Increasing the brightness of site controlled quantum dots with chip scale processing

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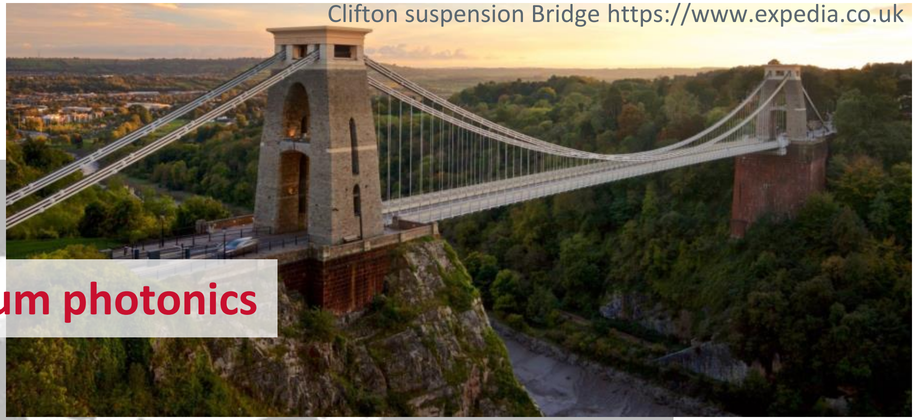
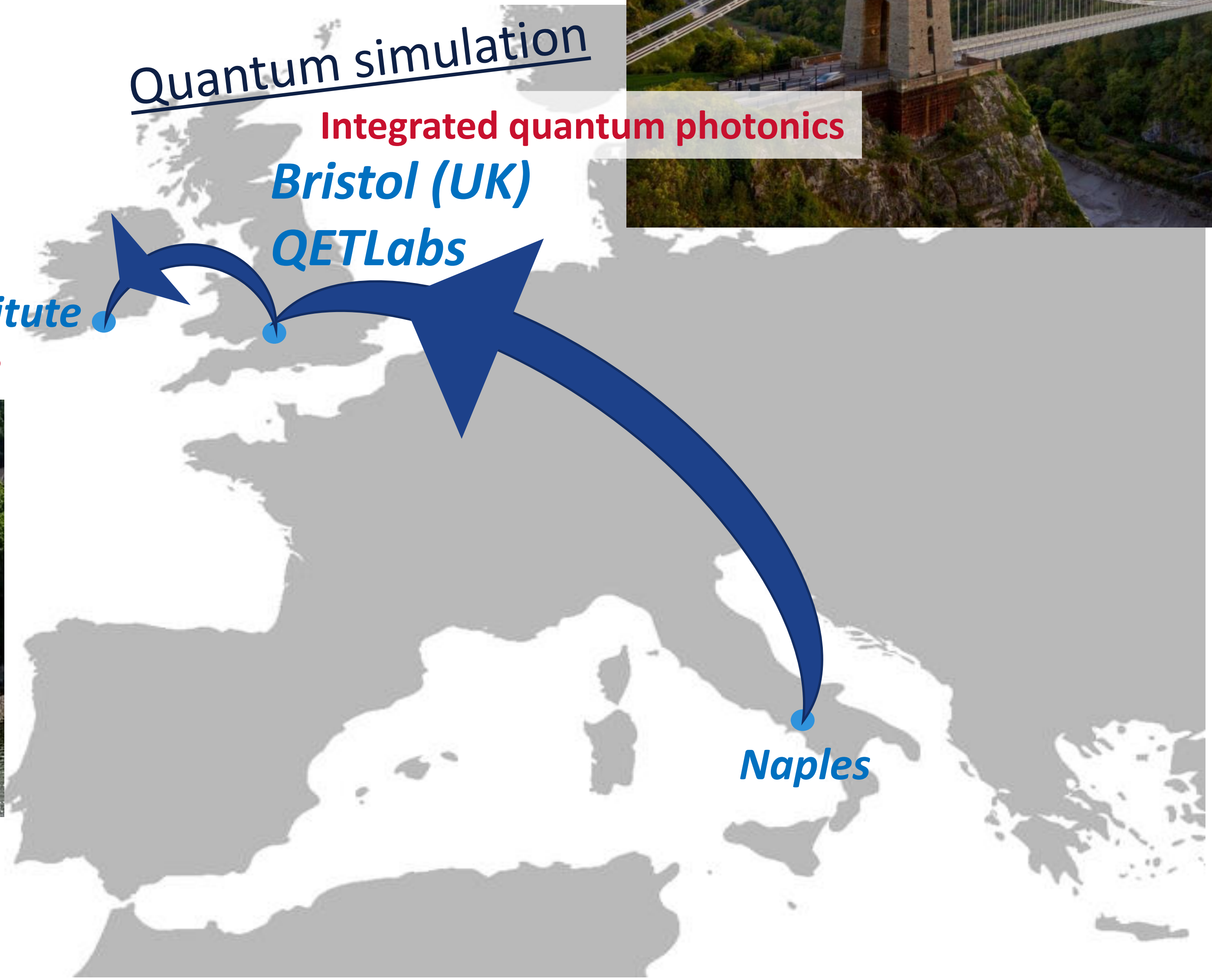
Personal journey

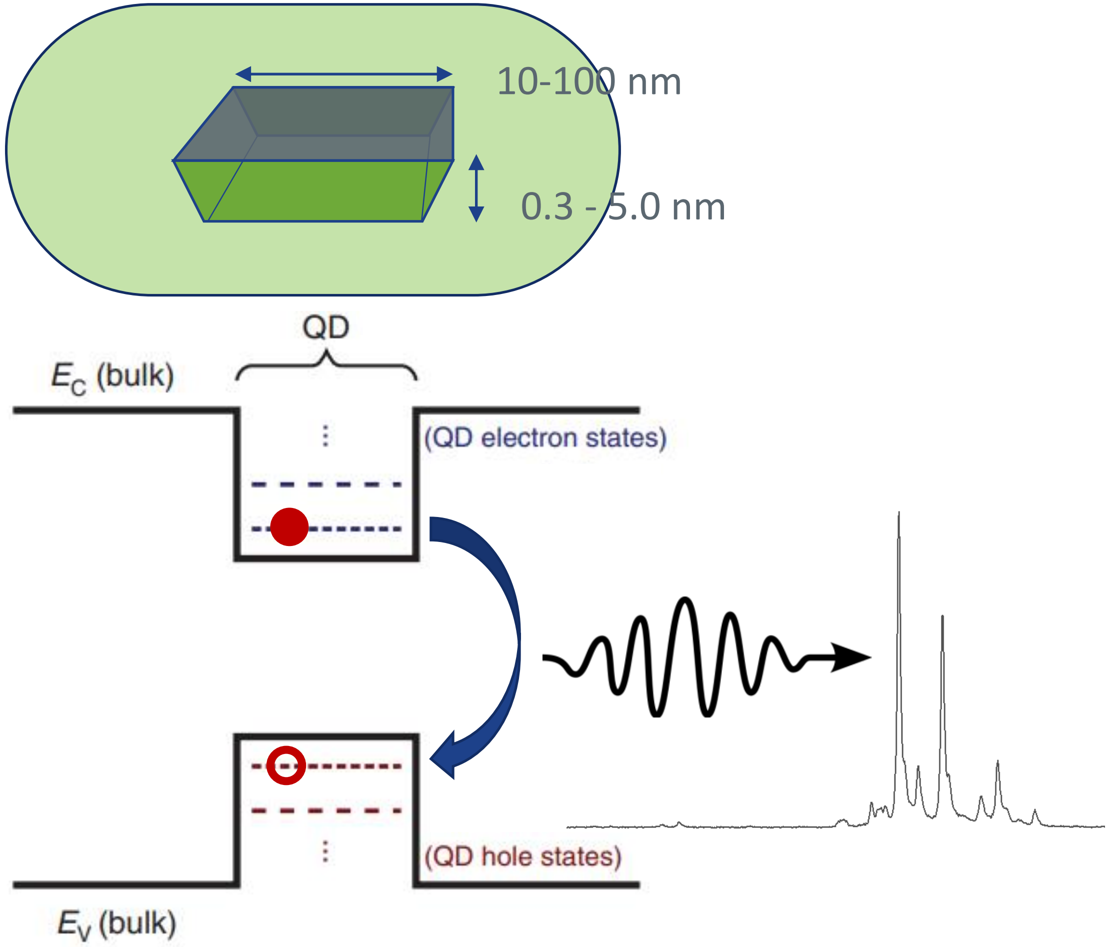

Clifton suspension Bridge https://www.expedia.co.uk




Blackrock castle observatory / Facebook page

What are semiconductor quantum dots? (QDs)

QDs can produce resource states to perform photonic quantum computation



Modified from: "H. Mäntynen et al.: Single-photon sources with quantum dots in III–V nanowires doi/10.1515/nanoph-2019-0007"

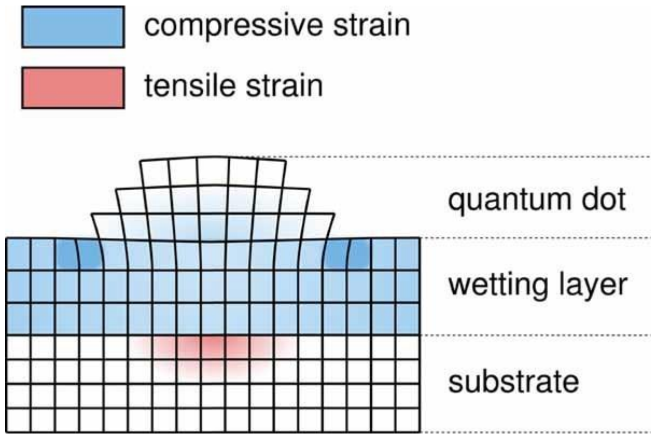
- QDs are little portions of direct band gap semiconductor material surrounded by a material with larger bandgap.
- Discrete energy levels (*artificial atoms*)
- Either single photon source or polarisation entangled photon source.
- Potential for high brightness and single photon purity.

BUT you need to work hard for

- Extraction efficiency (especially into waveguides).
- Low spectral purity and indistinguishability

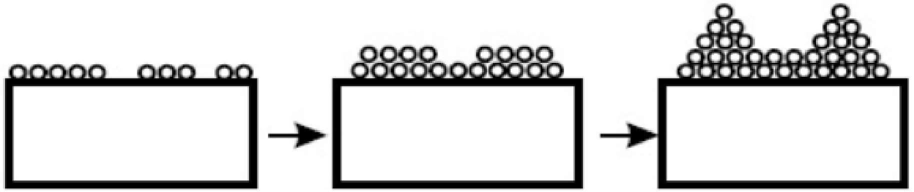
Common way to produce QDs

Semiconductor QDs are often obtained from a "self assembled" method that causes random nucleation of the QD.



S. Figge et al. InGaN quantum dot growth in the limits of Stranski–Krastanov and spinodal decomposition doi.org/10.1002/pssb.201147165

B. L. Liang et al. Correlation between surface and buried InAs quantum dots doi.org/10.1063/1.2243865

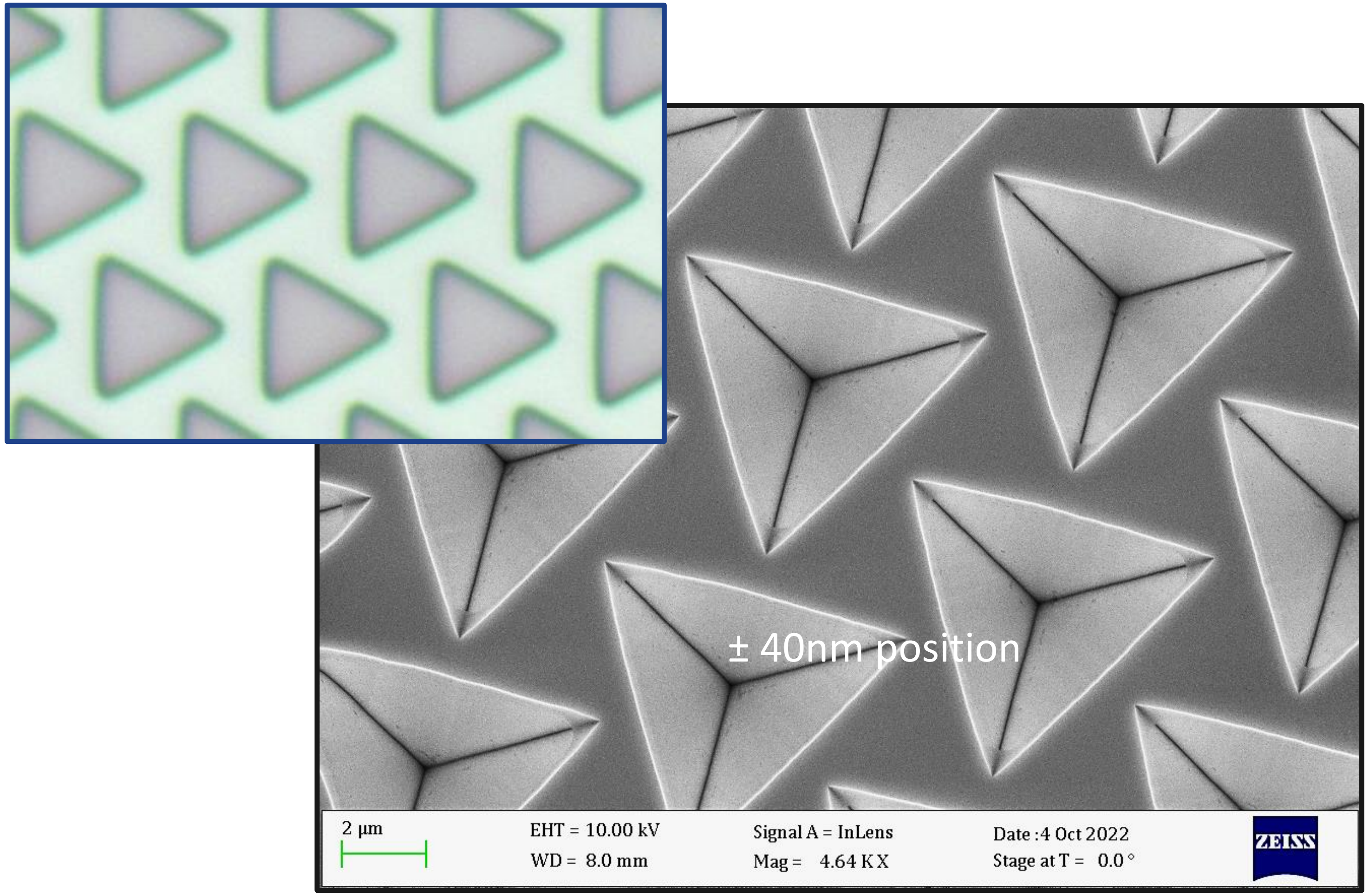


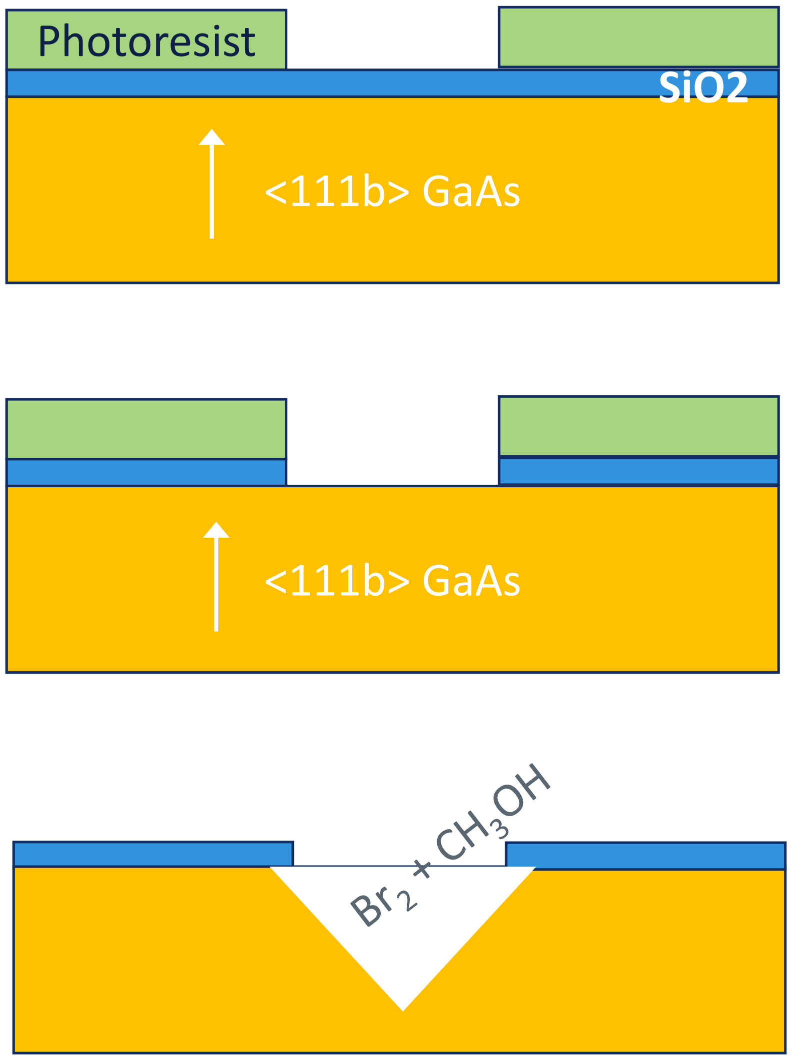
Stranski–Krastanov

InTech-Thin film growth through sputtering technique and its applications

How do we get site controlled QDs

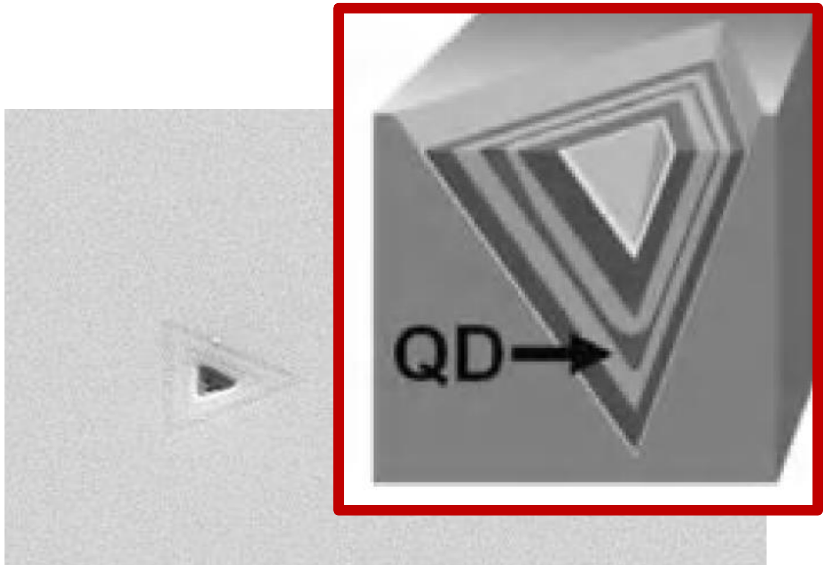
Crystallographic selective wet chemical etch

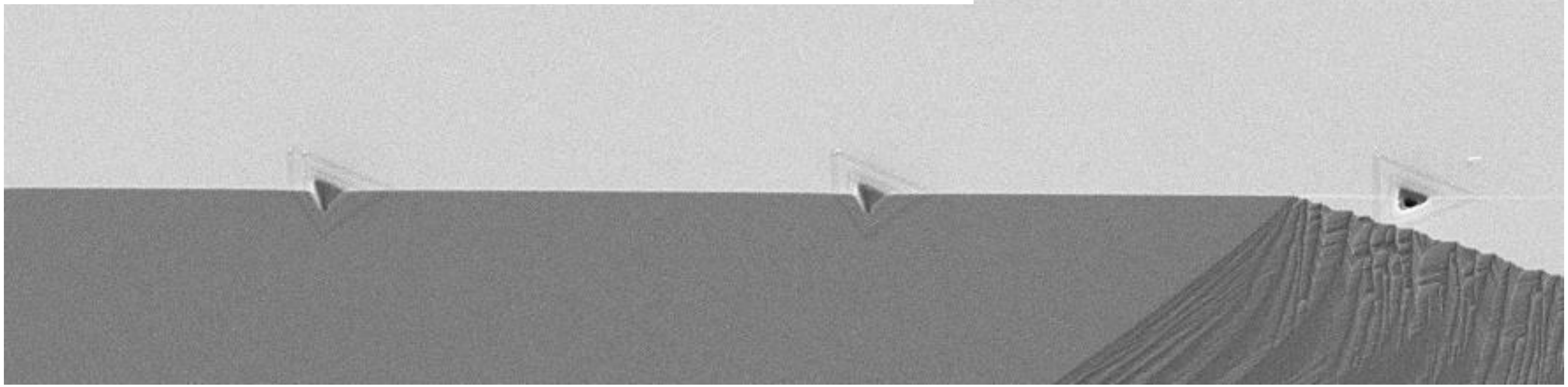




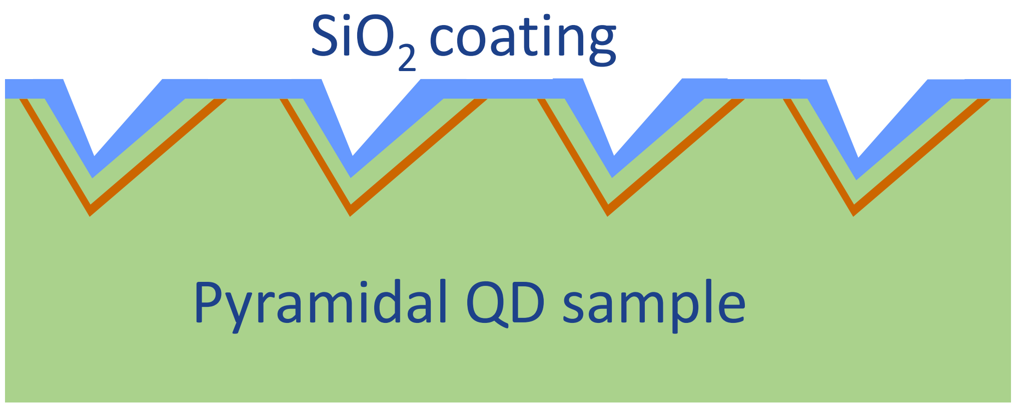
How do we get site controlled QDs

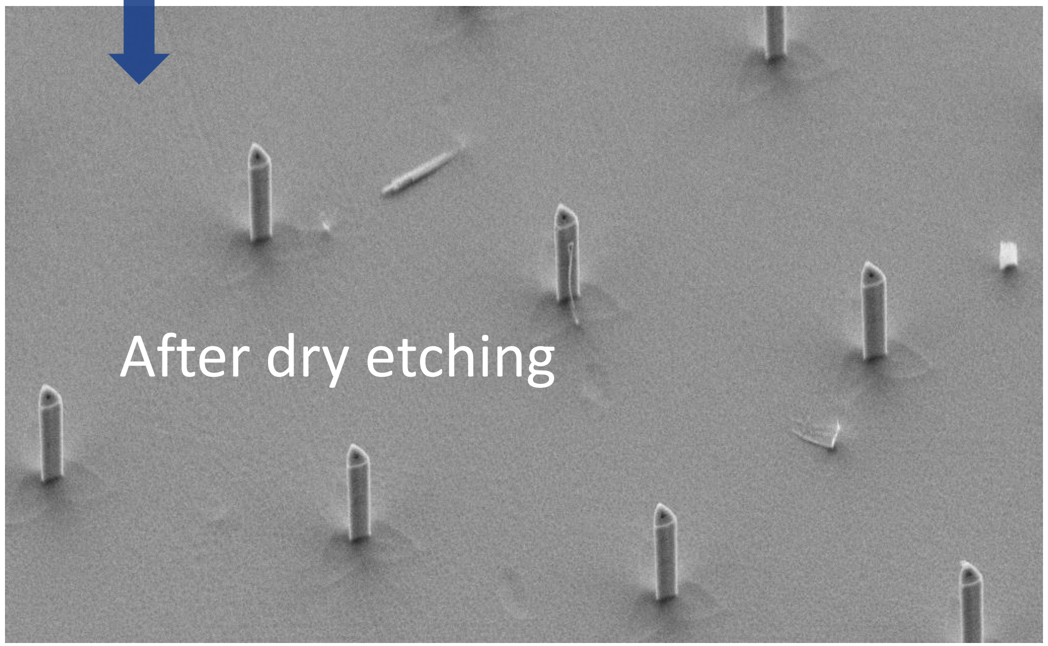
- Metal-organic gas precursors decompose in the etched recesses. (Metal-organic vapour phase epitaxy growth).
- Layers of AlAs, $Al_xGa_{(1-x)}As$, $In_xGa_{(1-x)}As$, and GaAs are used to control the energy bands.
- Details of the morphology are defined by diffusion mechanisms of adatoms.





On the path to increase extraction efficiency

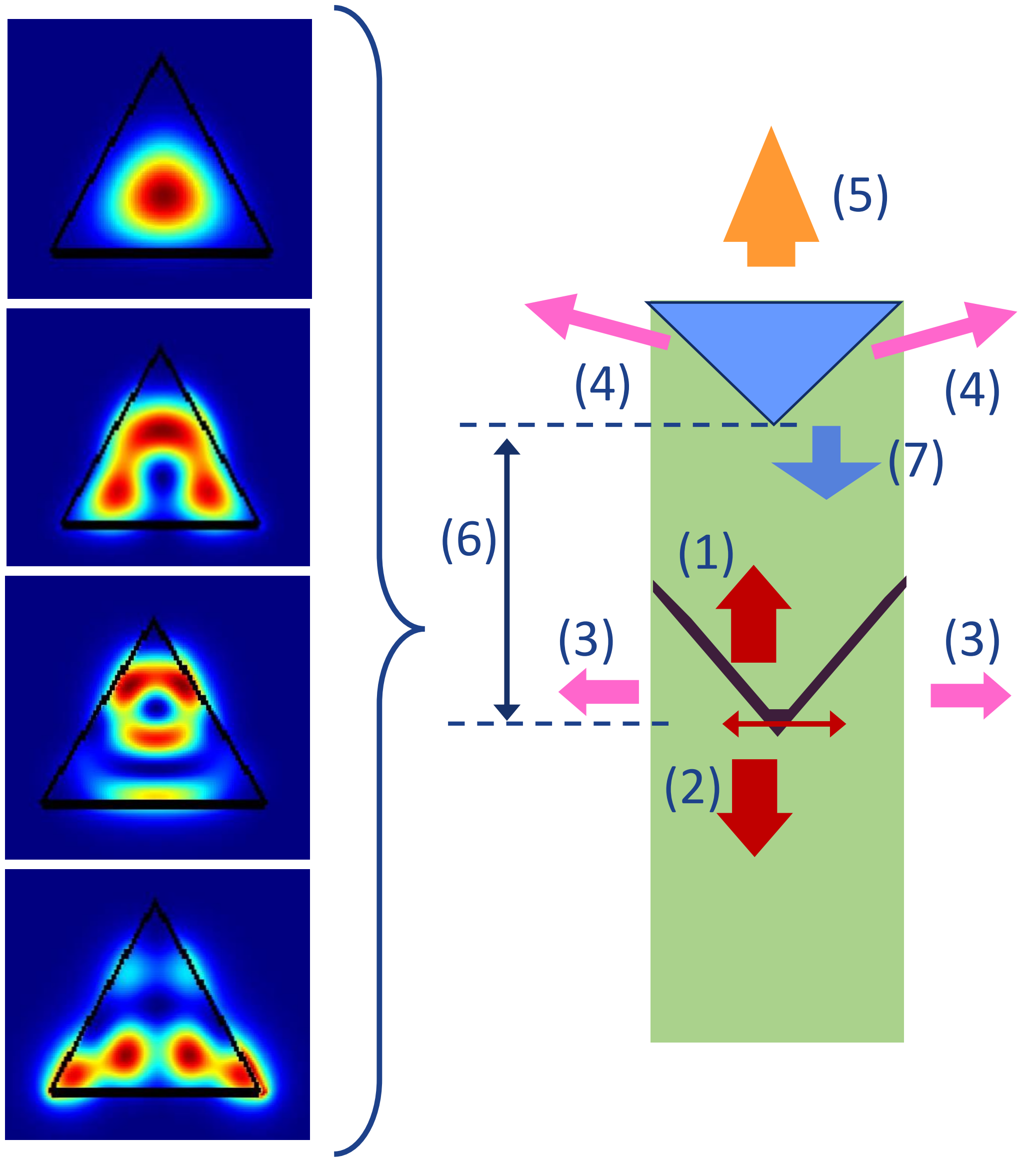




- Self aligned nanopillars are obtained by coating, polishing and then dry etching QD samples.
- Dimensions below optical resolution are achievable.

Reactive plasma composition Cl_2 / BCl_3 / Ar / N_2

On the path to increase extraction efficiency



1) 2) Multiple optical modes of the pillar are excited and propagate in both directions.

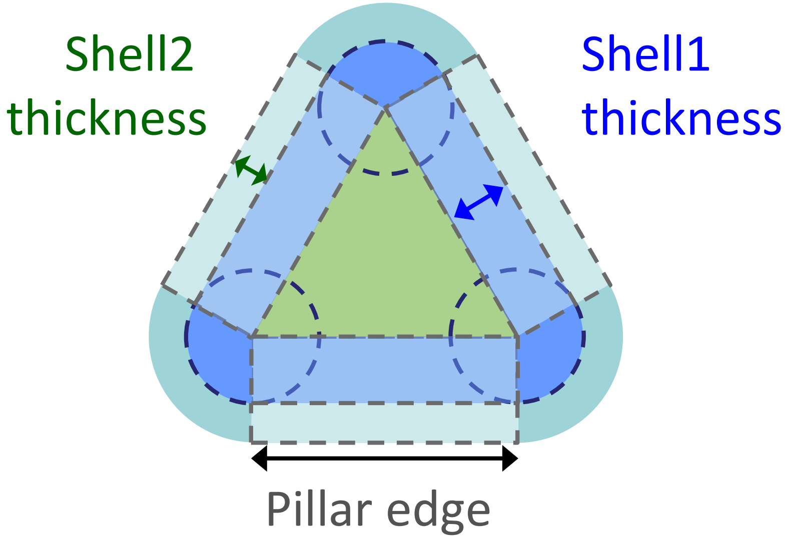
3) 4) Some light is radiated into free space or scattered by the SiO_2 filled recess.

5) We collect the light that is transmitted through the top of the pillar (at small emission angles)

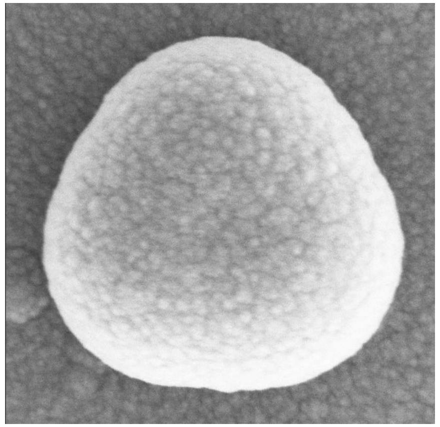
6) Different optical modes arrive at the top with a relative phase that depends on the distance between the QD and the scattering recess.

7) The SiO_2 cap and air interface reflect some the light back into the pillar.

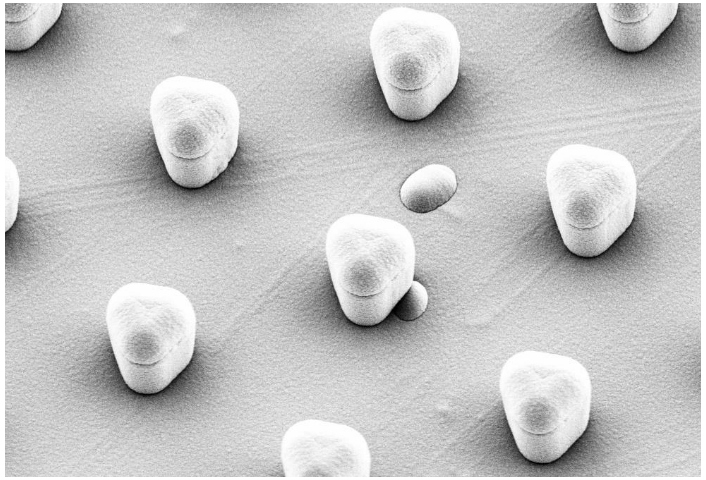
Additional tuning knob - encapsulation

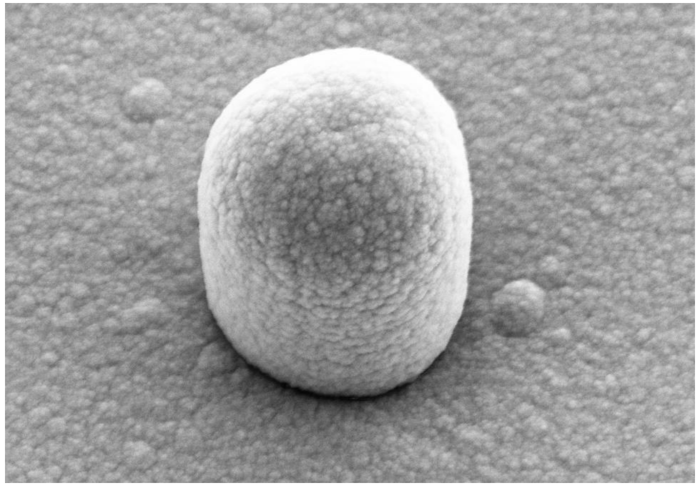


- Dielectric shells modify the interference of the supported modes.
- The rounded top help shaping the emission profile.

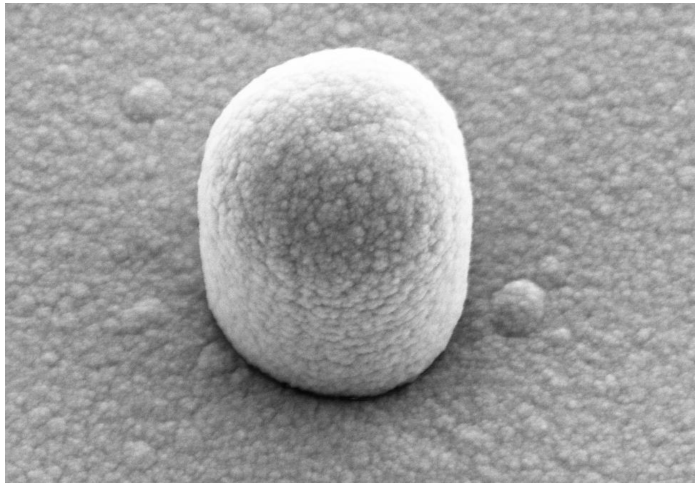


Shell thickness ≥ pillar edge



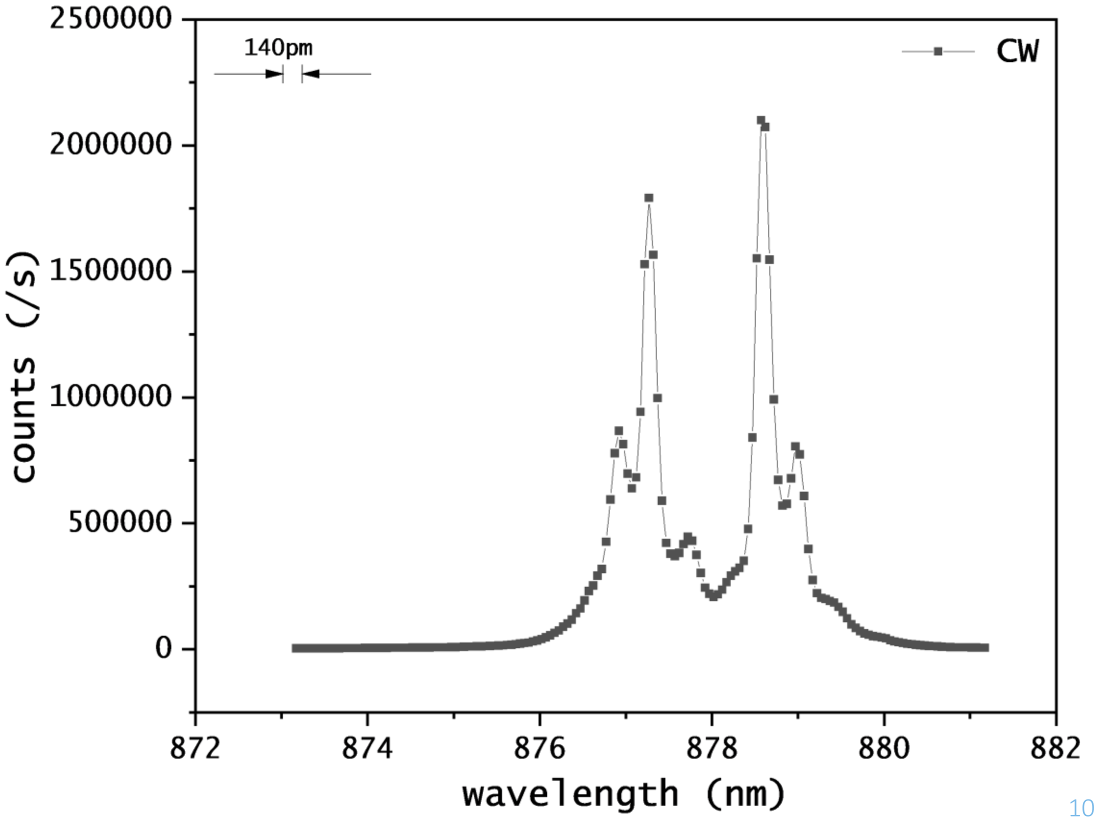


Lucky with the first coated sample



- The extraction efficiency from the GaAs pillars increased significantly. (5x)
- The initial SiO_2 coating red-shifted the emission by 30nm. Further SiN_x blue-shifted it back by ~10nm. (Strain induced)

APD single photon count rate measured after a monochromator under continuous wave excitation



Power collected at fixed numerical aperture (NA)

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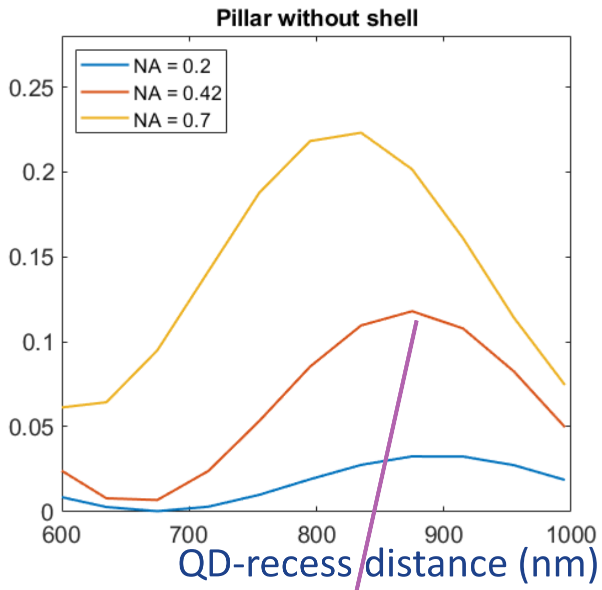
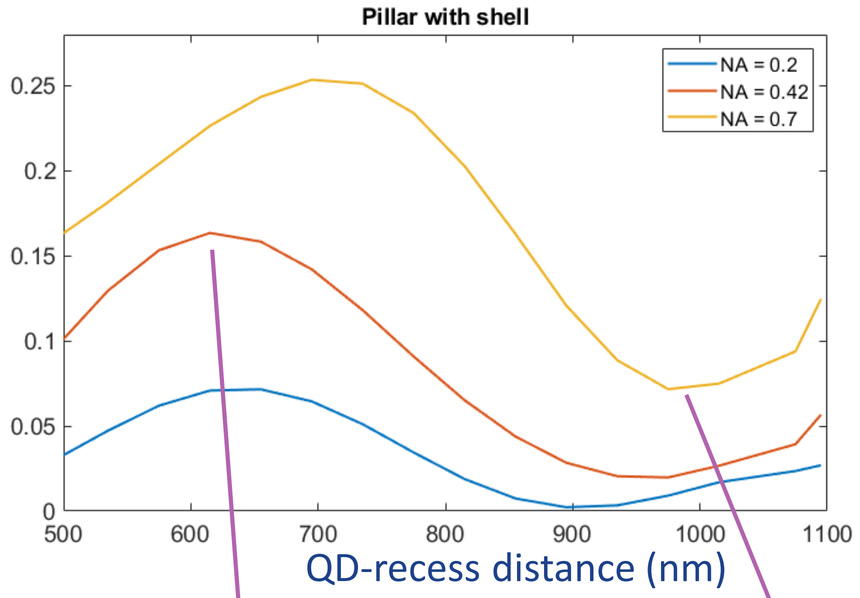


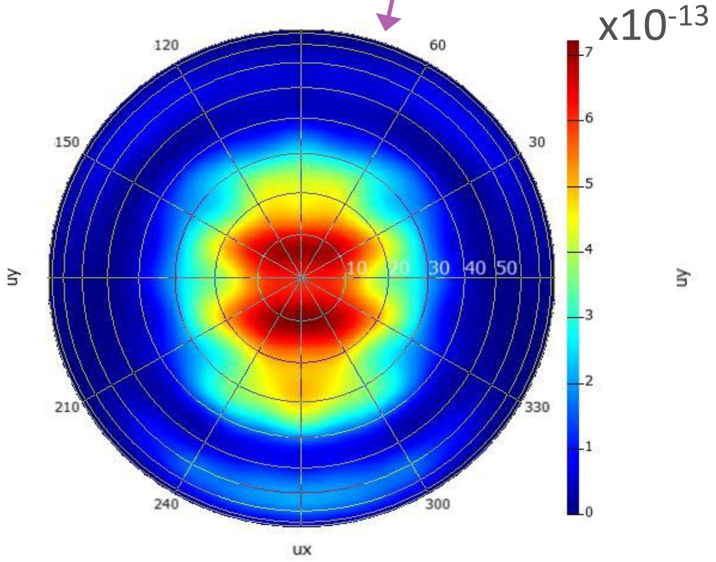


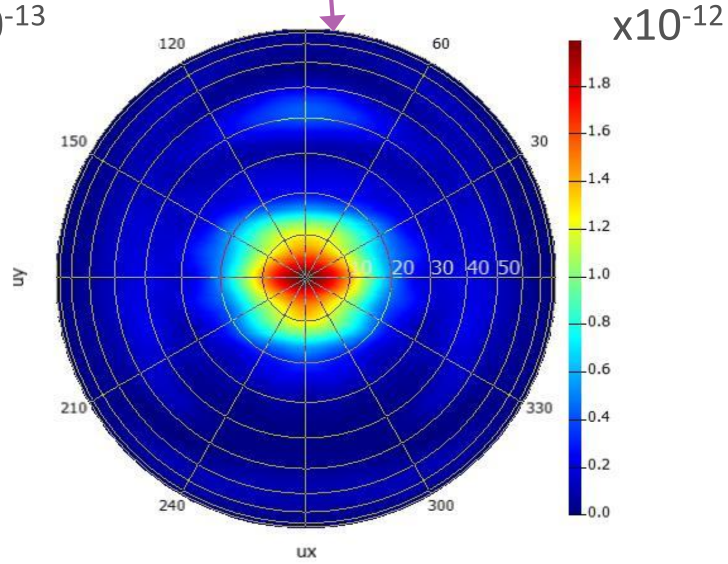
Shell1 = 50nm SiN_x

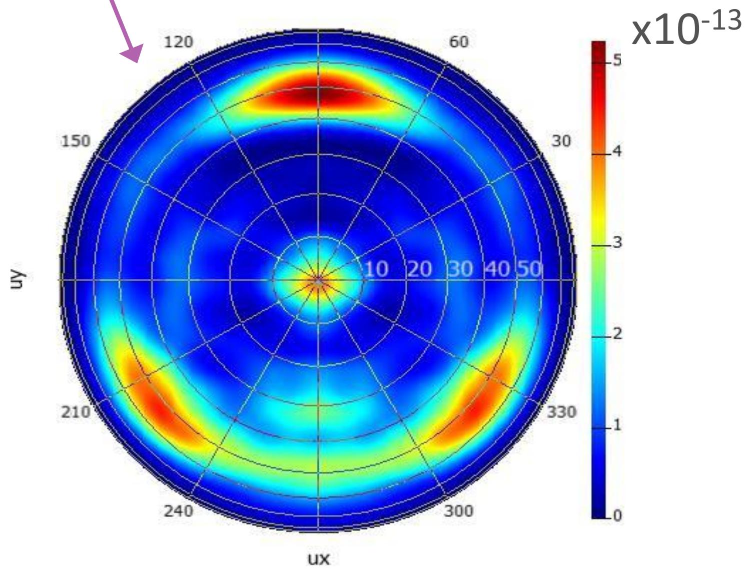
Shell2 = 480nm SiO_2

Shell3 = 310nm SiN_x

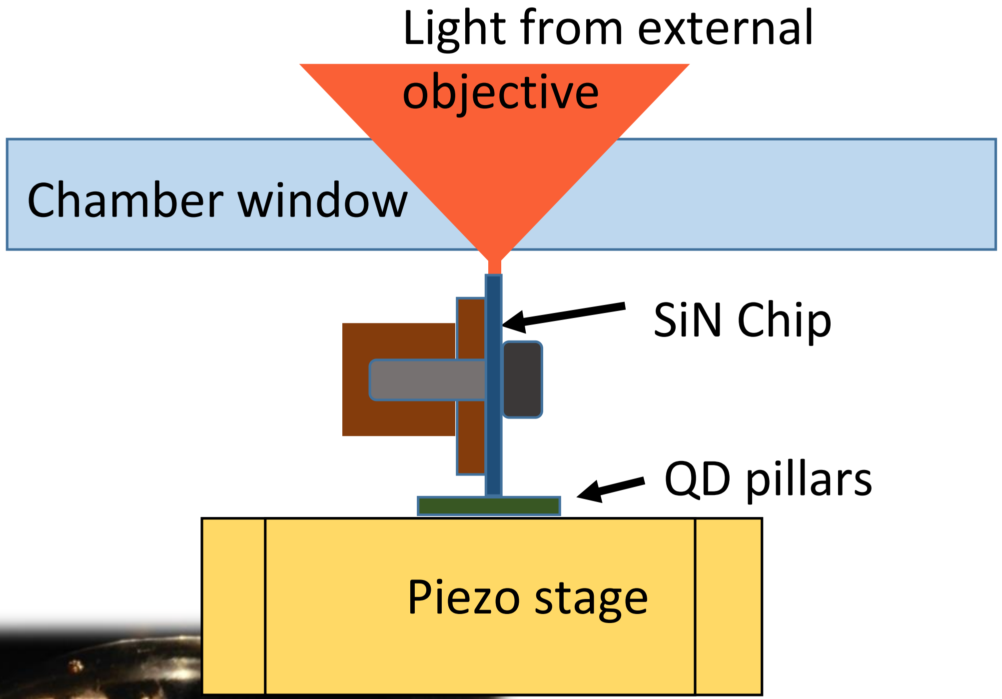
Far field projections

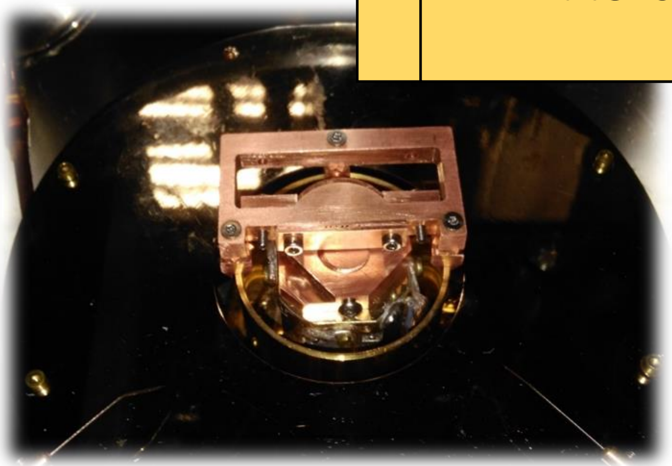




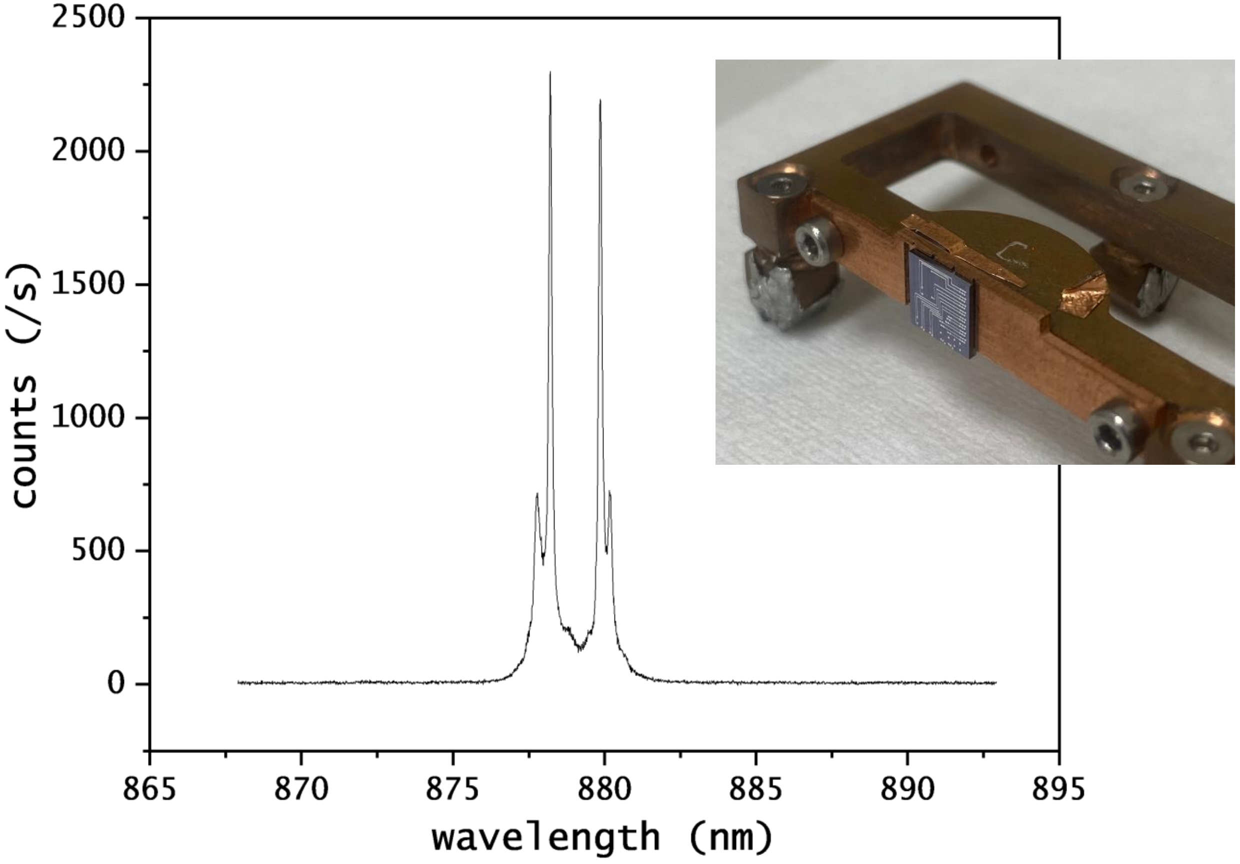


Coupling to integrated chip





CCD count rate from a spectrometer



The team

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