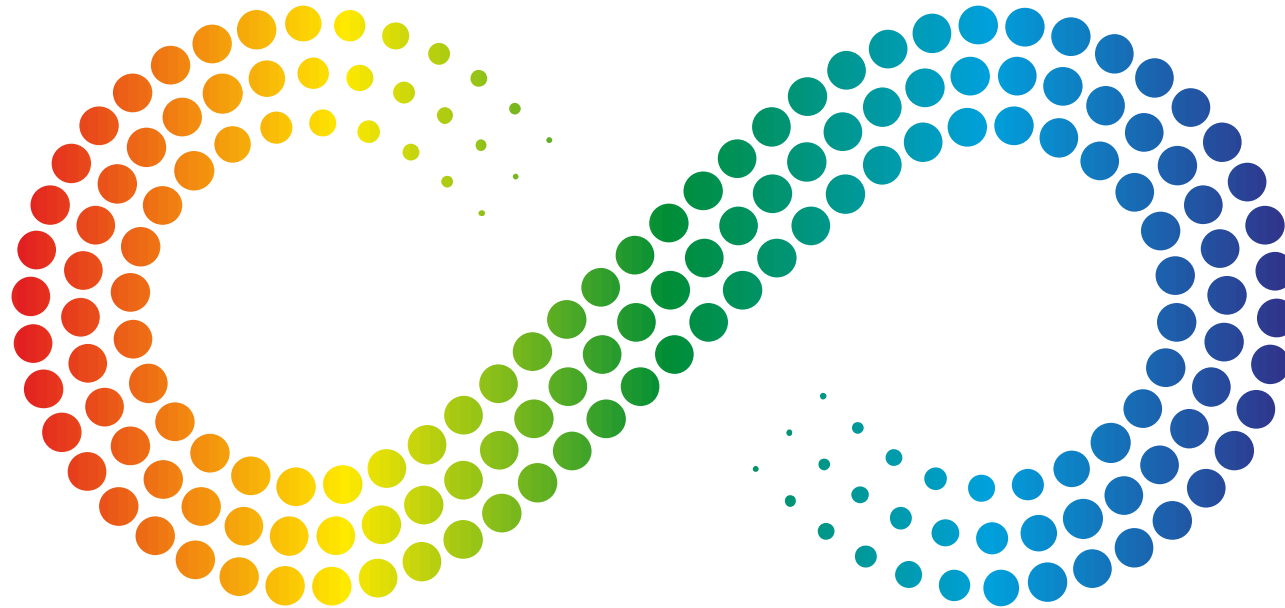


Molecular Seeding Technology: Enabling Display and Sensing Applications of the Future

Dr Nigel Pickett
September 2024



Business Description

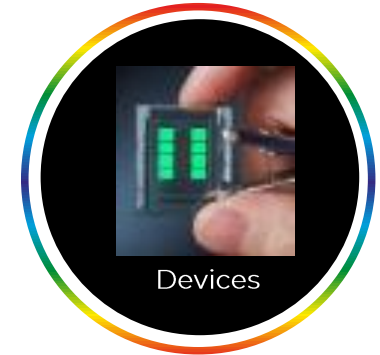
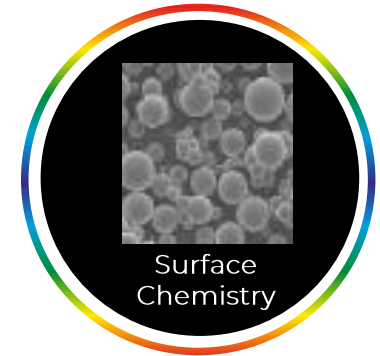
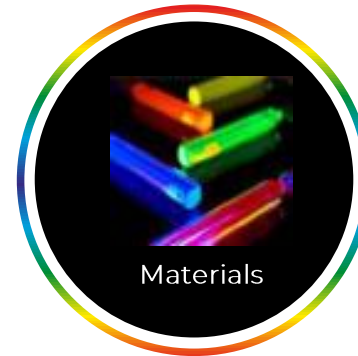
Status: Public (LON: NANO)
Founded: 2001
Headquarters: Runcorn, UK
Employees: 53 (16 PhDs)



Leader in the R&D, licensing and manufacture of high performing semiconductor nanoparticles

Key strengths include:

- Pioneer in cadmium-free quantum dots (CFQD[®] materials)
- IP protected
- Large scale production facility Runcorn UK
- Large patent portfolio (> 350 patents and patent application), with licensees including Samsung and Dow
- Unique IP-protected scale-up capability
- Key patents validated by PTAB in US



Serving multiple large and diverse end markets

Sensing

Display

QLED TV

Next-generation Technologies

bits	p-bits	q-bits
Either 0 or 1	Fluctuate Between 0 and 1	Superposition of 0 and 1

Company Origins

- 2000: most electronic devices produced by solid-state processes
- Mass produce: need cheap solution process methods
 - Quantum dots (QDs) fit in as solution, e.g. inkjet printing, spin-coating, dip-pen lithography
- 2001: Nanoco founded to address this problem
 - Large-scale manufacture of high quality QDs, especially III-V materials
 - Less toxic materials

Strengths

- Nanoparticle synthesis, particularly III-V QDs
- Scale-up
 - ISO 9001 & 14001 accredited



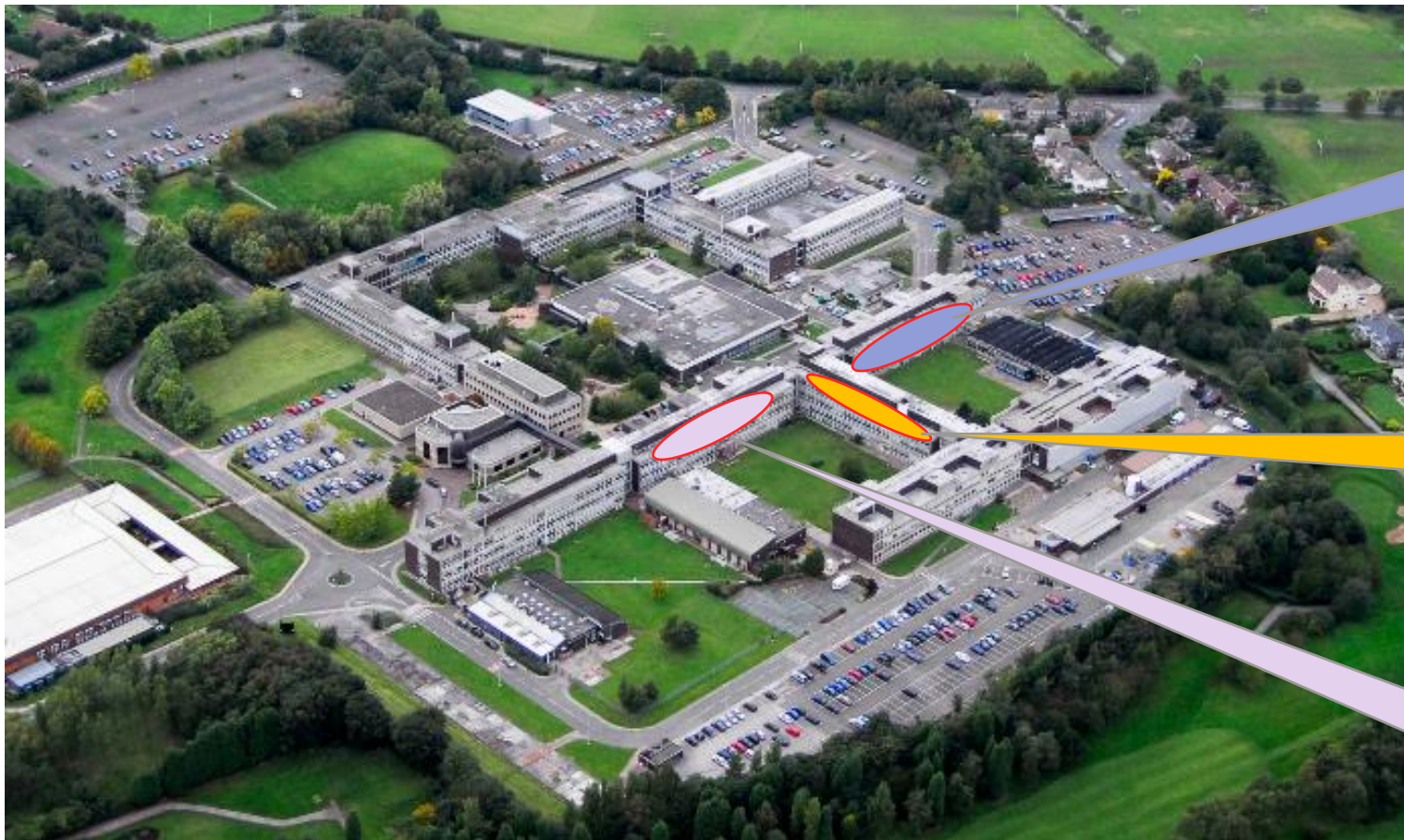
Early 2000s –
Office in converted men's toilet at UoM



2024 –
R&D and production facility in Runcorn

Location

- Nanoco's 30,000 ft² facility located in Runcorn, Cheshire
- Shared site – former ICI R&D centre
- Nanoco is single largest tenant
- All operations on this one site

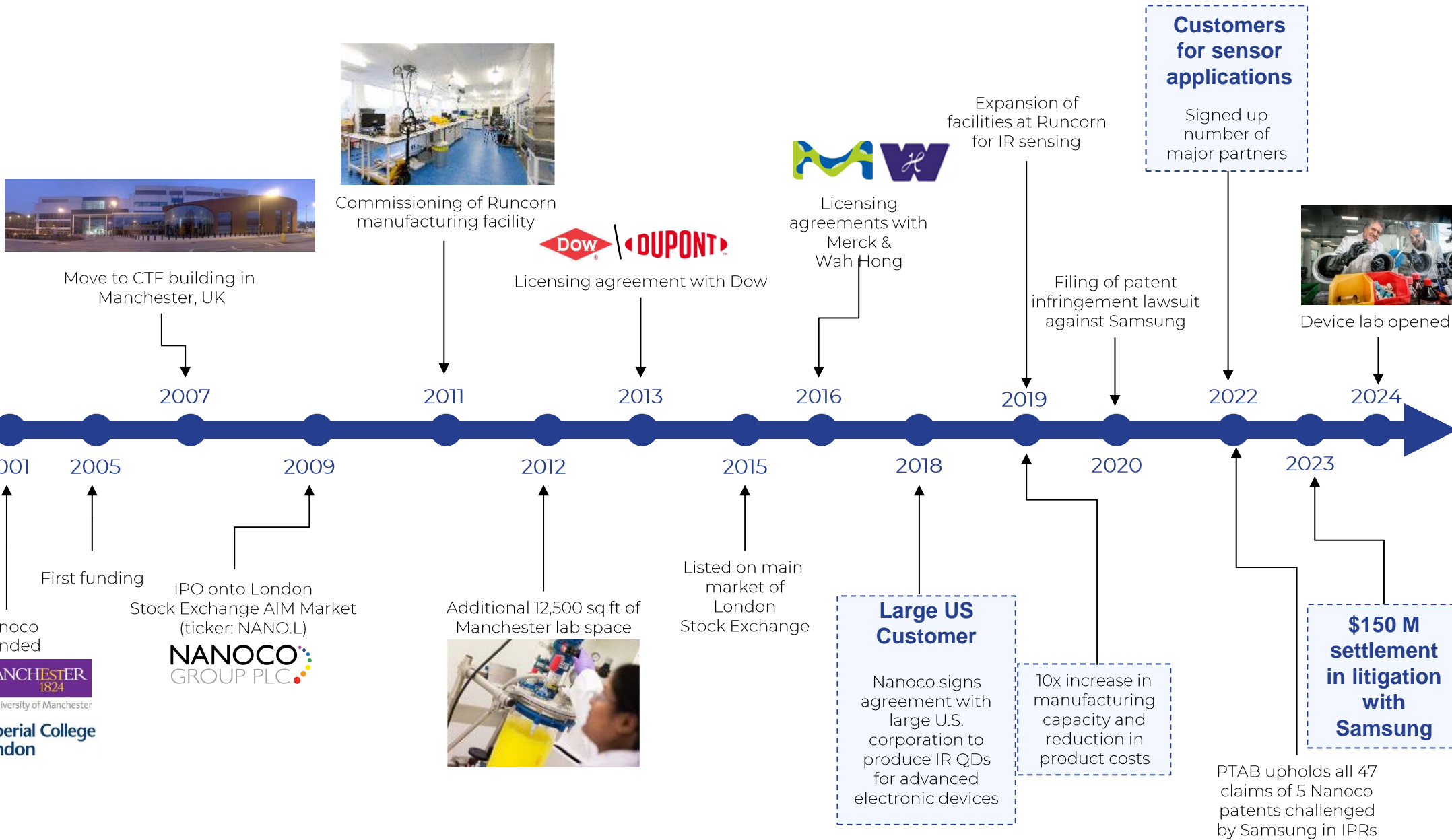


Block 1 – large-scale
production facility

Block 2 – device
facility

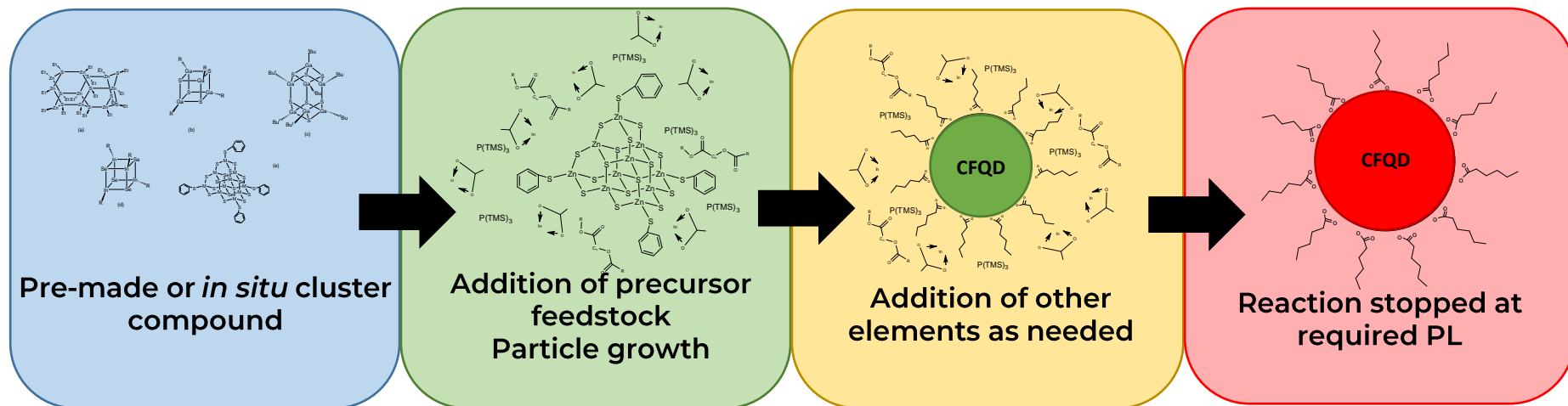
Block 3 – materials
R&D

A Pioneer in Quantum Dot Technology



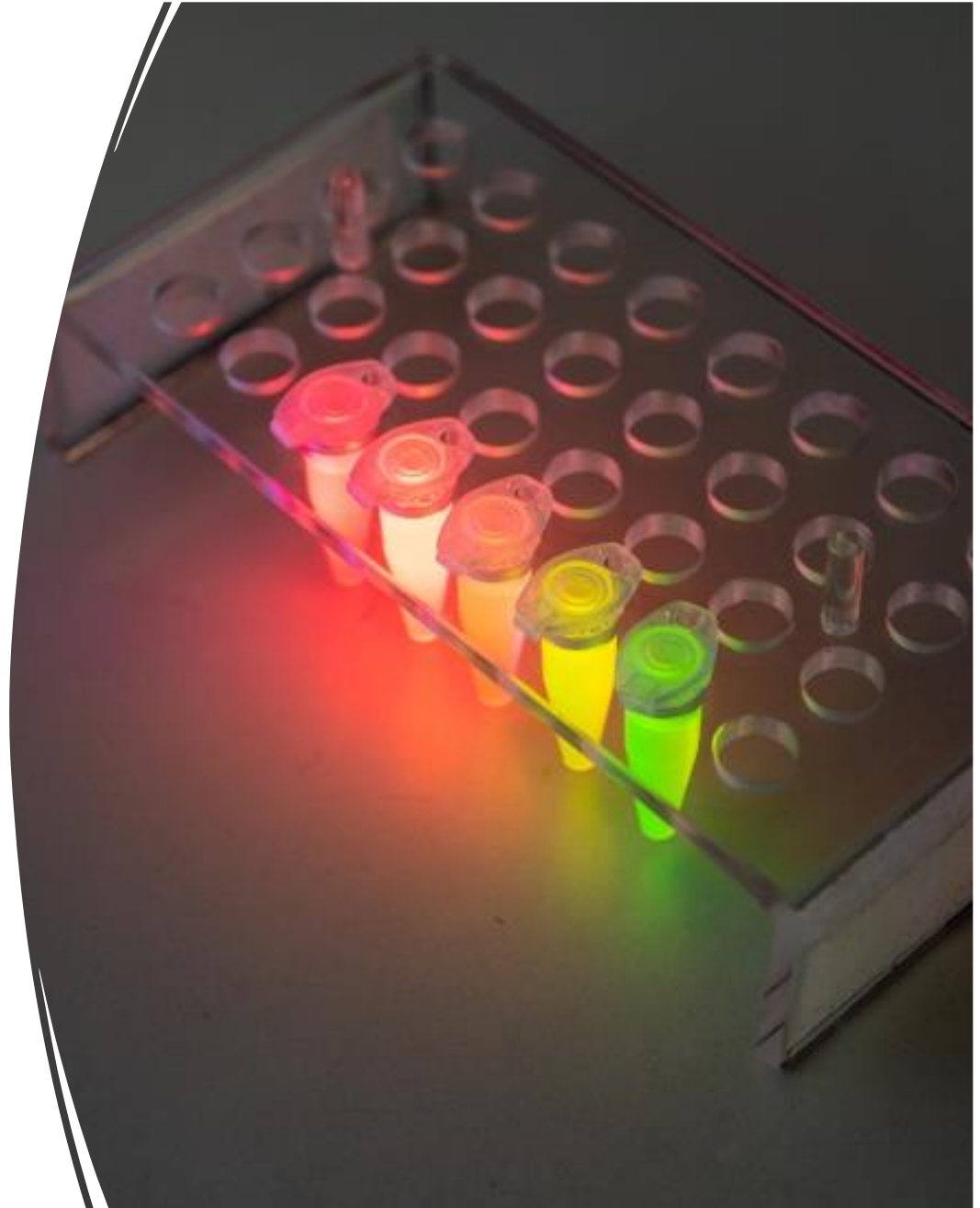
Molecular Seeding Technology: Industrial Process

- Main barrier was scale-up
- “Molecular seeding” process: molecular cluster compound acts as nucleation site for QD growth
 - Seed formed prior to/at early stage of synthesis
 - Removes need for high temperature injection step
- Easily scalable
- Works very well for many nanomaterials, e.g. III-V
- Cost-effective on large scale
- **IP fully validated in US by PTAB and licensed to Samsung**

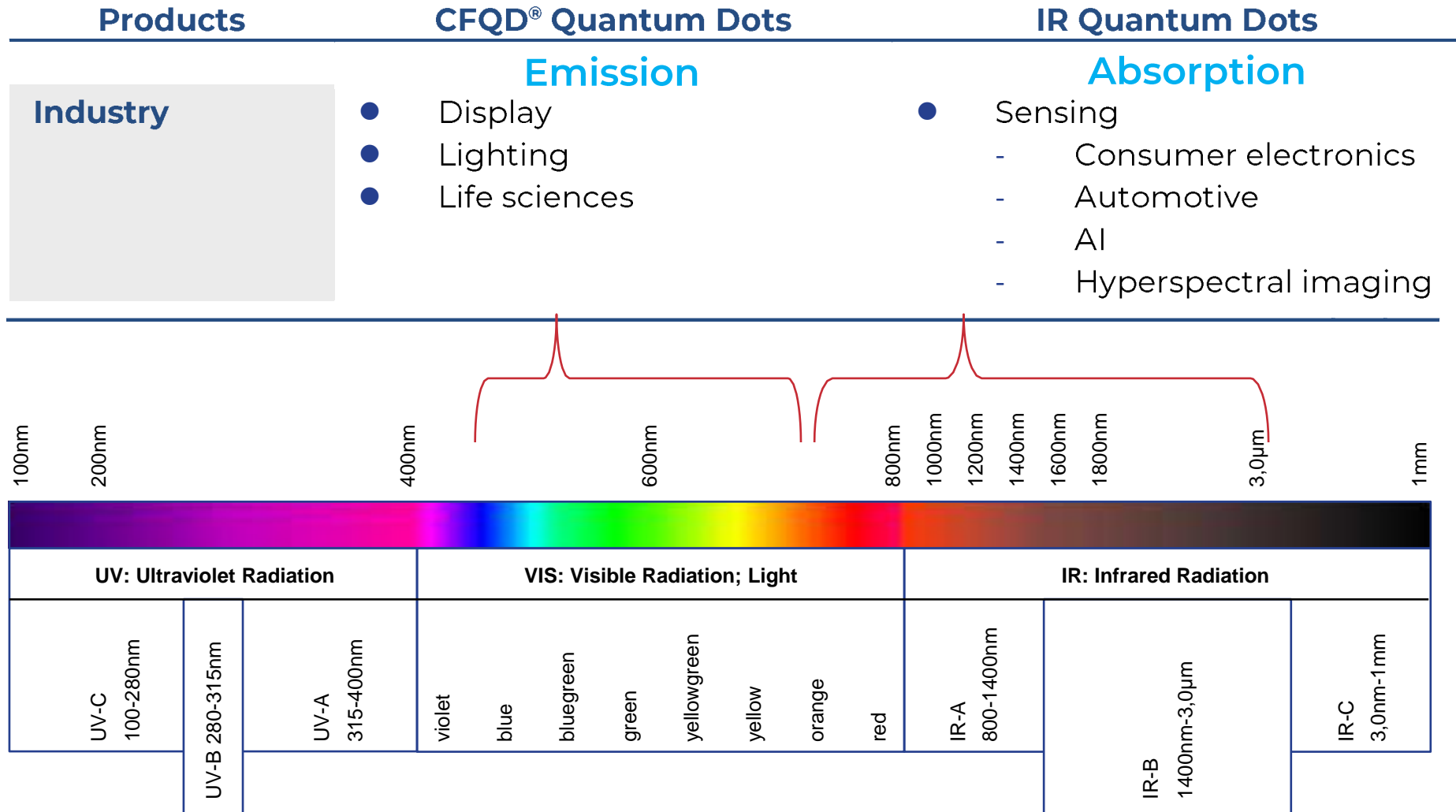


Intellectual Property

- As a small company, IP is critical to Nanoco's success
- Large IP portfolio covering:
 - Materials
 - Synthesis
 - Compositions
 - Functionalisation
 - Encapsulation
 - Devices
- “Molecular seeding” patents fully validated during litigation with Samsung – settled for \$150 million
- Independent expert opinion that III-V (*i.e.* Cd-free) QDs cannot be made on a commercial scale without infringing Nanoco's IP
- Licensees include Samsung and Dow
- Continuing to innovate and protect our IP



Quantum Dots – a “Platform Technology”

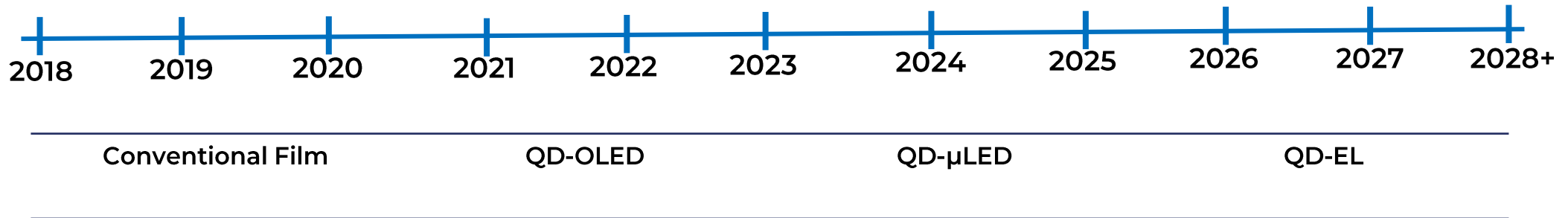
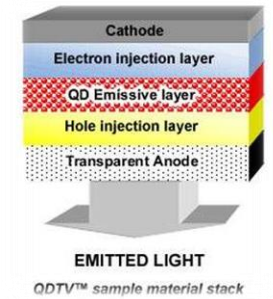
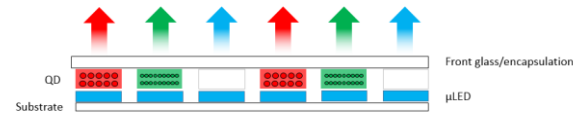
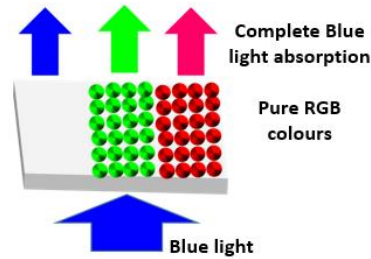
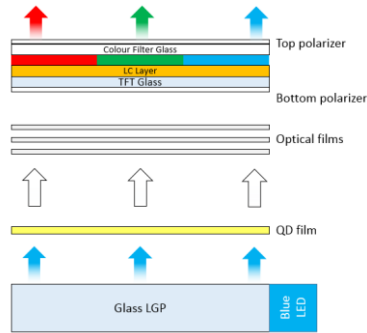


“Dot only” strategy allows us to focus on core capability of high quality nanomaterials development and scale-up, tailored for partners’ applications

R&D, Scale-up, Production & Device Capabilities



Nanoco active in display – mainly IP & royalties



- Next implementation – μ LED – presents similar issues to OLED in terms of prohibitive cost
- Need QDs; most other phosphors are not soluble for inkjet printing
 - Needs add-on
 - One way is to integrate sensors into displays

Markets and Applications

- Potential **DISPLAY** applications



TV



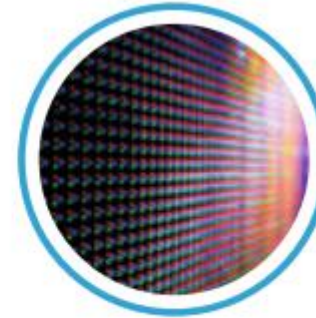
Tablets



Phones



Headsets



Monitors



Smart watch

- Potential **SENSING** applications



**Face / Iris
recognition**



**Agricultural
drones**



ADAS



**Quality control
systems**



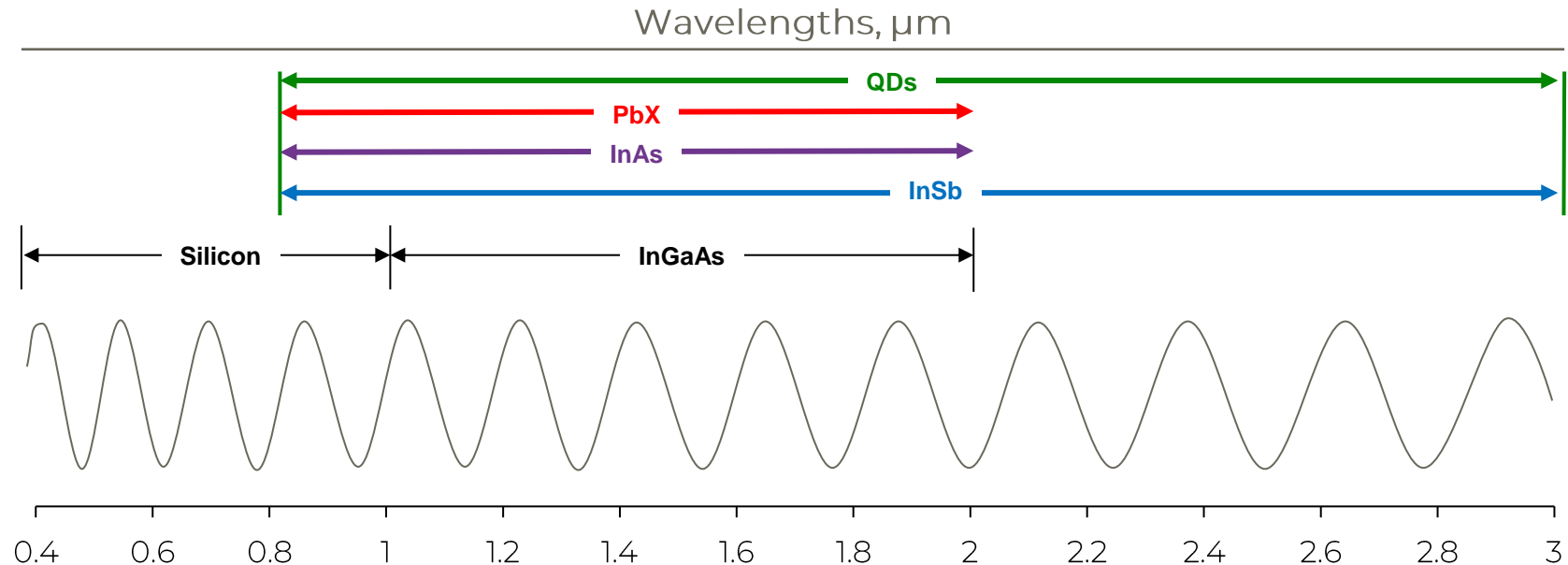
**Wearable
diagnostics**



**Security &
surveillance**

Why Quantum Dots for Sensing Applications?

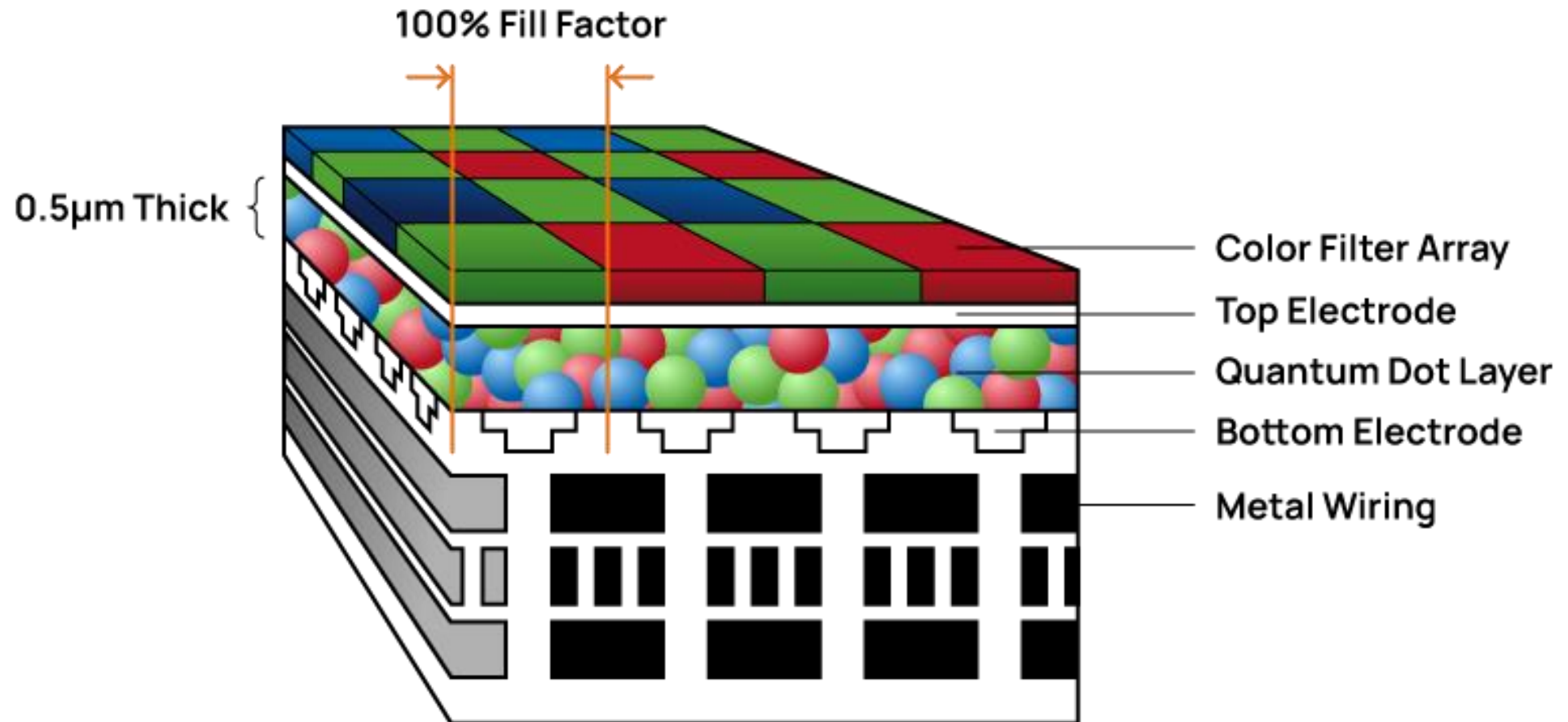
QDs expand absorption range of silicon sensors into the infrared at lower cost than InGaAs



Advantages of Quantum Dots

- Process compatible with silicon CMOS technology
- More sensitive, thinner, lower power sensors
- Expand working dynamic range of CMOS devices
- Inexpensive alternative to current InGaAs technology
- Nanoco's role in stack is QDs
- Work closely with device partners – iterative process

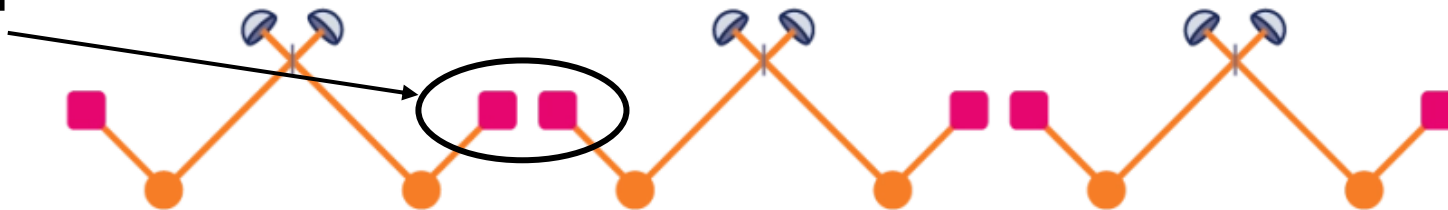
Why Quantum Dots for Sensing Applications?



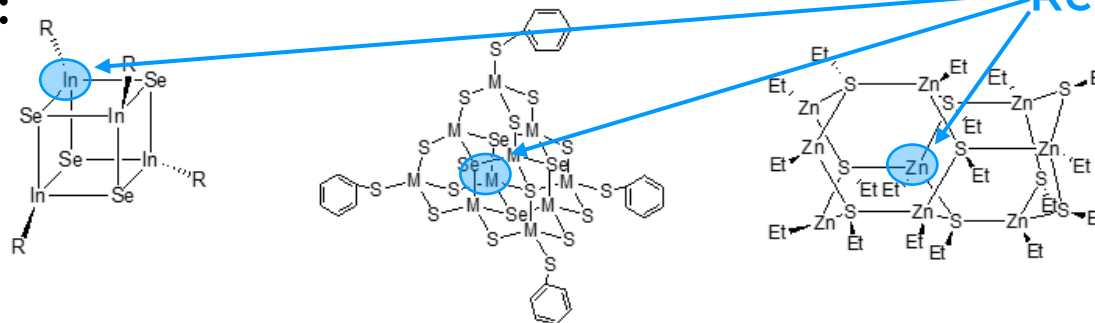
- Another area where molecular seeding process may enhance technology is in development of **singly-doped colloidal QDs for quantum technologies**
- Quantum communications networks currently limited to ~ 500 km
 - “Trusted nodes” being developed to extend range, but need human intervention so can be compromised
- Alternative is to use “quantum memory” as quantum repeater to amplify signal
 - Using singly-doped colloidal QDs doesn’t need human intervention, providing secure communications



Quantum repeater

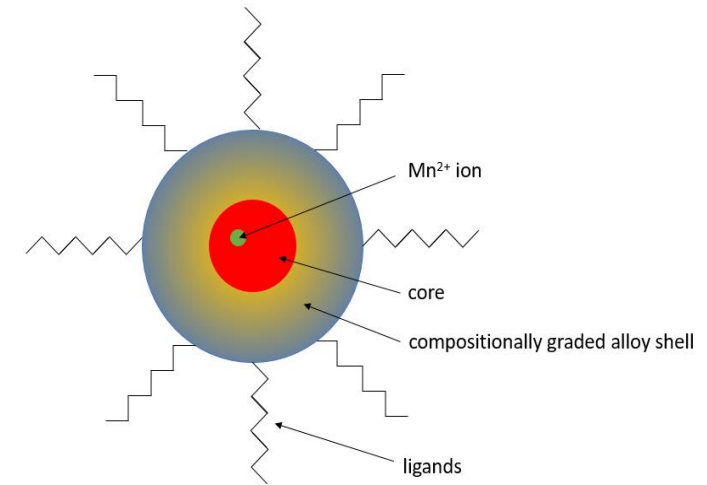


Singly-doped clusters:

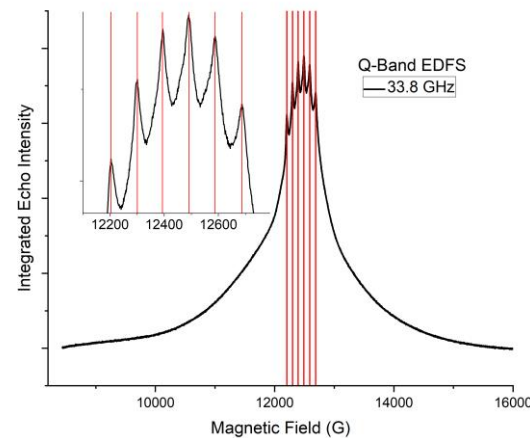
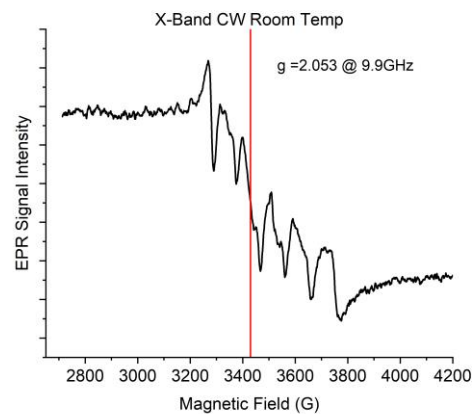
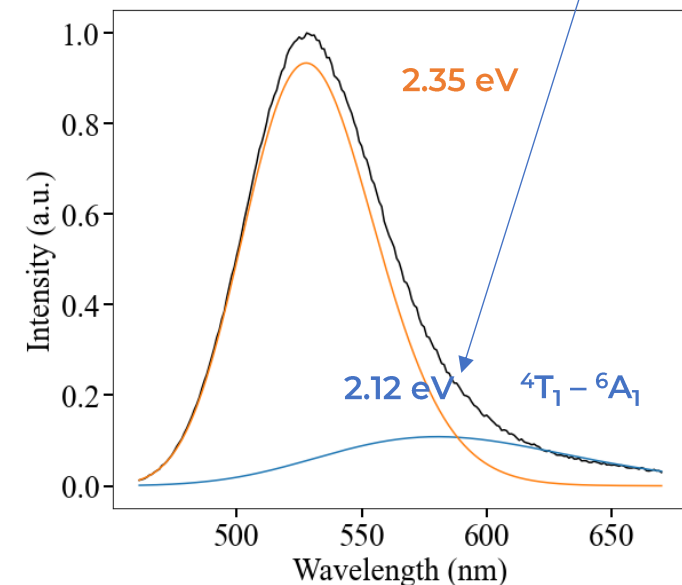


Replace one metal ion with dopant

- Nanoco has designed singly-doped cluster as building block for singly-doped QDs
- Precise doping with one dopant ion only per QD
- Proof-of-concept demonstrated
- Next step to build nano-antenna device demonstrator



Consistent with combined QD and Mn^{2+} emission



- EPR spectra show six peaks, characteristic of six spin states of Mn^{2+}
- Sharp peaks, especially in Q-band, consistent with doping of QDs with single Mn^{2+}

Summary

- Pioneer in nanomaterials synthesis
- Strong IP portfolio relating to:
 - Materials
 - Scale-up
 - Surface functionalisation
 - Formulation
 - Device integration
- Validated IP licensed, with licensees including Samsung
- Current focus on sensing and displays
- Continuing to innovate and explore new areas such as quantum technologies



