

Quantum Dots — One-Page Primer (2026)

Semiconductor nanocrystals 2–10 nm with size-tunable light emission due to quantum confinement.

Core Physics

• QDs emit pure monochromatic red/green/blue light. Energy levels depend strongly on size. CdSe tunes from red (~5 nm) to violet (~1.5 nm). Bandgap $\propto 1/\text{size}^2$ — smaller = bluer photons. Two modes: photo-emissive (PL) and electro-emissive (EL).

Key Families (2025–2026)

Type	Strength	Note
II–VI (CdSe)	Highest color purity	Restricted by RoHS
III–V (InP)	Cadmium-free	Lifetime improving
Carbon QDs	Low toxicity, soluble	Bio, sensing
Perovskite CsPbX ₃	PLQY 50–90%	Patternable
MXene N-MQDs	Portable sensing	Smartphone readout
Ag ₂ S QDs	NIR imaging	■Ga-labeled tumors

Applications

Displays: As of June 2025, all QLED TVs use photo-emissive QDs; EL-QLED only in labs. QD-OLED (since 2023) reaches ~90% Rec.2020 at 1500 nits. Micro-LED QD-COB 0.22" commercial 2023–24; 0.13"/0.39" pilots 2025.

Quantum comms: U. Copenhagen QD source emits 40M identical telecom O-band photons/s — fiber-compatible.

Biomed: ■Ga-Ag₂S QDs for breast tumor imaging; CQDs for low-toxicity biomarker detection.

Sensing: CQDs & N-MQDs for environmental/pharma monitoring; Cu-In₂S₃/CeO₂ detects Pb²⁺/Cd²⁺/Hg²⁺ at 32–60 nM; perovskite QDs reach 0.1 nM via cation exchange.

Security: QD-PUFs use intrinsic randomness for anti-counterfeiting.

Forensics: CQDs enhance fingerprints, drug ID — challenges: reproducibility, standards.

Energy: Surface engineering improves emission efficiency for PV/lighting.

2025–2026 Trends

• Cadmium → InP/perovskite-free transition • QD integration with AR micro-LEDs • Telecom single-photon pilots • Smartphone-linked point-of-care sensors • QD-PUF supply-chain trials

Challenges

• RoHS toxicity limits • EL-QD conductivity & lifetime (Nanosys targets prod. ~2026, market ~2029) • InP stability • Standardization for bio/forensic use • Micron-scale patterning yield

Sources: Wikipedia QD Display (2025), Nature Sci Rep Ag₂S, RSC Advances (CQDs, MXene, PUFs, sensing), Phys.org roadmap, TechXplore telecom photons.