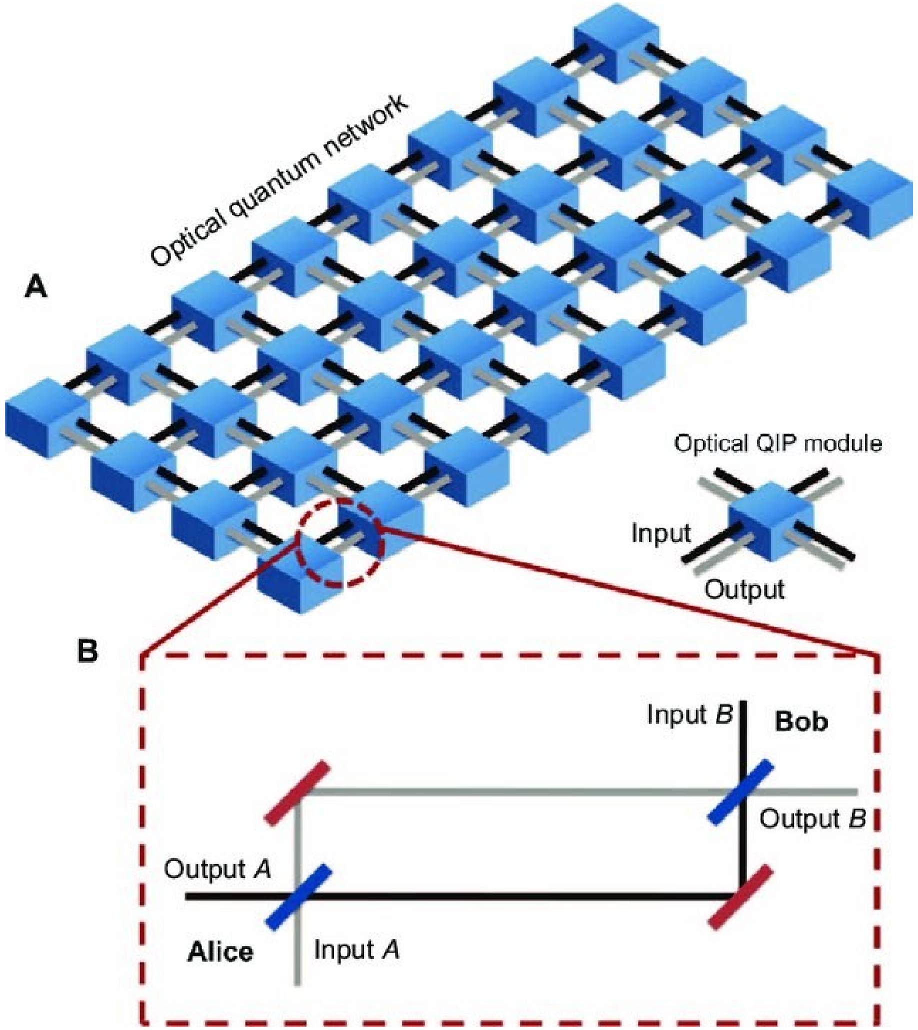
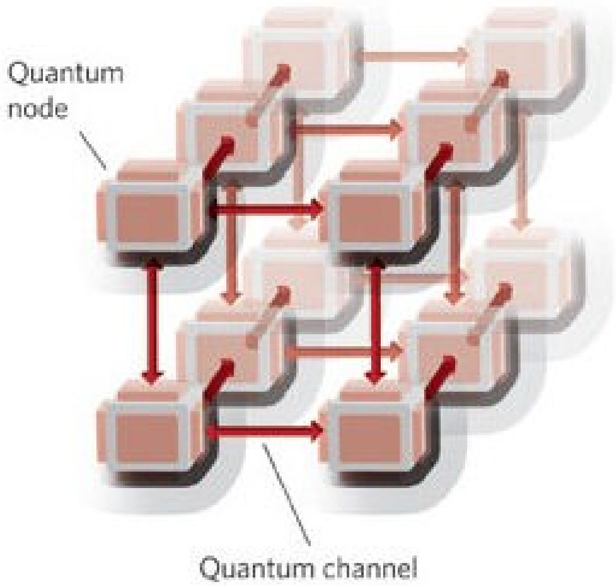
Quantum Networks





Quantum Networks

The quantum network consists of discrete nodes linked by entanglement.

Each node consists of a quantum bit (qubit) or multiple qubits that can be entangled together at will using deterministic and reversible local gate operations.

Entanglement between nodes is generated by first entangling the nodes with photons and then performing measurements on the photons which project the nodes into an entangled state.

The use of photonic channels provides flexibility in the physical scale of the network, from chip-based systems to larger networks utilising optical fibres or free-space line-of-sight pathways.

The fact that the nodes themselves are not required to interact directly with each other also provides opportunities for heterogeneity between different systems.

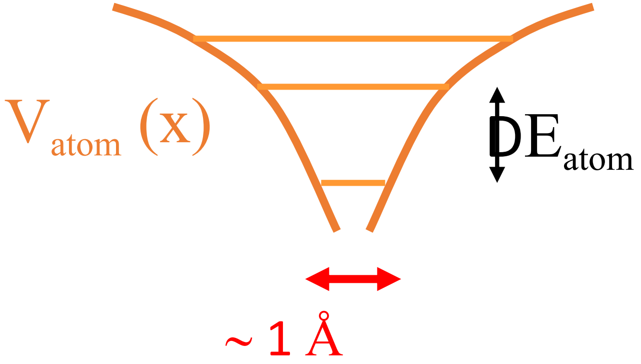
Nodes might consist for example of ion trap systems, cold atoms, superconducting circuits, or solid state devices incorporating spins on defects or quantum dots.

Quantum entanglement between devices will provides information gathering, security, communication and processing that exceed the limits of classical information systems.

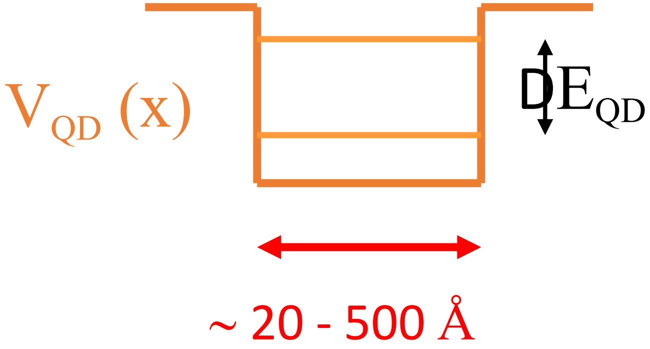
Quantum Dots

- Artificial structures that confine electrons (and holes) in all 3 dimensions.

Atoms



Quantum dots (QD)



⇒Quantized (discrete) eigenstates in both cases (≡ 0D density of states).

$$DE_{atom} \sim 1\text{–}10 \text{ eV} >> kT_{room} = 26 \text{ meV}$$

$$DE_{QD} \sim 1\text{–}100 \text{ meV} \sim kT_{room} \text{ !}$$

Unlike atoms, QDs are sensitive to thermal fluctuations at room temp.

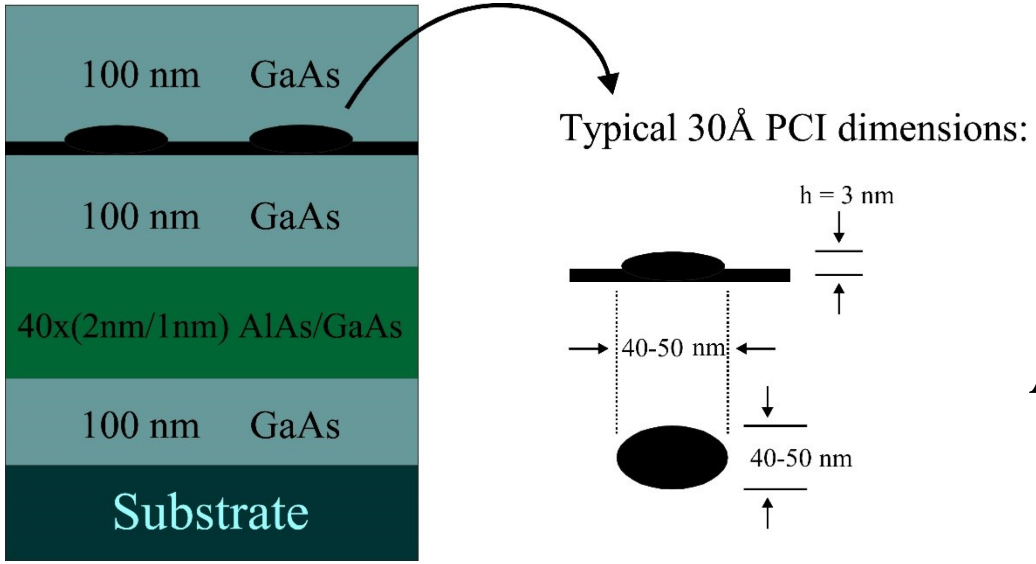
Quantum Dots vs. Atoms

- Strongly trapped emitters: QDs do not have random thermal motion.
- Easy integration in nano-cavity structures.
- Strong coupling to optical fields: QD oscillator strength

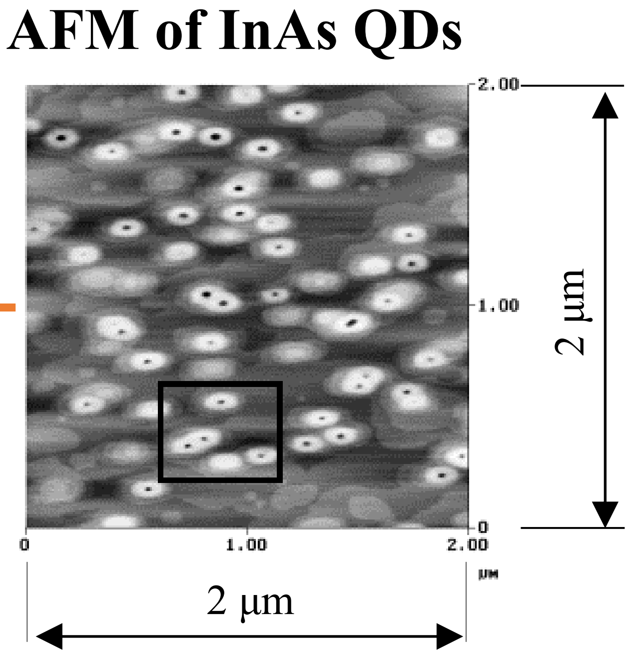
  $f \sim 10 - 300$ (collective enhancement).
- Electrical injection of carriers (electrons and holes).

- Each QD has a different resonance (exciton) energy.
- Difficult to tune QDs into resonance with cavity modes.

Self-Assembled InAs Quantum Dots



Quantum dots appear spontaneously due to lattice mismatch, during MBE growth.



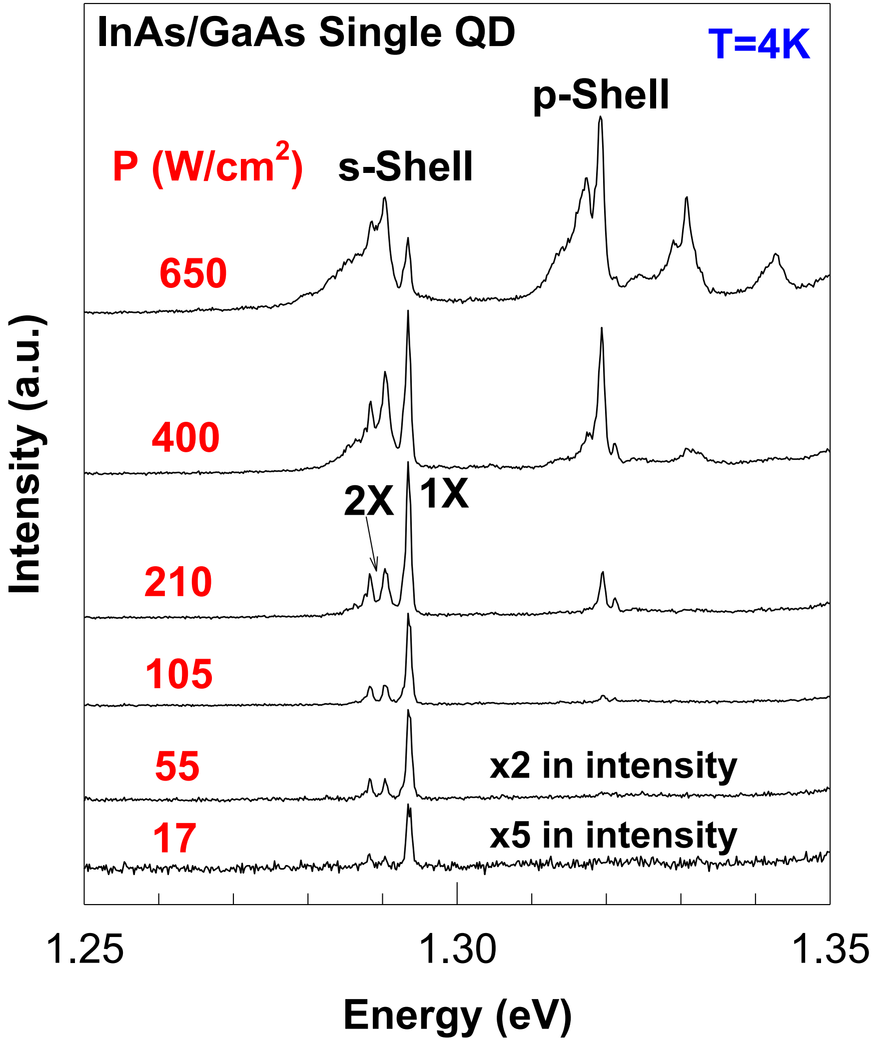
Each quantum dot is different

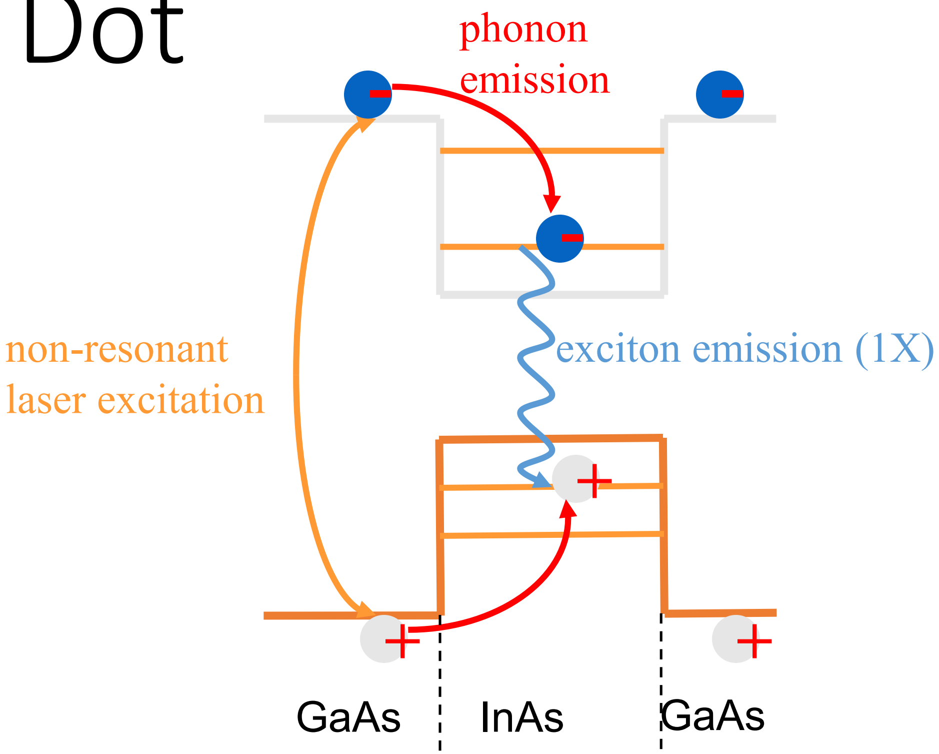
<u>Atom-like characteristics of Quantum Dots:</u>

- sharp emission lines
- photon antibunching

$\Rightarrow$ artificial atom for T < 77 K!

A single InAs Quantum Dot





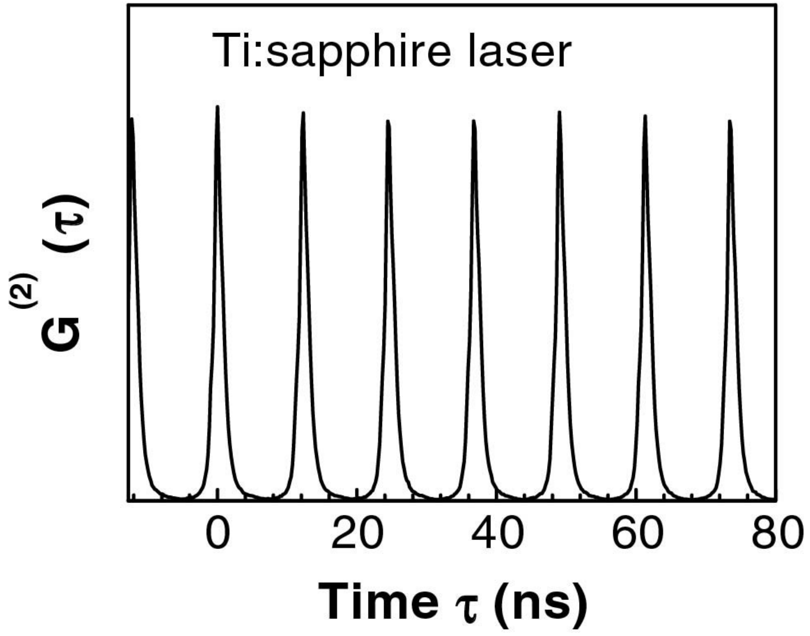
<u>Two principal emission lines from lowest energy s shell</u>

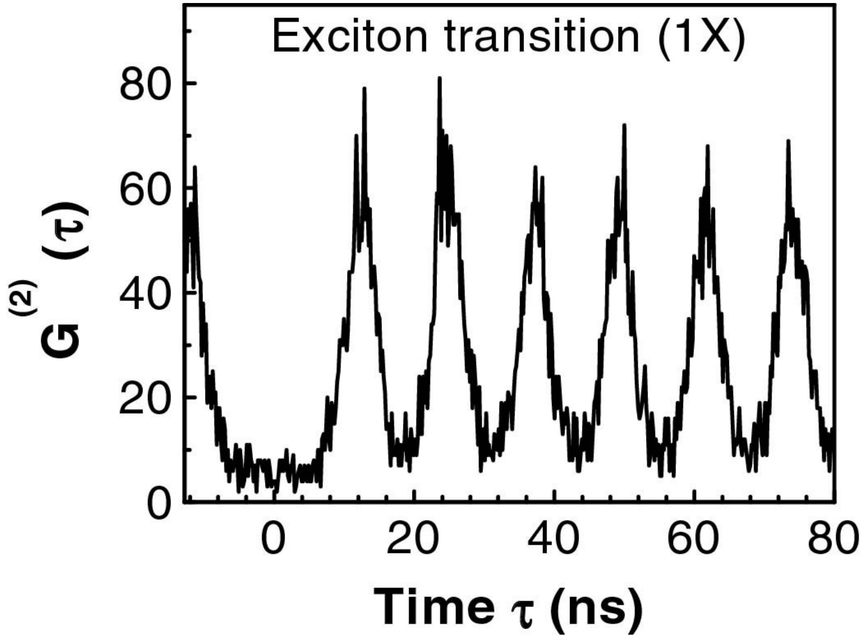
- 1X radiative recombination of a single e-h pair in the s-shell (exciton)
- 2X radiative recombination when there are two e-h pairs in the s-shell (biexciton)

Due to ***carrier-carrier interaction***
Typically $h\nu_{1X} = h\nu_{2X}$ + **3 meV**

Photon correlation of a single-photon source

Pump power *well above* saturation level



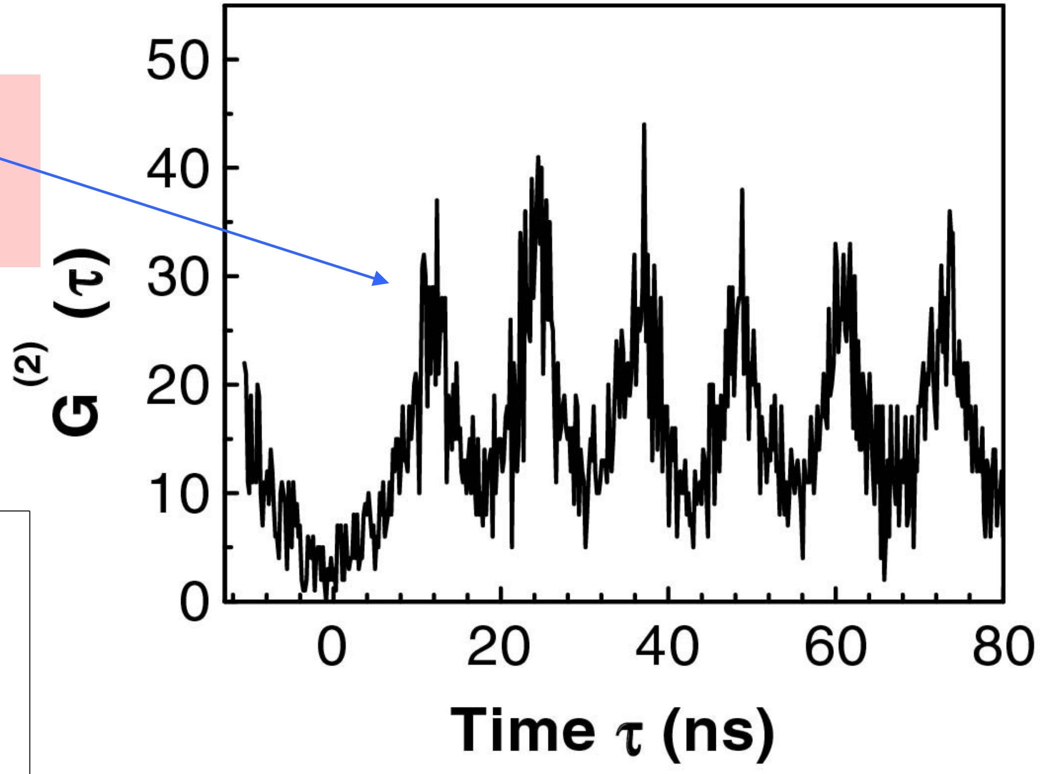


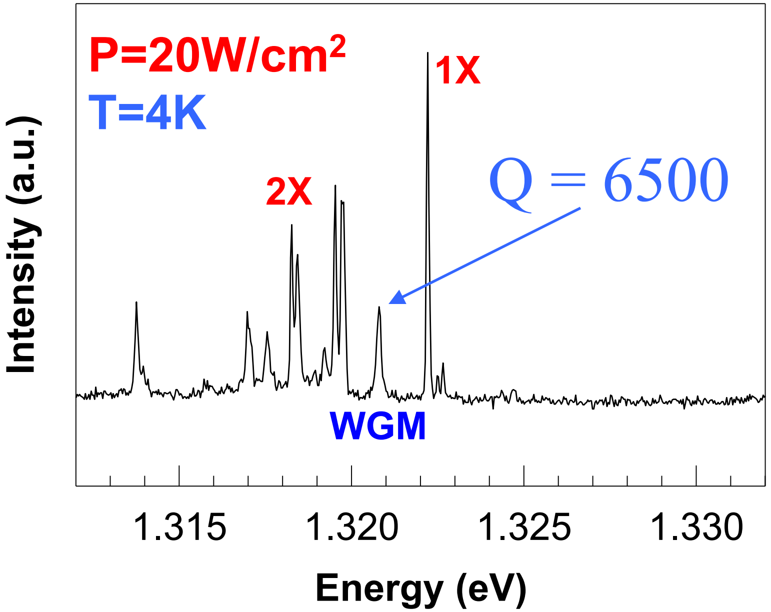
➔ all peaks in $G^{(2)}(t)$ have the same intensity
➔ pulsed coherent light

➔ the peak at t=0 disappears.
➔ single photon turnstile device with at most one photon per pulse

A single quantum dot embedded in a microdisk

Larger width of the peaks due to *longer lifetime* of the quantum dot





Pump power *well above* saturation level

Linear optics quantum computation (LOQC)

- Key step is two-photon interference on a beam-splitter:

$|y_{in}\rangle = |11\rangle$