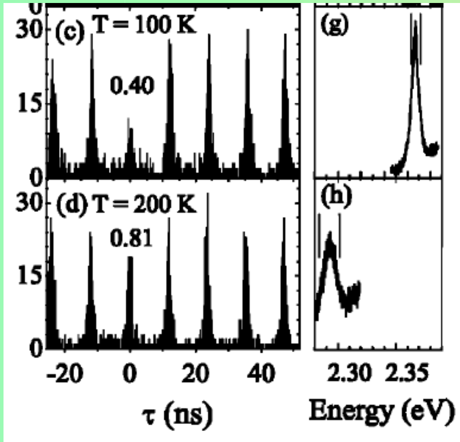


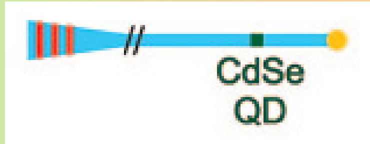


[Michler, Science 2000
Yuan, Science 2002
Faraon, Nat. Phys. 2008,
Rischle, Opt. Exp. 2008
Lochmann, El. Lett. 2009,
Claudon, Nat. Phot. 2010
Heindel, APL 2010,
Hafenbrak, NJP 2007
Dousse, Nature 466 (2010),
Salter, Nature 465 (2010)]

100 - 300 K

Ga(In)N, Zn(Cd)Se



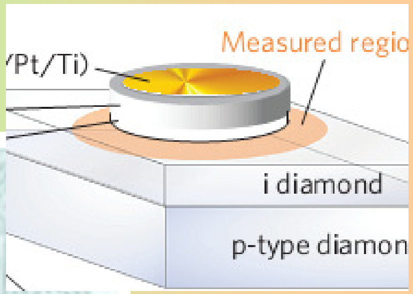


[Tribu, Nano Lett. 2008,
Nano Lett. 2012]

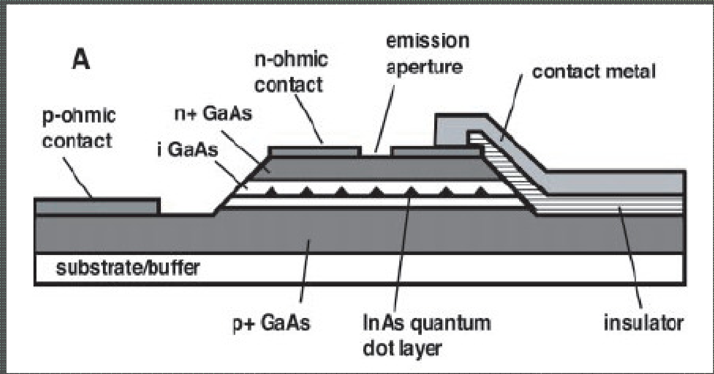
[Sebald, APL 2002,
Kako, Nature mat. 2006]

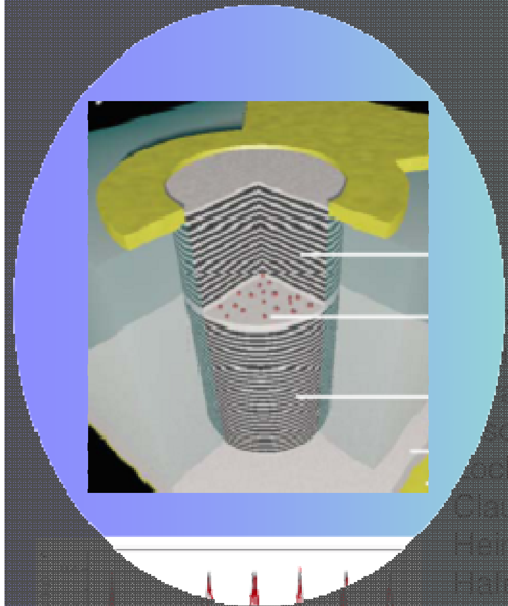
Single molecules, nanocrystals, color centers

[Lounis, Nature 2000
Michler, Nature 2000,
Pisanello, APL 2009,
Mizuochi, Nat. Phot. 2012]



Electrically driven single photon sources





4 K – 100 K

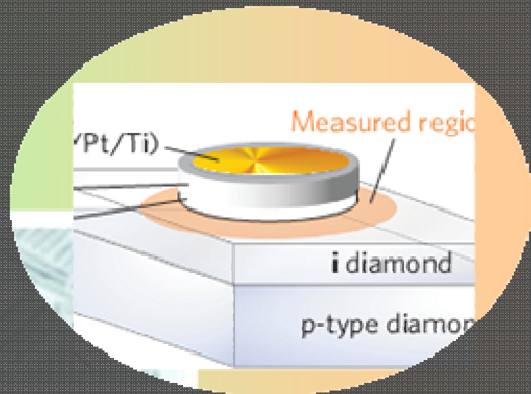
Ga(In)As, Ga(In,Al)P QDs

- Established devices

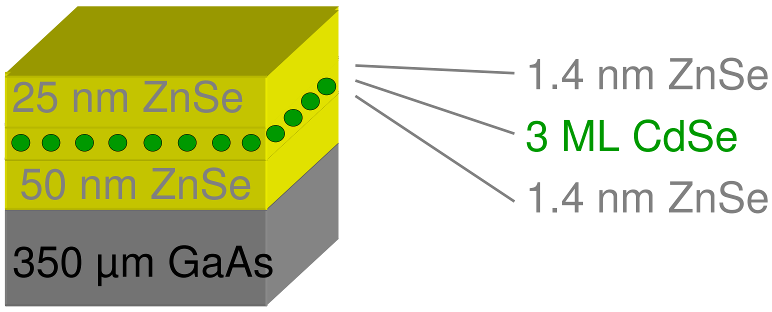
300 K

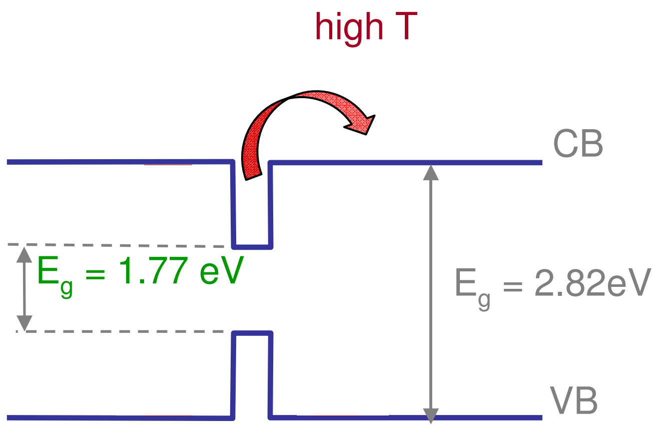
NV centers in diamond

- First approaches (40 V)

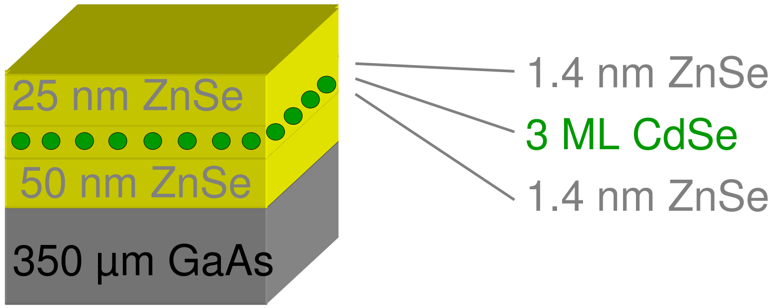


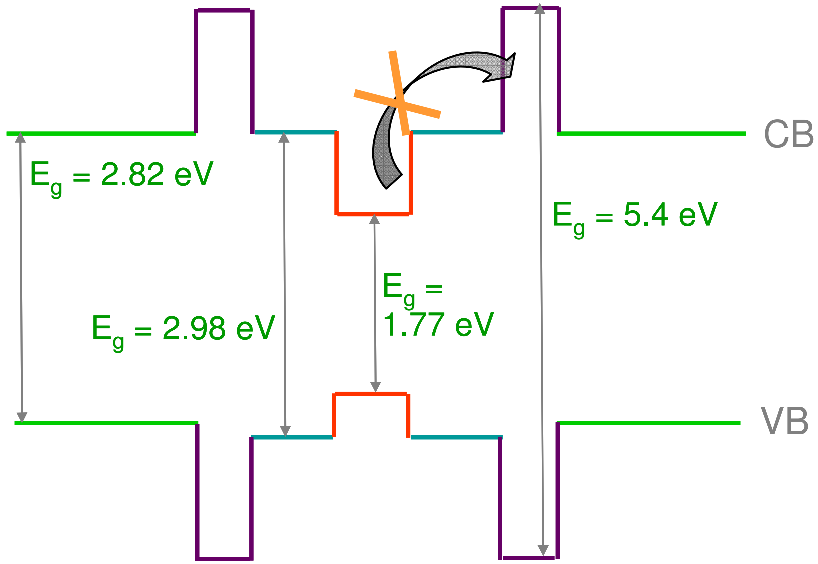
Carrier confinement in quantum dots

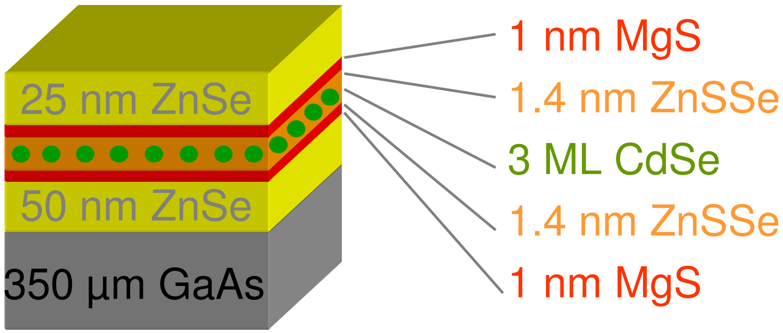




Carrier confinement in CdSe/ZnSSe/MgS QDs







- ZnSSe/MgS barrier structure
- E_g(ZnSSe) = 2.98 eV
- E_g(MgS) = 5.4 eV
  - *Enhanced carrier confinement*

Optimizing quantum dots for high T

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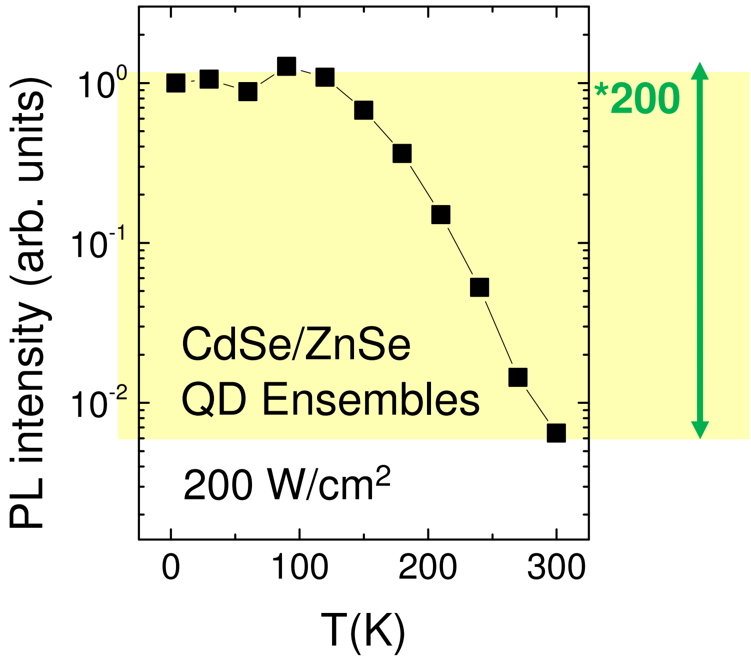
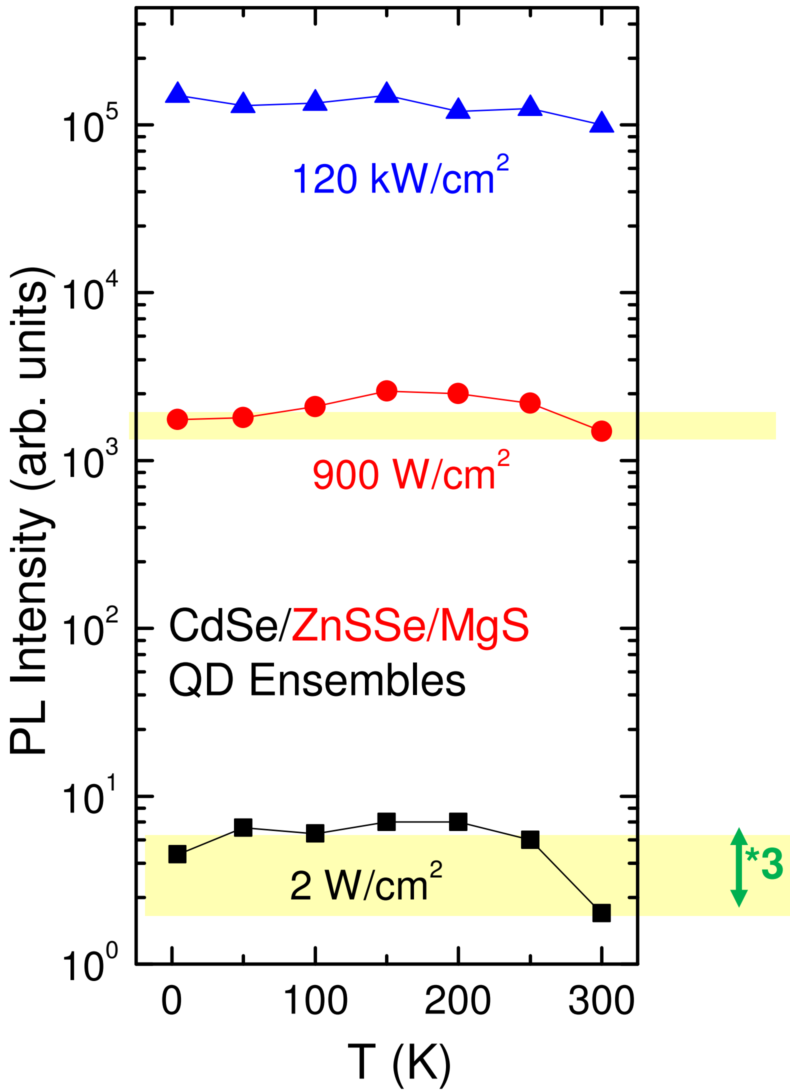
- Experiment: Photoluminescence spectroscopy of QD **ensembles**

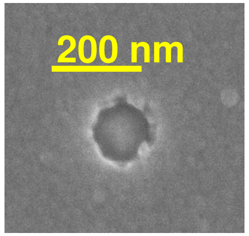


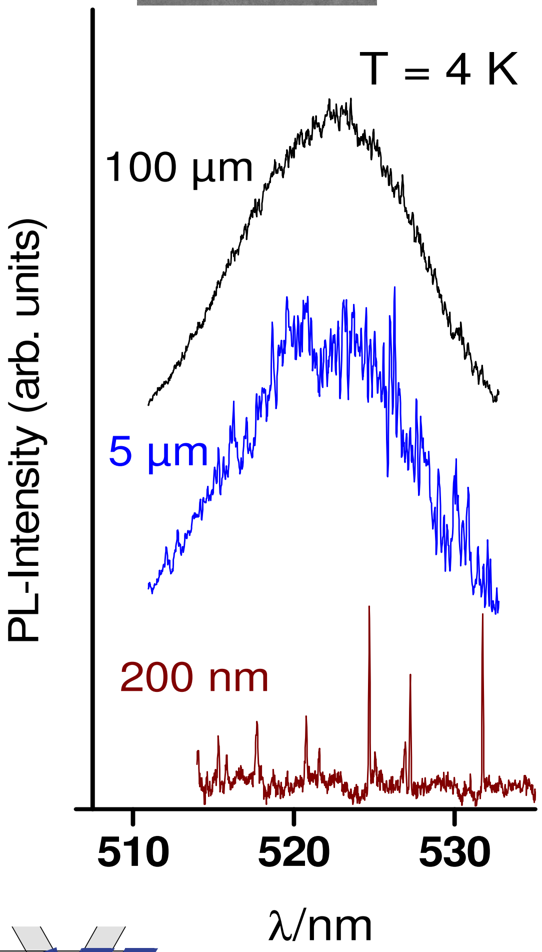


Adding **ZnSSe/MgS** barriers:

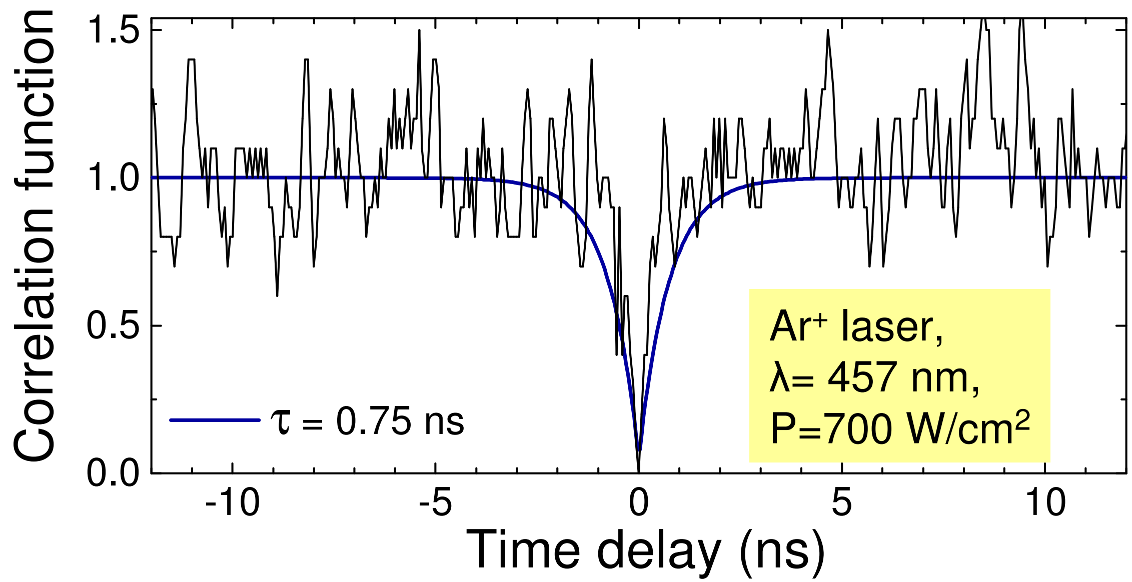
➢ *Drastically improved quantum efficiency at room temperature*

Single dot spectroscopy at 4 K



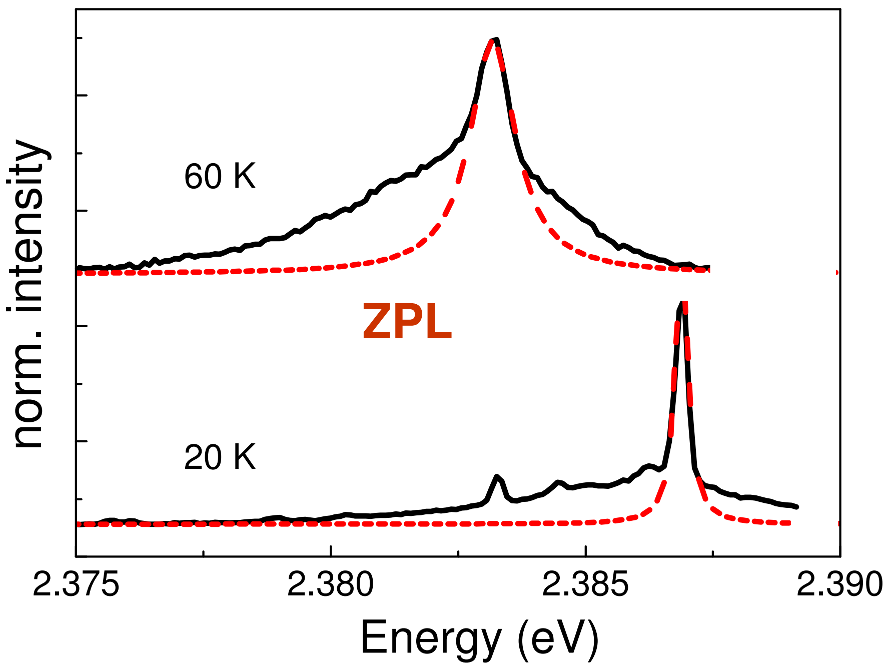


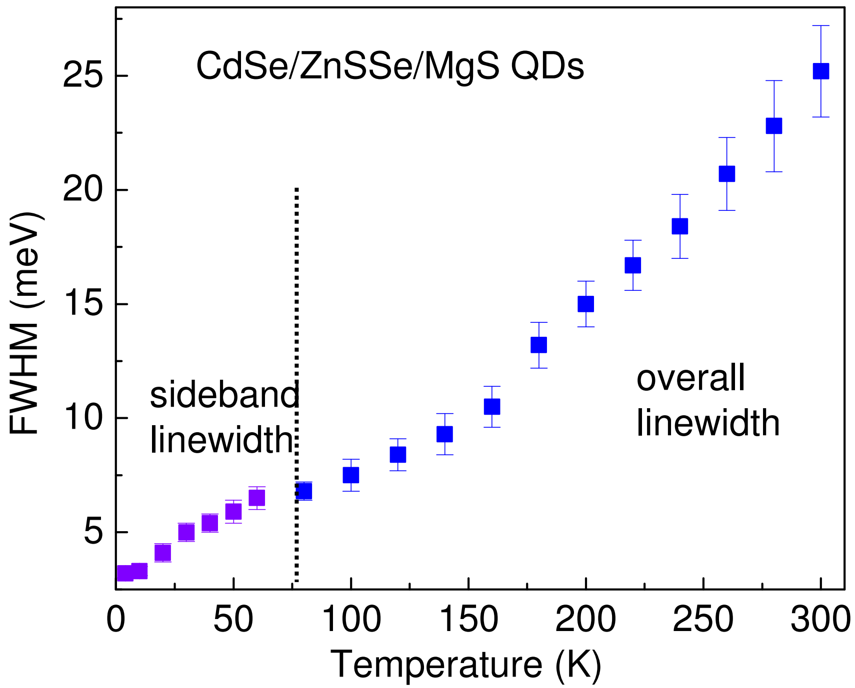
- Single dot spectroscopy: Nanoapertures in Al masks
- Photon correlation measurements using Hanbury-Brown-Twiss setup (100 ps time resolution)
- ➢ Single photon emission detectable



? Access to “high temperature“ regime ?

Linewidth enhancement due to phonons

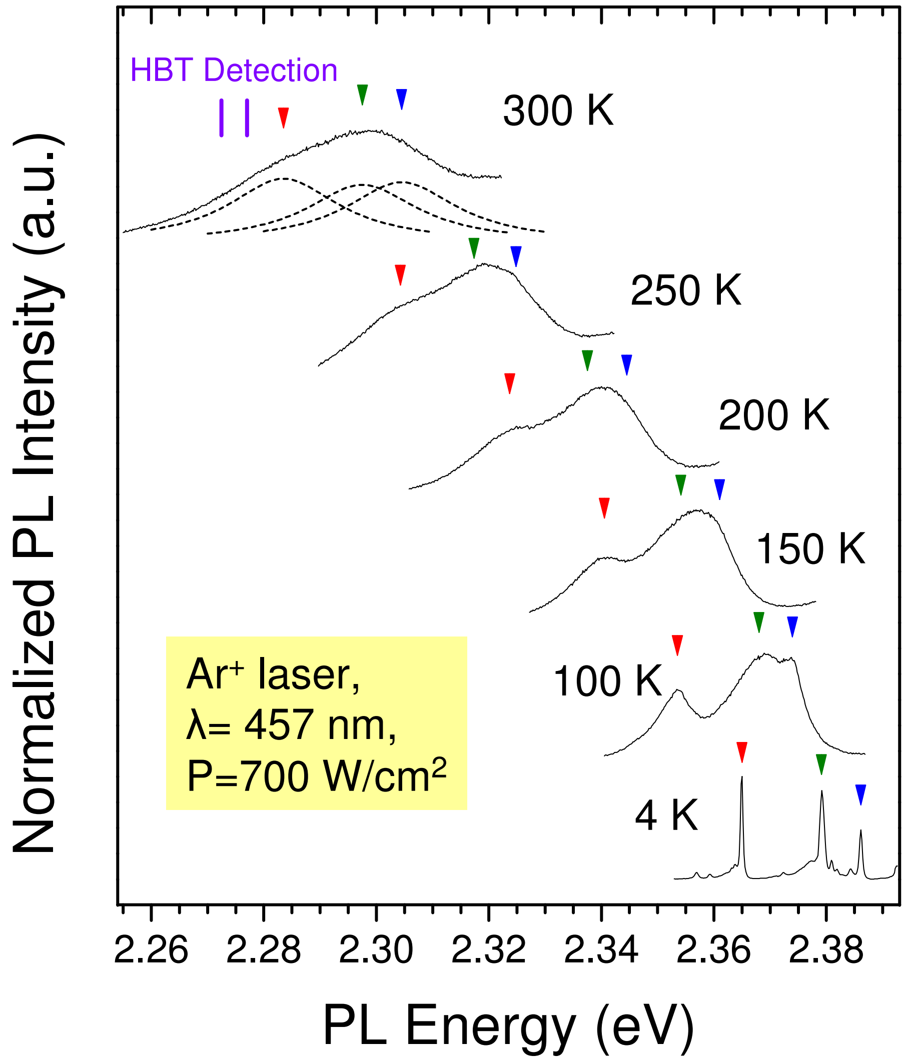




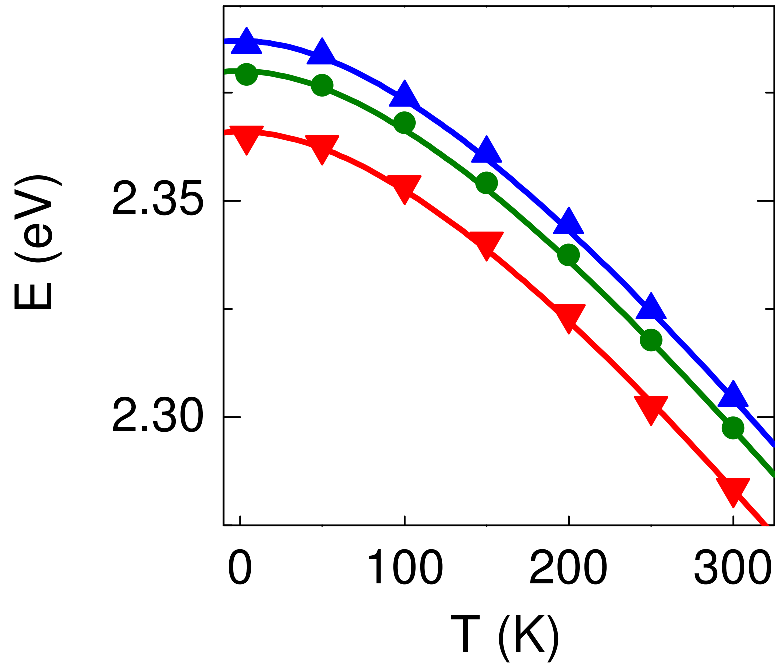
- Below 70 K: **Zero phonon line** and **acoustic sidebands** visible
- For higher T: Strong broadening [Besombes et al., PRB (2001), Arians et al., APL (2007)]

➢ *Spectral separation at high temperatures is challenging*

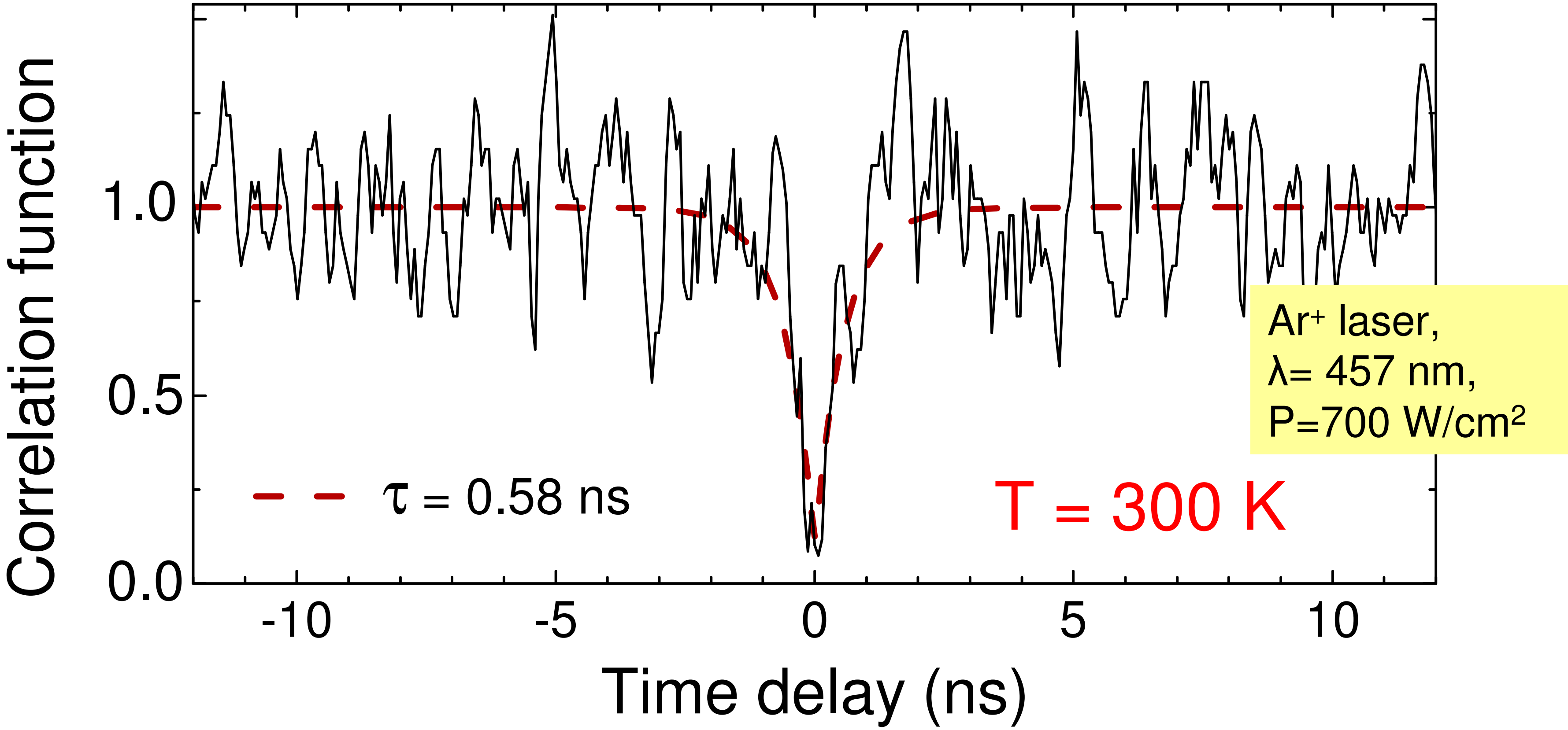
Spectral filtering of SQD emission



- **Optically** pumped QDs
- cw excitation below the ZnSSe band gap (for T = 4K…300 K)
- Identification of single quantum dot emission up to room temperature



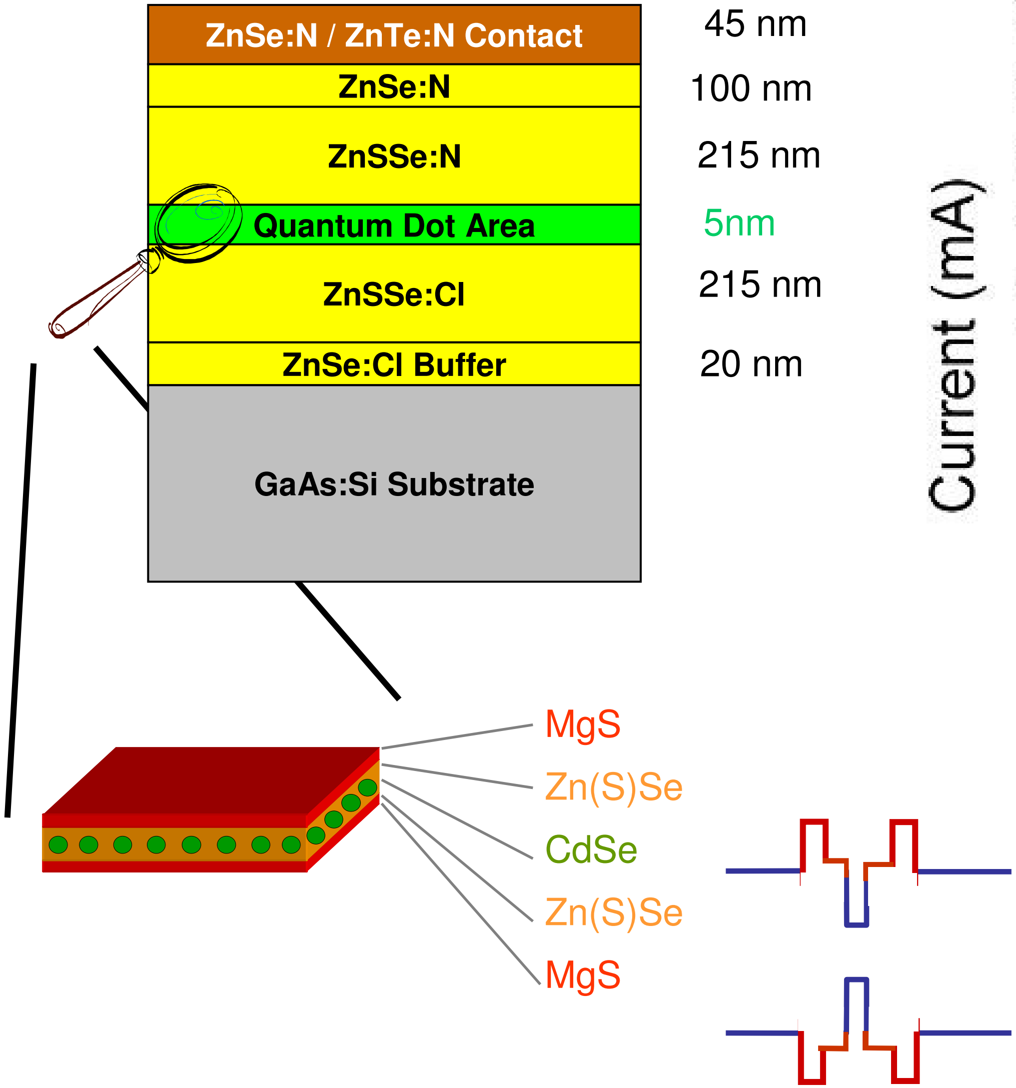
Room temperature single photon emission

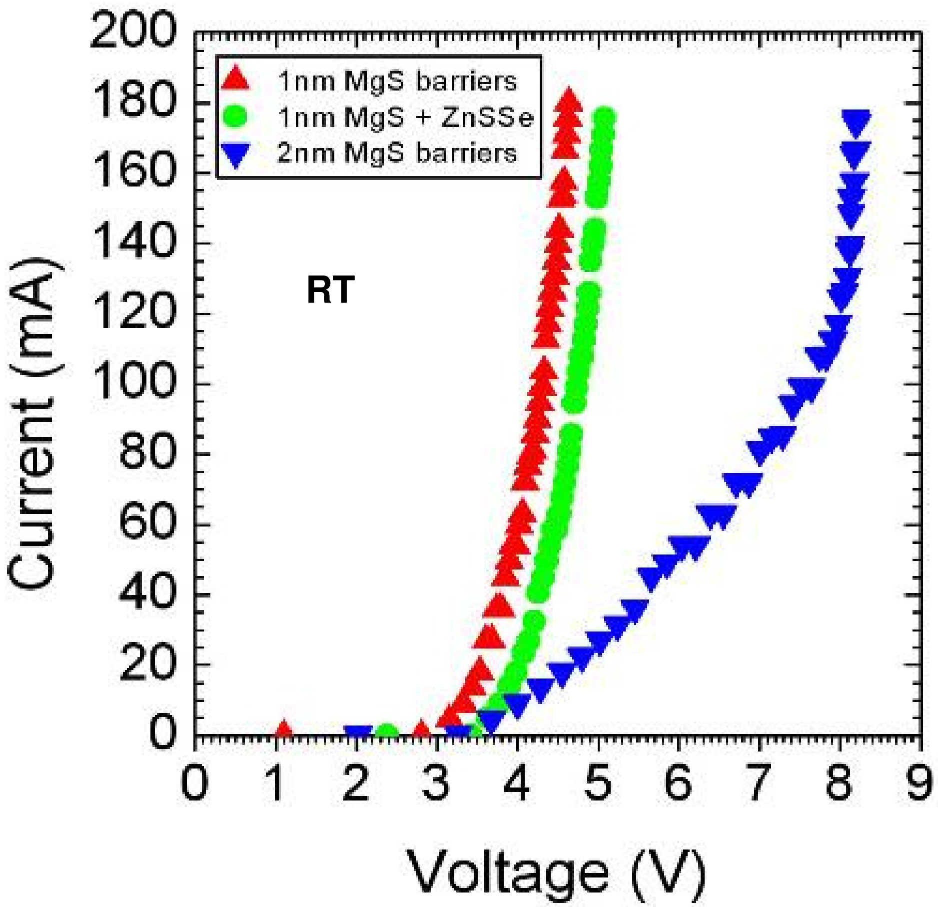


- **Optical excitation:** Single photon emission at room temperature
- $g^{(2)}(t=0) = 0.16$ from raw data even at 300 K
    - ➢ overlap with high-energy lines
- ➢ Good multiphoton suppression

[Fedorych et al., APL 100, 2012]

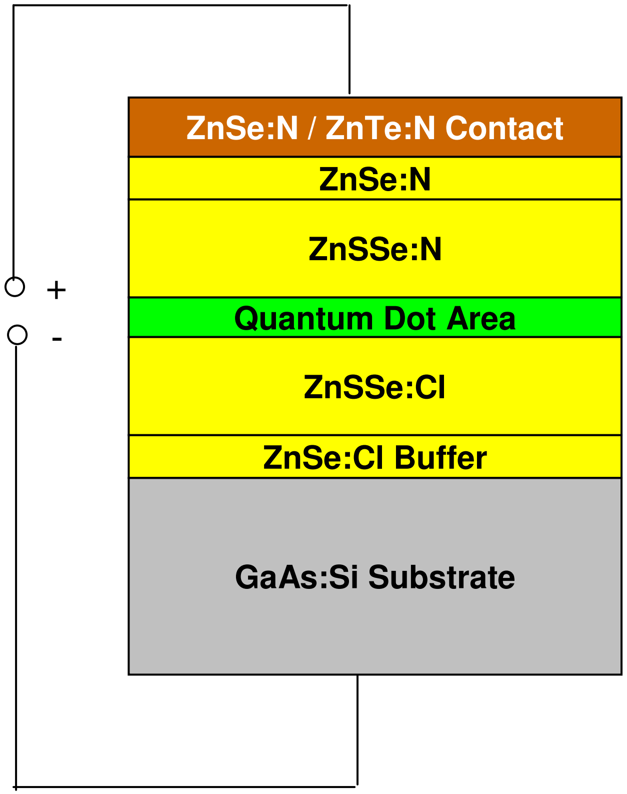
Optimizing barriers for electrical operation

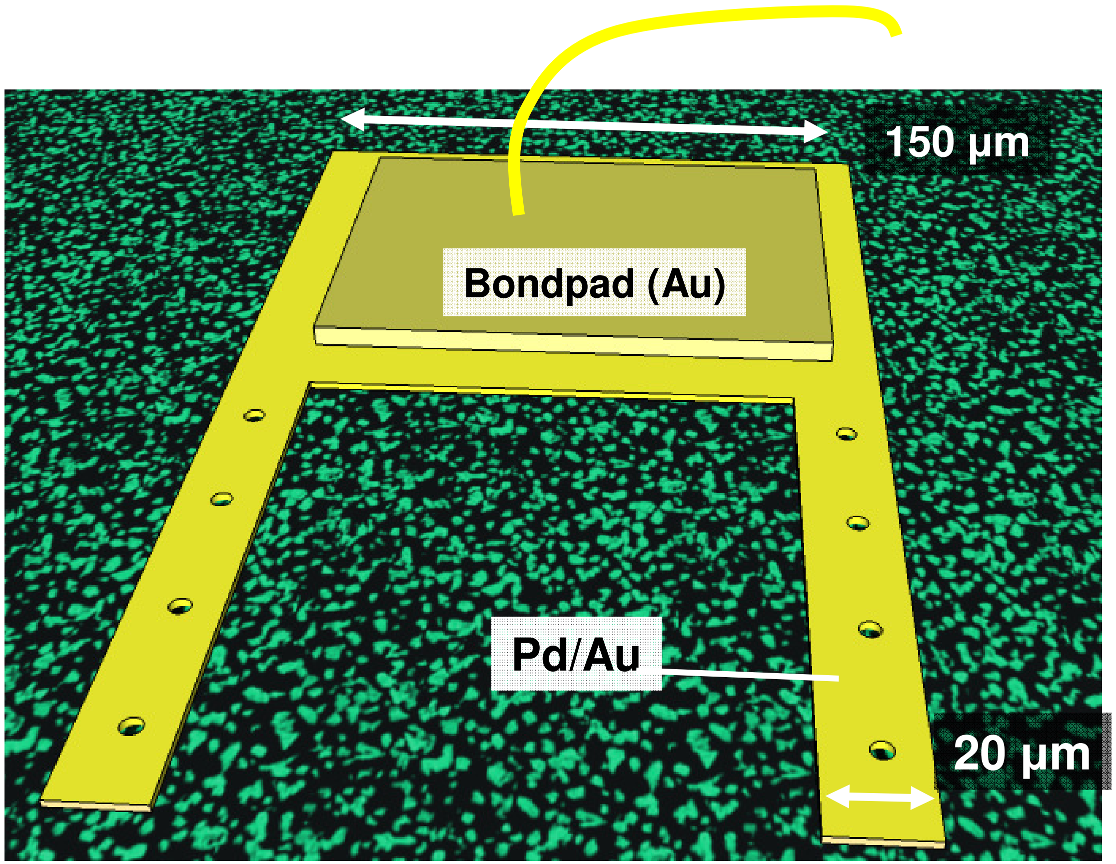




1 nm MgS barriers allow for efficient electrical carrier injection

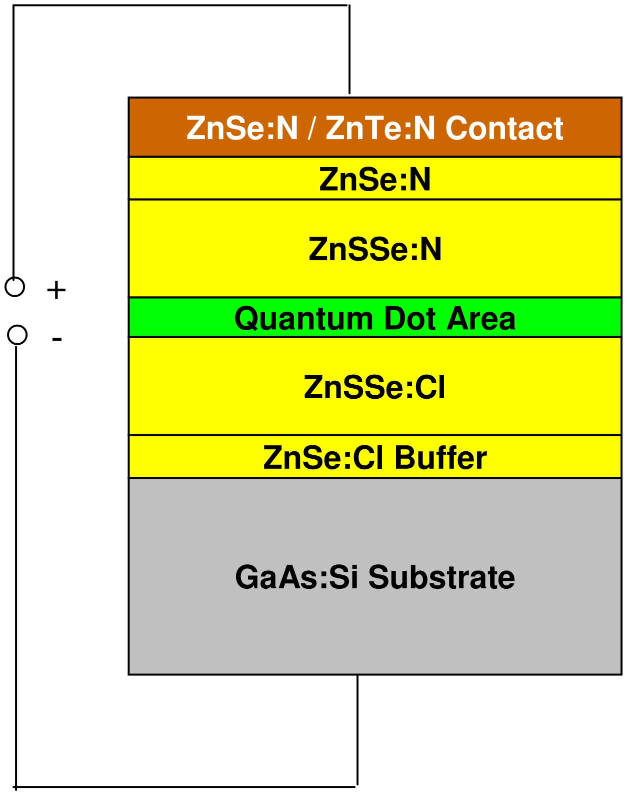
LEDs with highly confined QDs

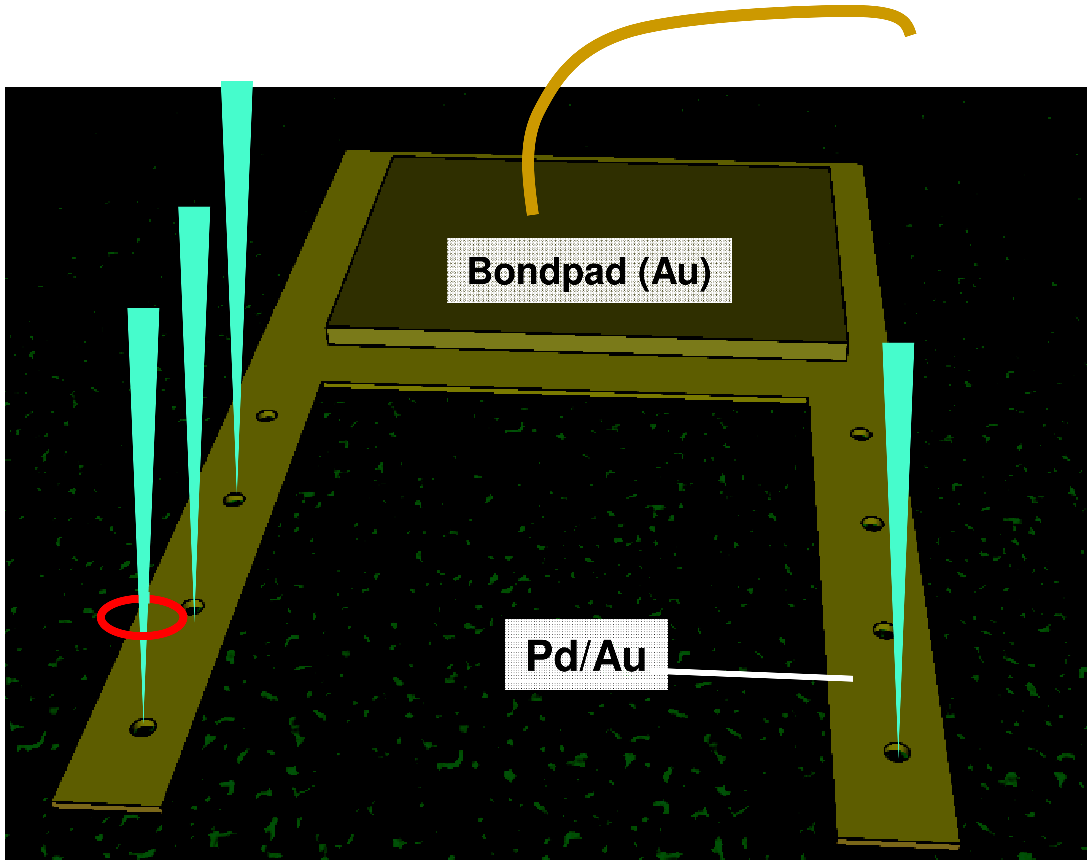




- Nanoapertures between 500 nm and 2 µm
- Local current injection by small contacts
  - Reduction of background electroluminescence

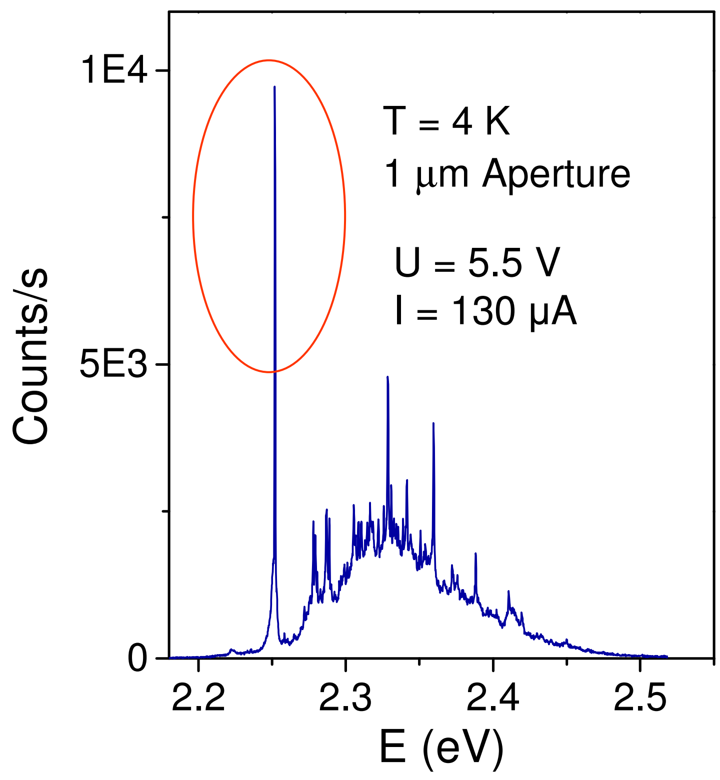
LEDs with highly confined QDs

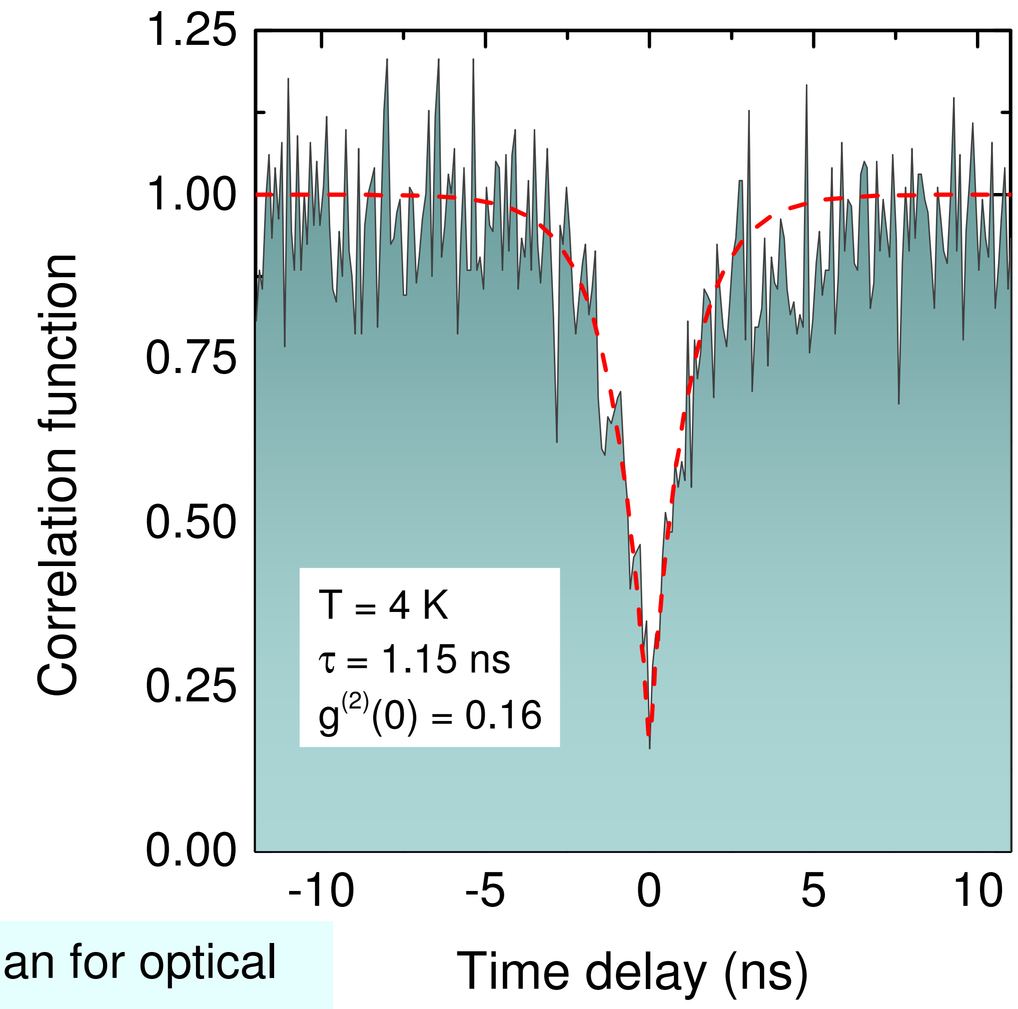




- Nanoapertures between 500 nm and 2 µm
- Local current injection by small contacts
  - Reduction of background electroluminescence
- Micro-EL setup using a pinhole → EL from one single aperture

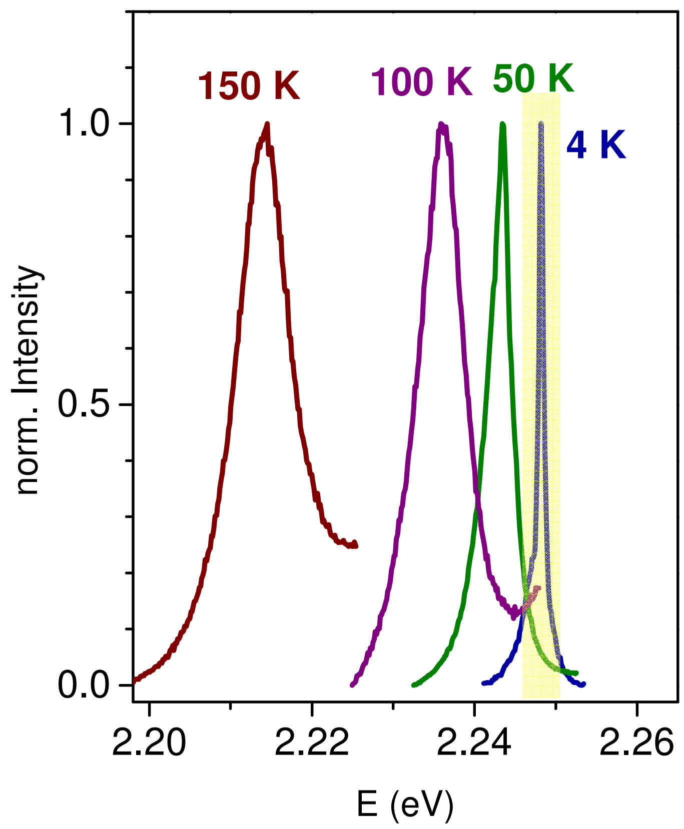
Electrically driven single photon emitter

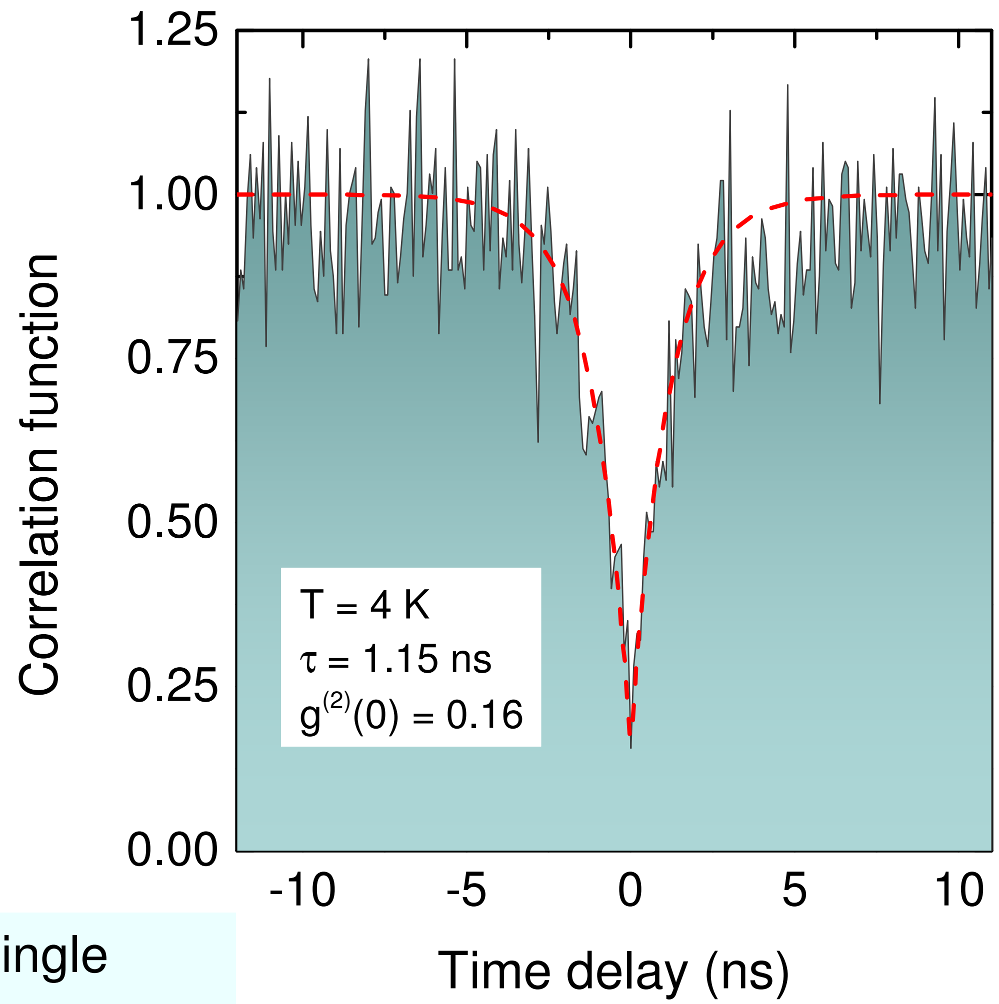




- Density of emitting dots lower than for optical excitation
- „Easy“ selection of single quantum dots

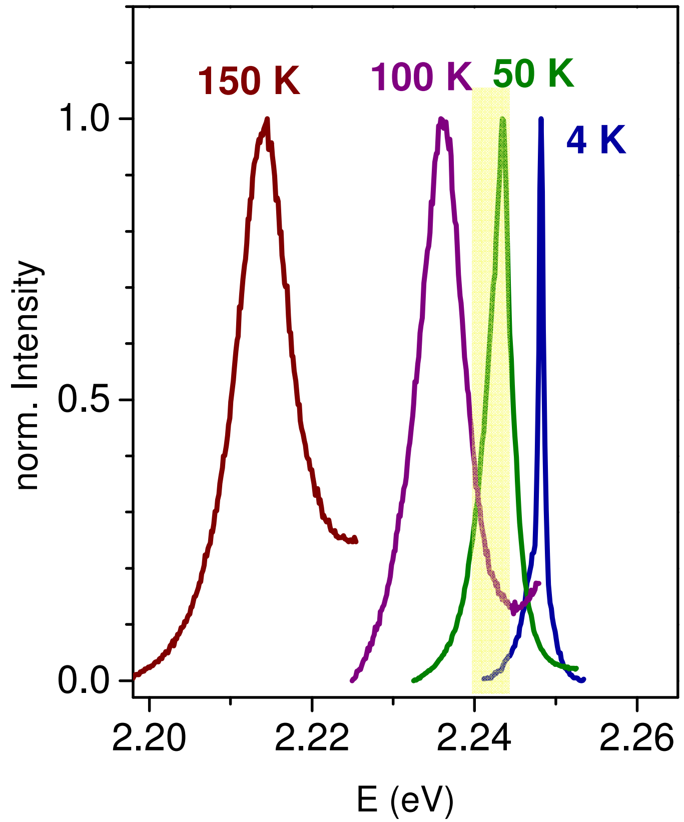
Electrically driven single photon emitter

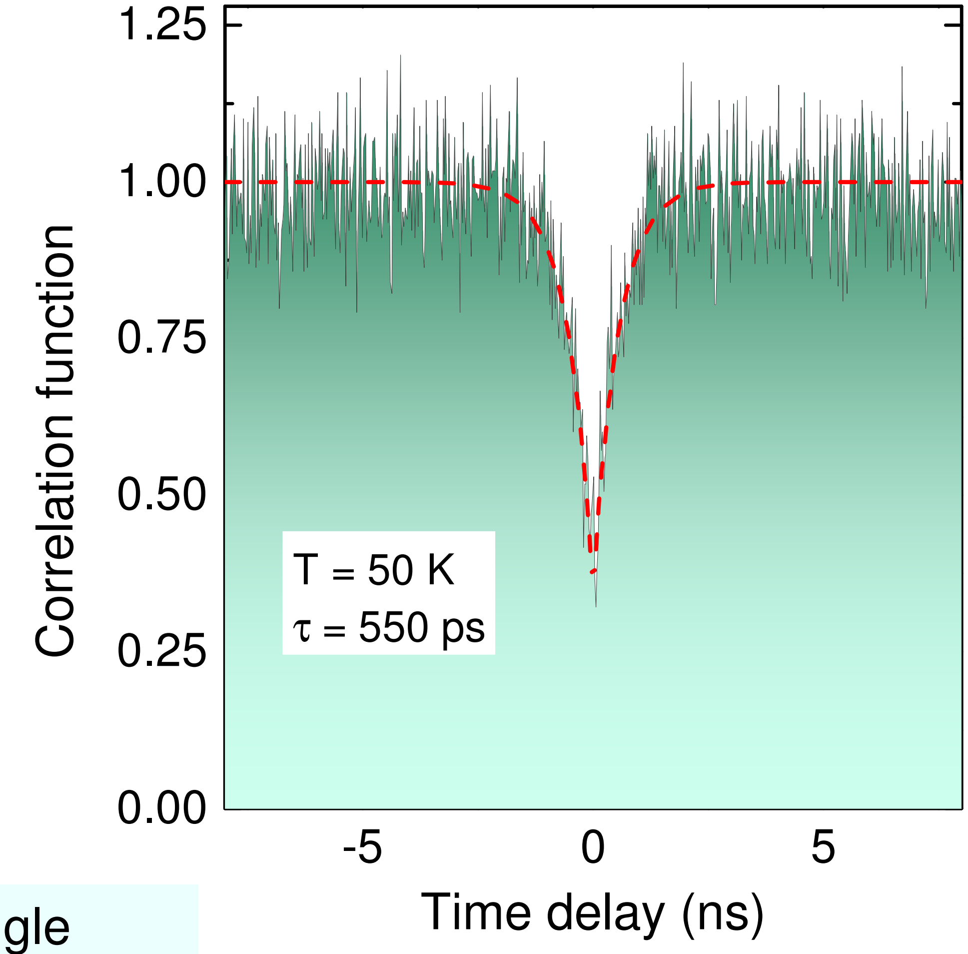




- Good spectral separation of single emission line up to 150 K

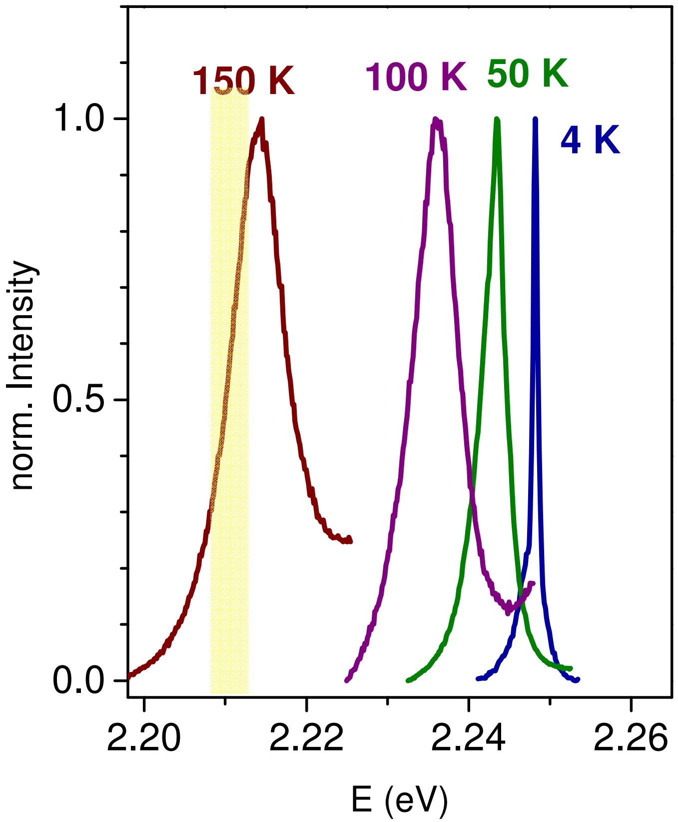
Electrically driven single photon emitter

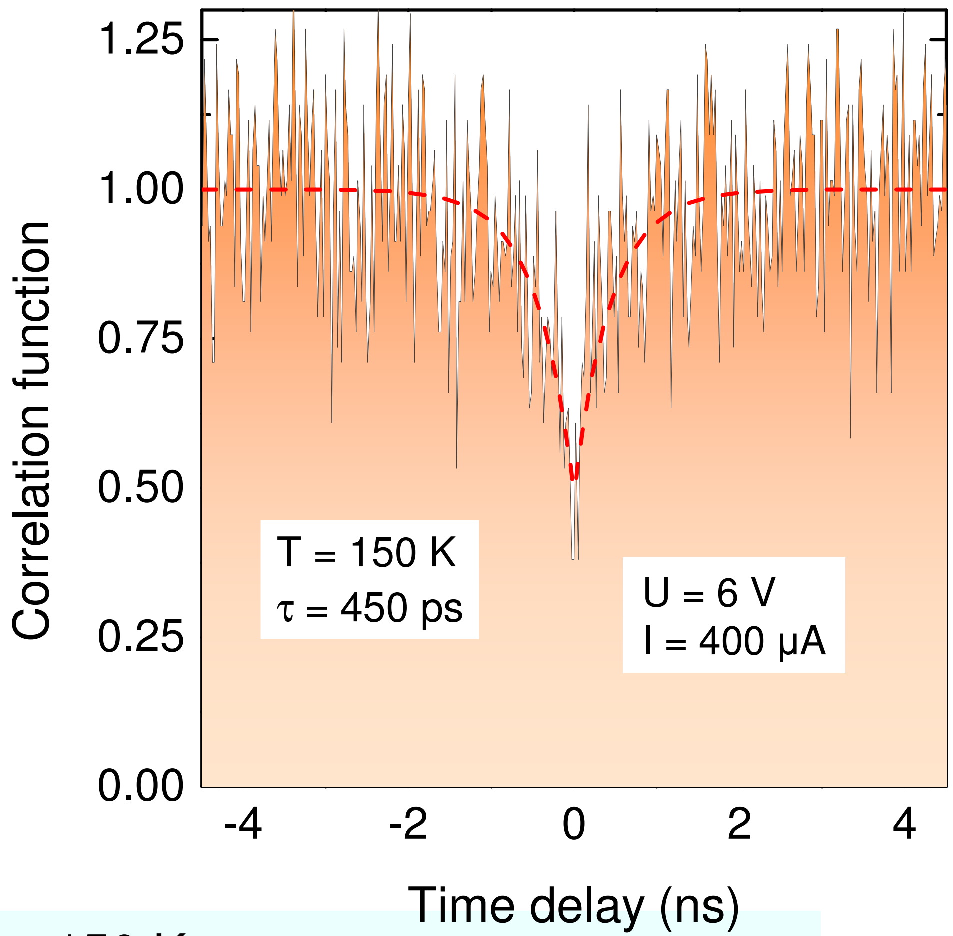




- Good spectral separation of single emission line up to 150 K

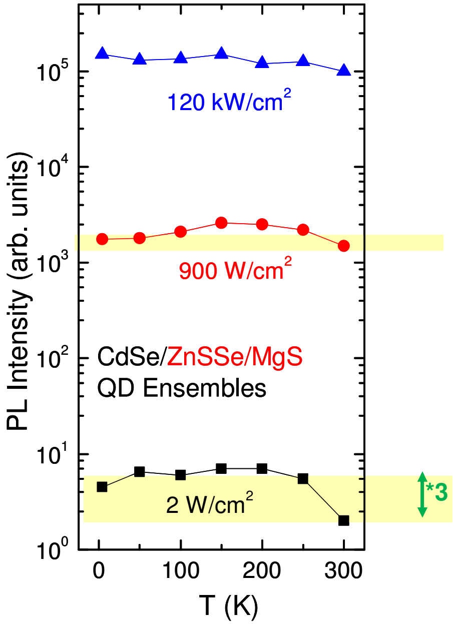
Electrically driven operation at T = 150 K





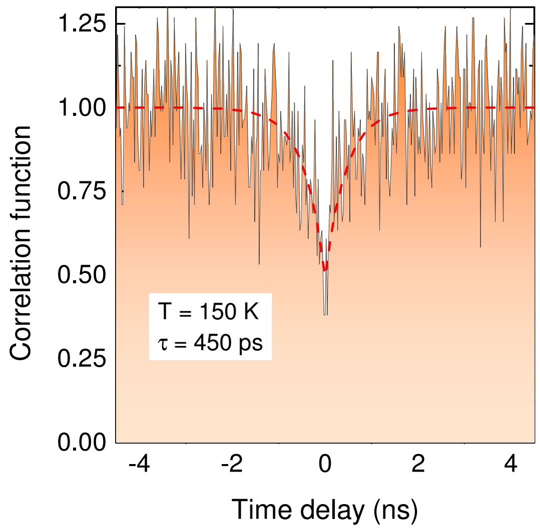
- Antibunching detectable up to 150 K
- Highest temperature for electrically driven single photon emission from a semiconductor quantum dot

Summary



- **CdSe/ZnSSe/MgS: Epitaxial quantum dots with high carrier confinement**
  - High quantum efficiency up to 300 K
  - Single dot emission and antibunching visible up to room temperature under optical excitation
  - $g^{(2)}(t=0) = 0.16$ from raw data

- **Electrically driven devices**
  - Optimized barriers for electrical operation
  - Single photon emission detectable up to 150 K



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Open-Minded

Thank you for your attention!

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