Science Turns to Technology: Quantum Dots and Perovskite Thin Films



November 6, 2026

MITei Celebration

2023 Nobel Prize in Chemistry: For the Discovery and Synthesis of Quantum Dots



Louis E. Brus

Alexei Ekimov

Stockholm, Dec. 10 2023



Discovery – 1980-1983

Ekimov, A. I.; Onushchenko, A. A. Quantum Size Effect in Three-Dimensional Microscopic Semiconductor Crystals. *JETP Lett.* **1981**, *34*, 345– 349.

Rossetti, R; Nakahara, S.; Brus, L. E. Quantum Size Effect in the Redox Potentials, Resonance Raman Spectra, and Electronic Spectra of CdS crystallites in aqueous Solution. *J. Chem. Phys.* **1983**, *79*, 1086–1088.

2023 Nobel Prize in Chemistry: For the Discovery and Synthesis of Quantum Dots



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Stockholm, Dec. 10 2023



Discovery – 1980-1983

Synthesis – 1993

Murray, C. B.; Norris, D. J.; Bawendi, M. G. Synthesis and Characterization of Nearly Monodisperse CdE (E = S, Se, Te) Semiconductor Nanocrystallites. *J. Am. Chem. Soc.* **1993**, *115*, 8706–8715.

MIT QDs 1990-1993

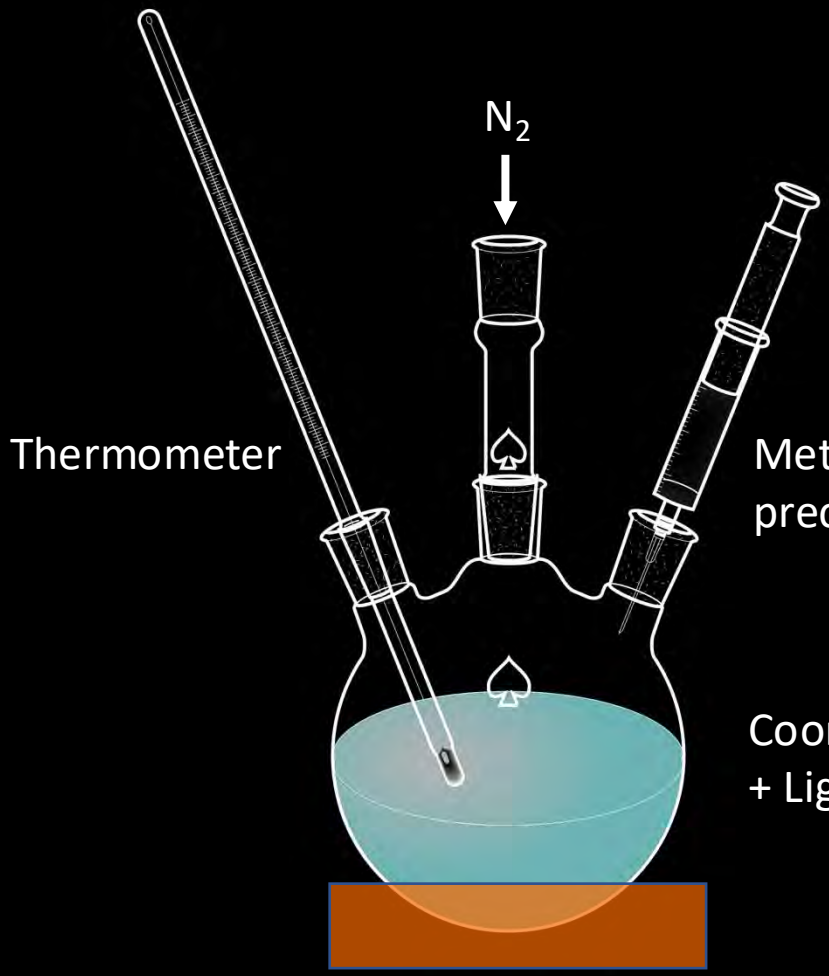
High Temperature Nucleation and Growth



Christopher Murray, early 1990's



David Norris,
early 1990's





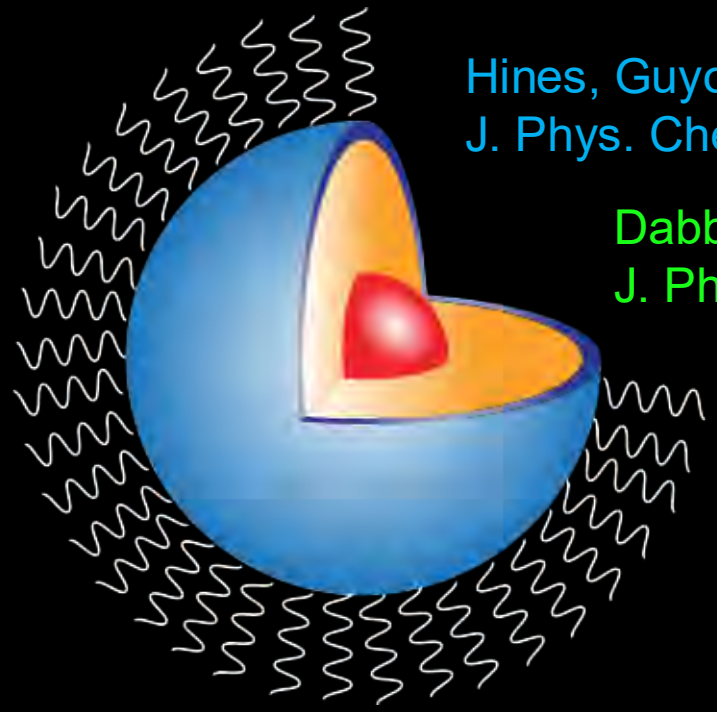
Core-Shell QDs, Bright Emitters

Kortan,…MGB,…Steigerwald, Brus
JACS 112, 1327 (1990)
(CdSe)ZnS and (ZnS)CdSe, Room Temp prep



Core-Shell QD

Danek, Jensen, Murray, MGB
Chem. Mater. 8, 173 (1996) (CdSe)ZnSe

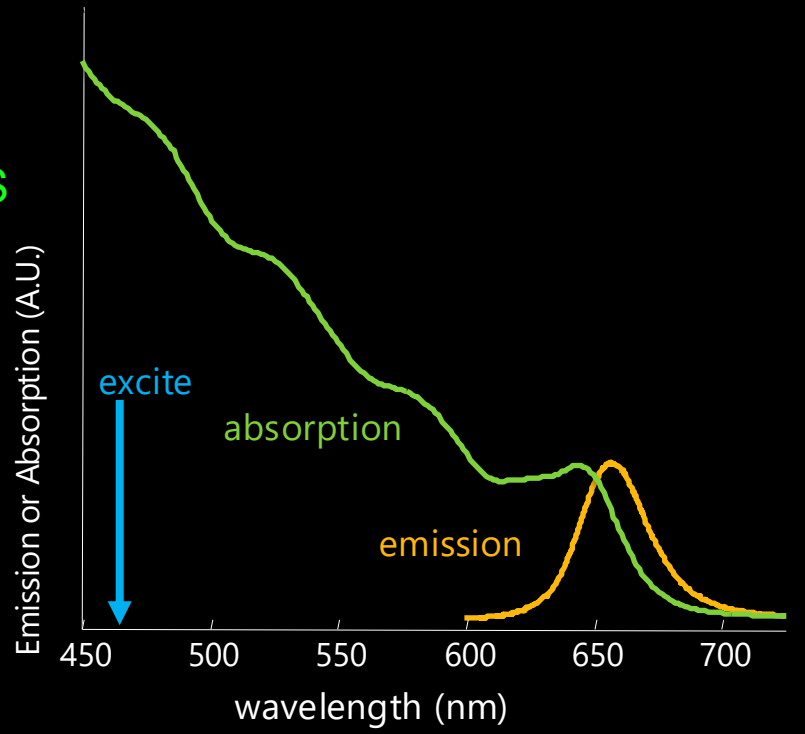


Graphic: D. Berkinsky

Hines, Guyot-Sionnest
J. Phys. Chem. B 100, 468 (1996) (CdSe)ZnS

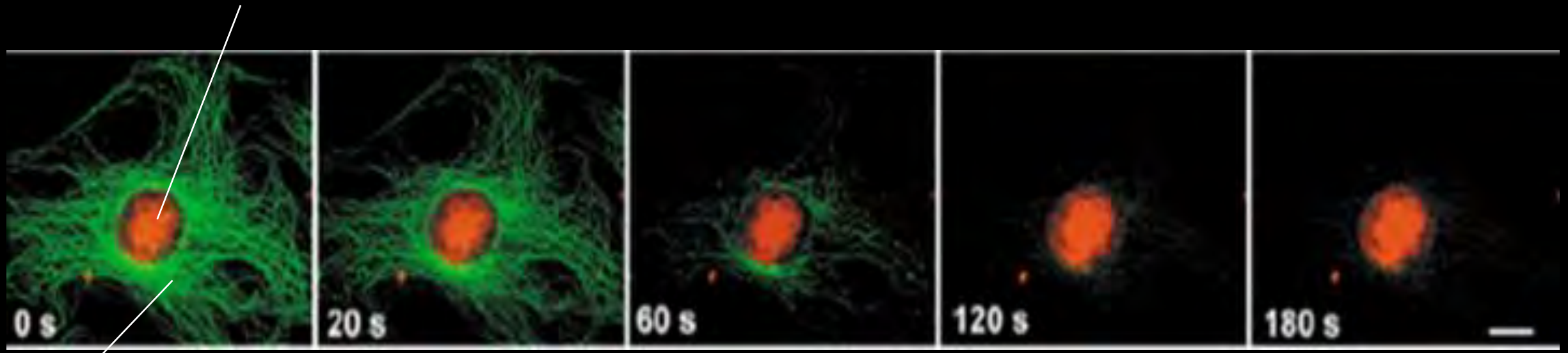
Dabboussi,…,MGB
J. Phys. Chem. B 101, 9463 (1997) (CdSe)ZnS

Peng,…,Alivisatos
JACS 30, 7019 (1997) (CdSe)CdS



APPLICATIONS IN BIOMEDICAL IMAGING (2000's- Today)

Cell imaging

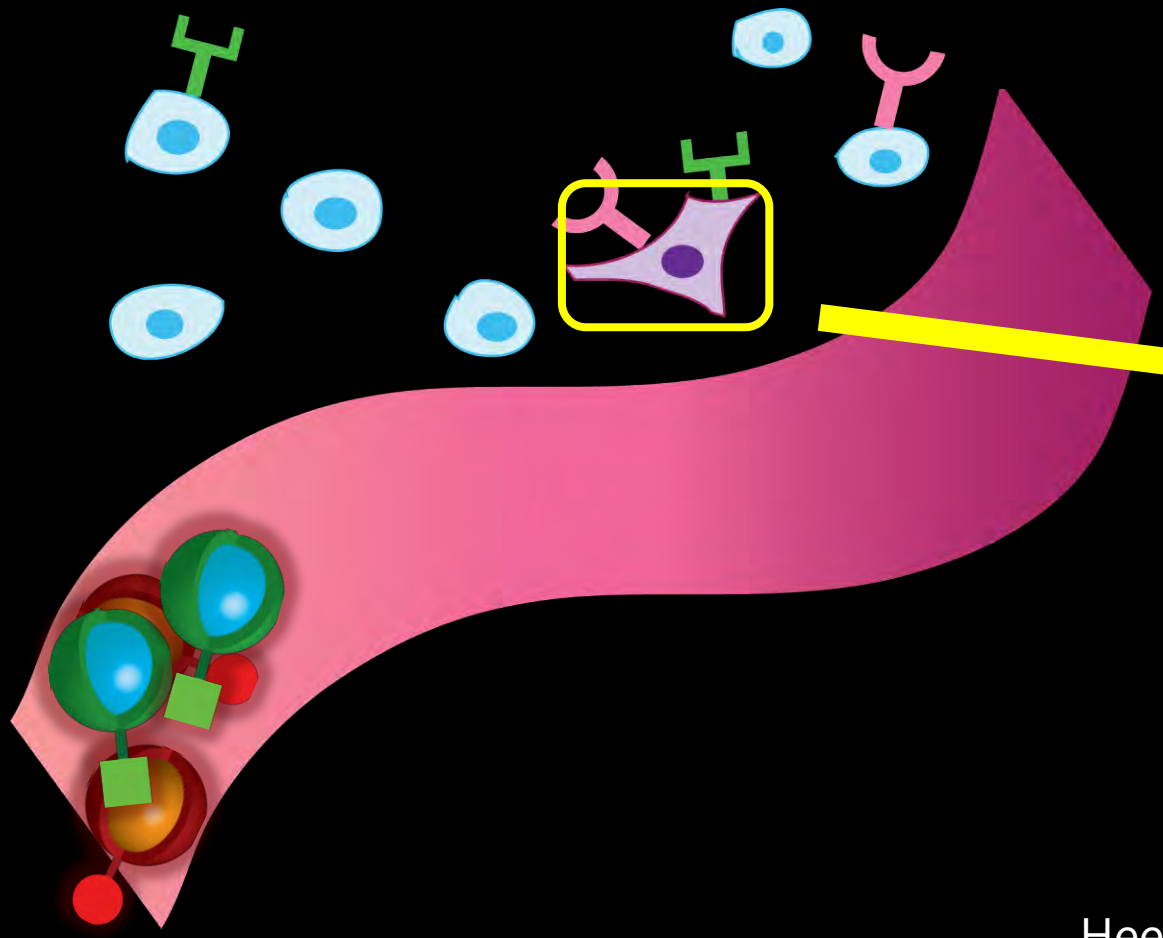


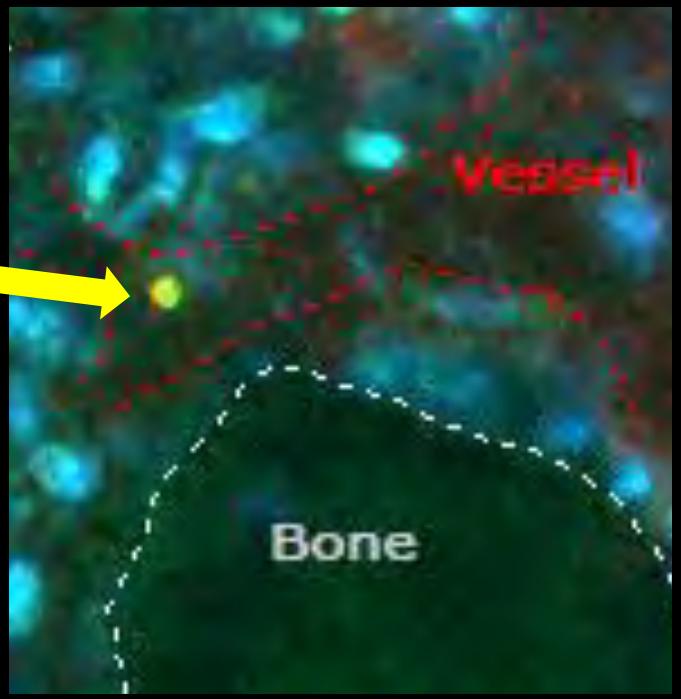
X. Wu et al., *Nature Biotechnol.* **2003,** *21*, 41-46
Quantum Dot Corporation

QUANTUM DOT CORP (1998)
(Now part of Thermo-Fisher)

Labeling and imaging single hematopoietic precursor cell (HPC)

- Intravital two-photon microspocy
- HPC labeling
  Bone marrow cavity (Calvarium window)
  Ab(Sca-1)$^{+}$, Ab(c-Kit)$^{+}$, Hoechst 33342^{-}



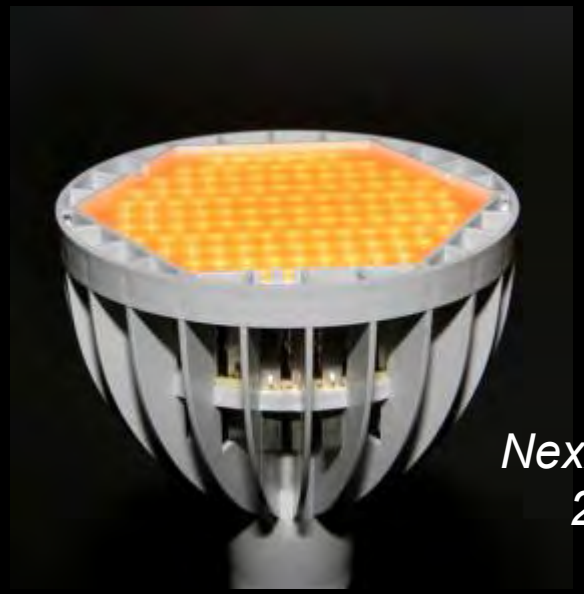


Han,…,Fukumura, Jain, MGB, Duda PNAS 112, 1350 (2015)

Hee-Sun Han with Steele Lab, Jain, Fukumura, Duda, MGH/Harvard Med School

Applications in color downshifting: lighting, displays, concentrators (2010's-today)

Nanosys Inc. (2002) (Now part of Shoei chemicals)
QDVision Corp (2005) (Now part of Samsung)



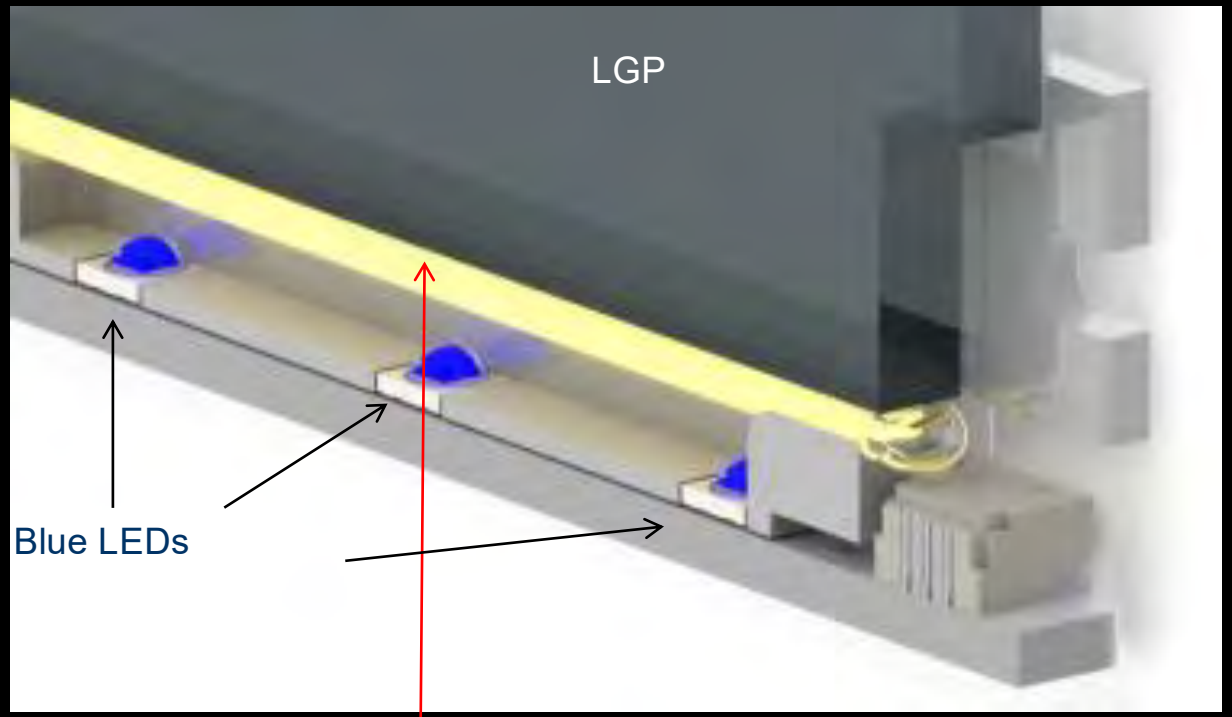
2010
Nexxus R30 LED Array
2700K, 90+ CRI,
>60 LPW

Courtesy of QD Vision

Applications in color downshifting: lighting, displays, concentrators (2010's-today)

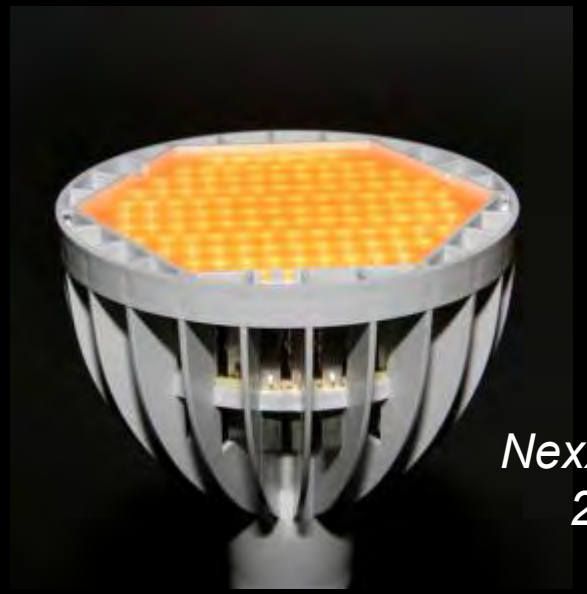
Nanosys Inc. (2002) (Now part of Shoei chemicals)
QDVision Corp (2005) (Now part of Samsung)

LED/LCD Displays



Green and Red Emitting Dots in Polymer

2012 Sony XBR 4K UHD – CdSe based



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Nexxus R30 LED Array
2700K, 90+ CRI,
>60 LPW

Courtesy of QD Vision

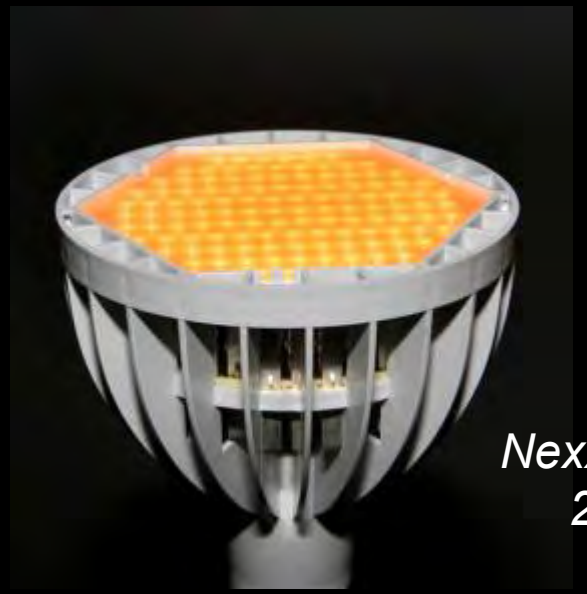
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LED/LCD Displays



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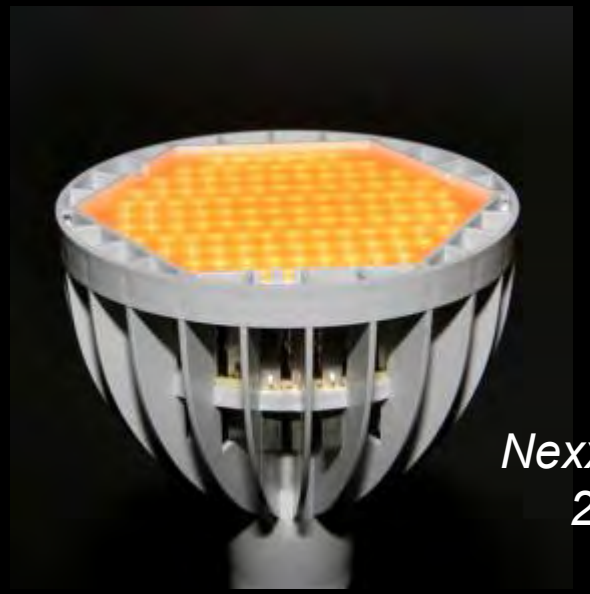
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LED/LCD Displays



Samsung - InP QD based displays 2015-today



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Nexxus R30 LED Array
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Courtesy of QD Vision

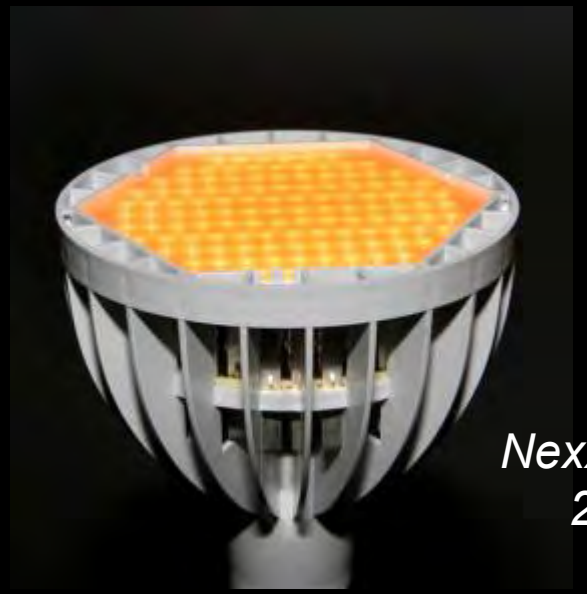
Applications in color downshifting: lighting, displays, concentrators (2010's-today)

Nanosys Inc. (2002) (Now part of Shoei chemicals)
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QD-OLED Displays



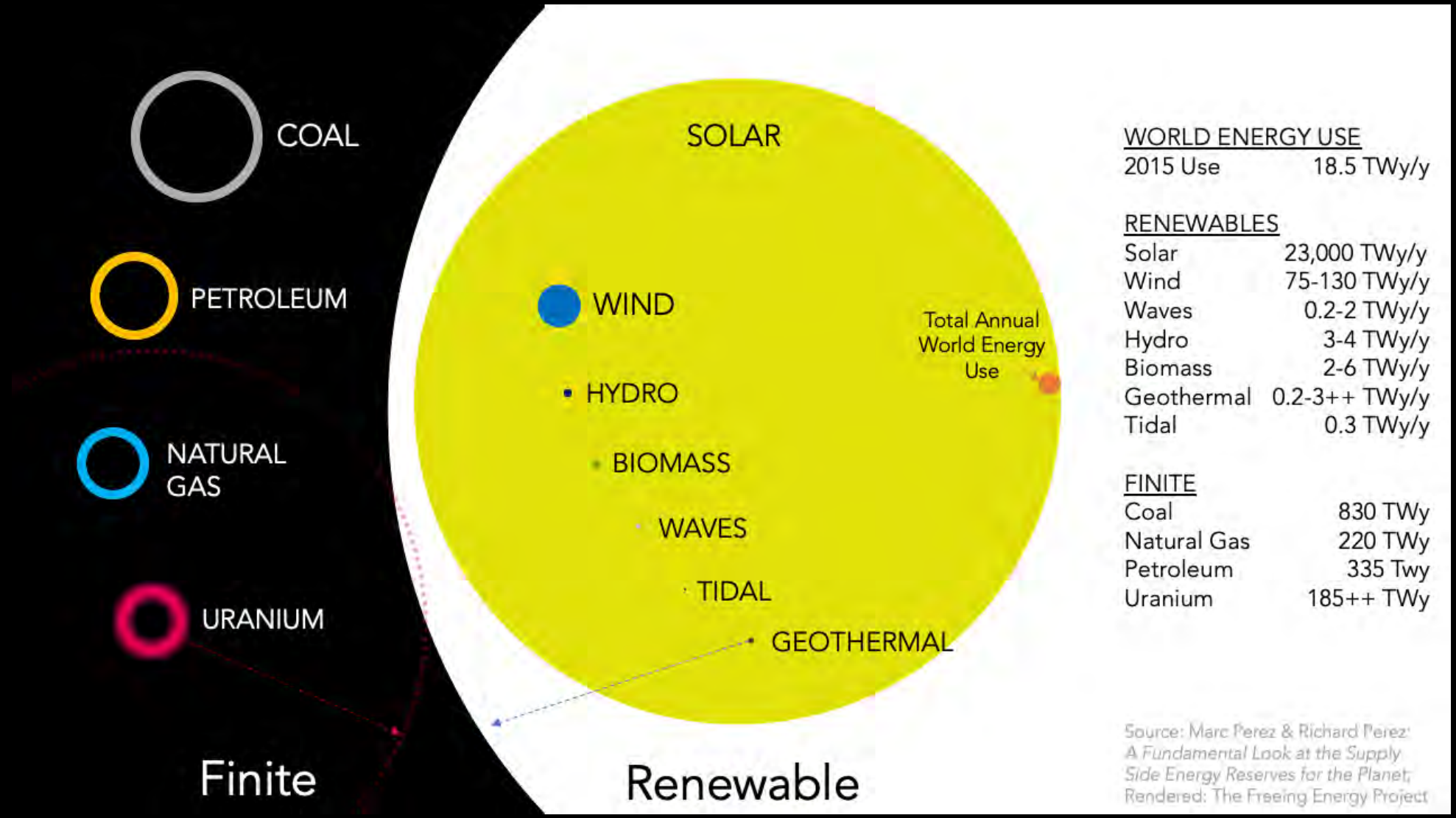
Samsung - InP QD based displays 2015-today



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Nexxus R30 LED Array
2700K, 90+ CRI,
>60 LPW

Courtesy of QD Vision

Why Solar



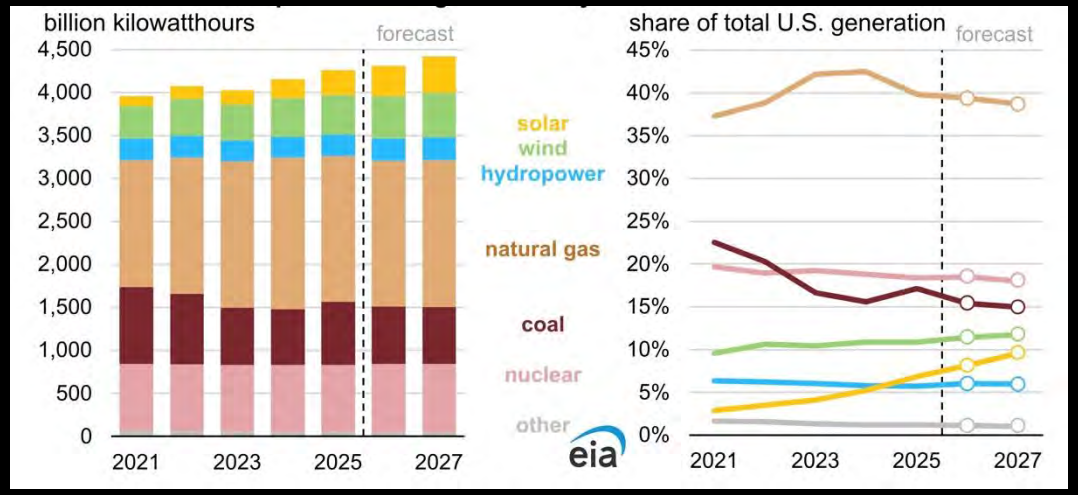
https://www.freeingenergy.com/the-earth-gets-more-solar-energy-in-one-hour-than-the-entire-world-uses-in-a-year/

Harvesting Energy From Sunlight With Solar Photovoltaics (PV)

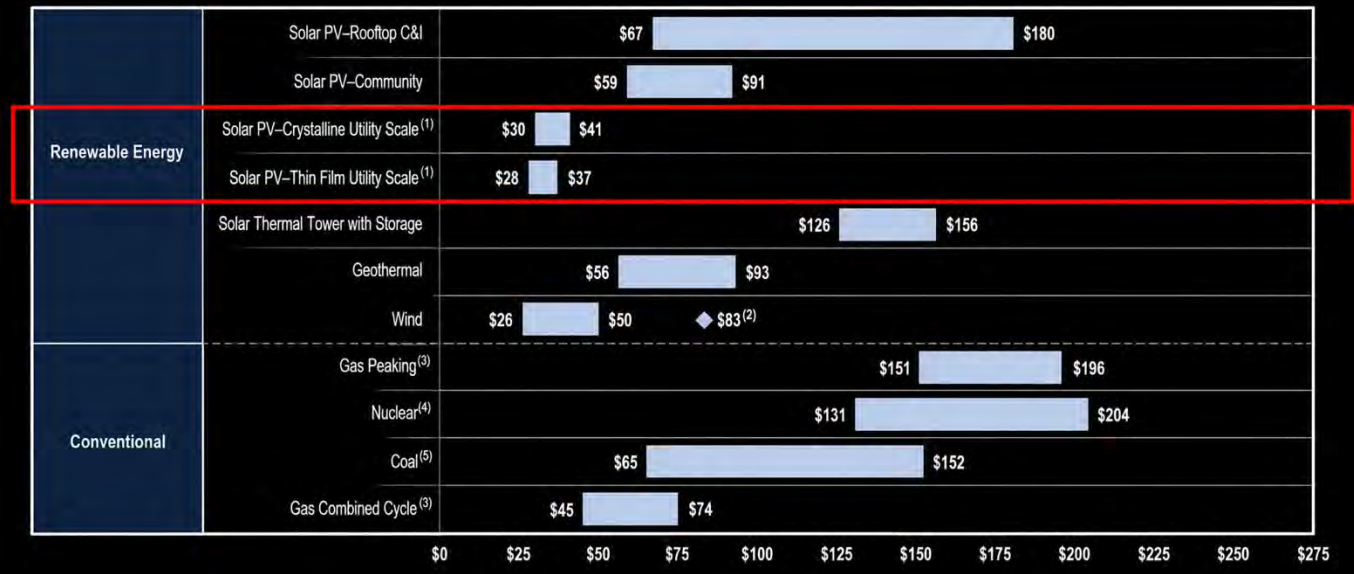
Silicon PV. Credit: Intermountain Solar, UT, USA



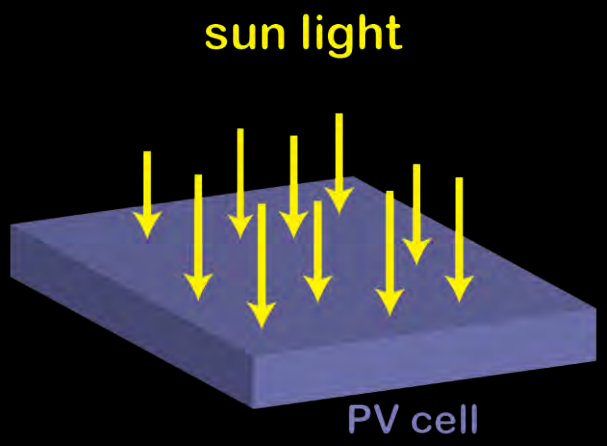
U.S. annual electric power sector by source. Credit: EIA.gov (Jan 2026)

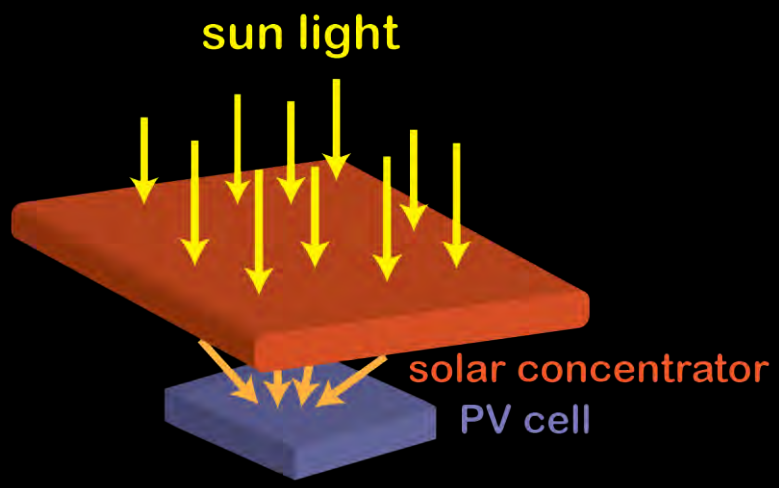


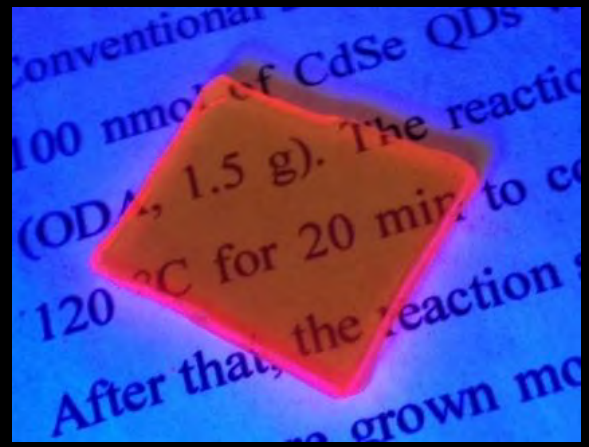
Levelized Cost of Electricity ($/MWh). Credit: Lazard 2023



Solar Concentrators: General Principles



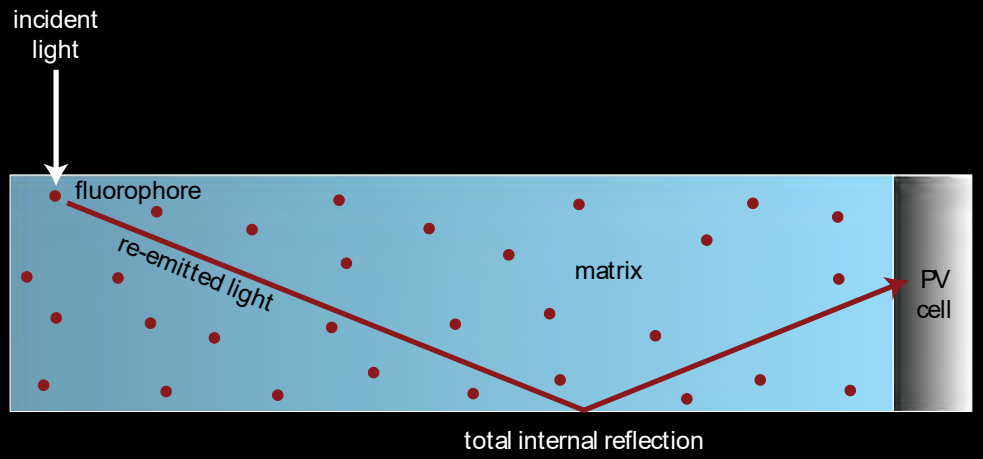


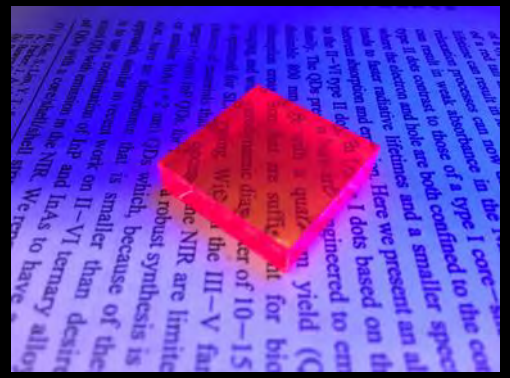


Luminescent Solar Concentrator
LSC

Luminescent Solar Concentrators (LSCs)

LSC structure

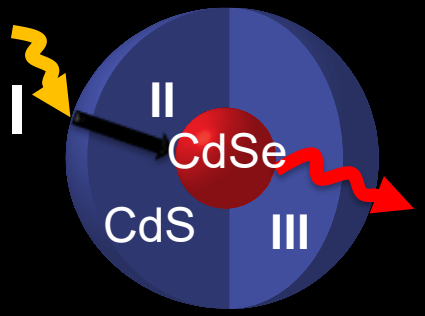




Requirements:

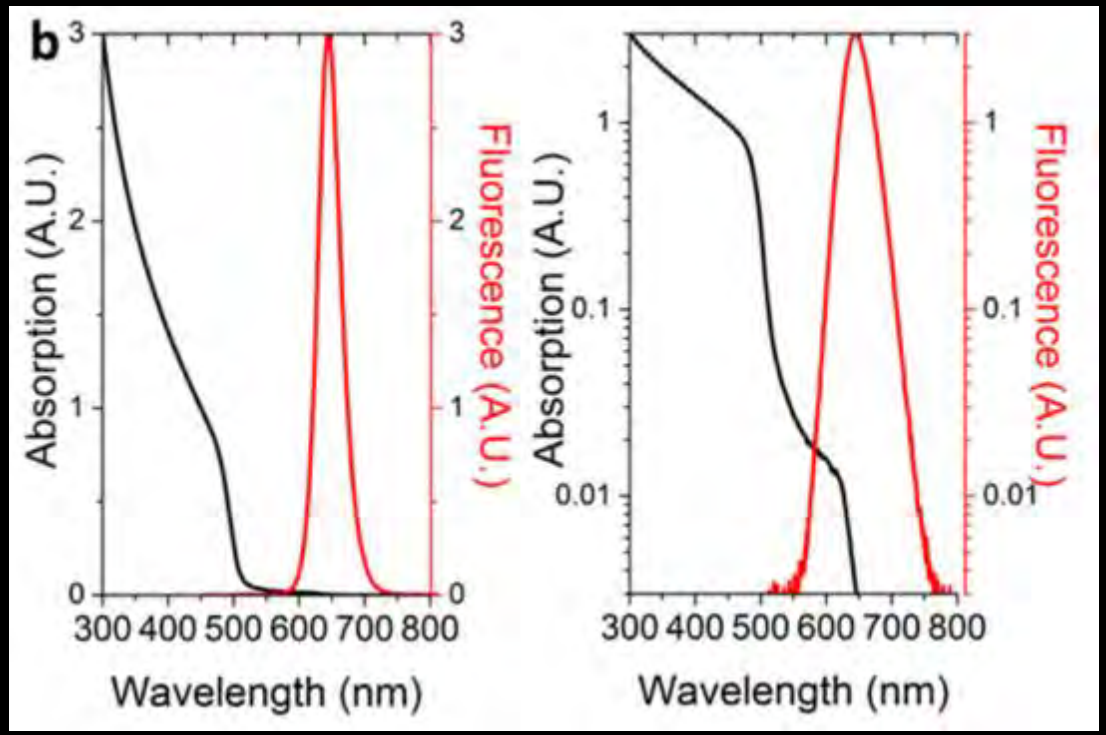
High concentration of fluorophores
High absorption cross section
Broad spectral absorption range
High emission quantum yield
Low absorption and emission overlap

Thick-Shelled Quantum Dots

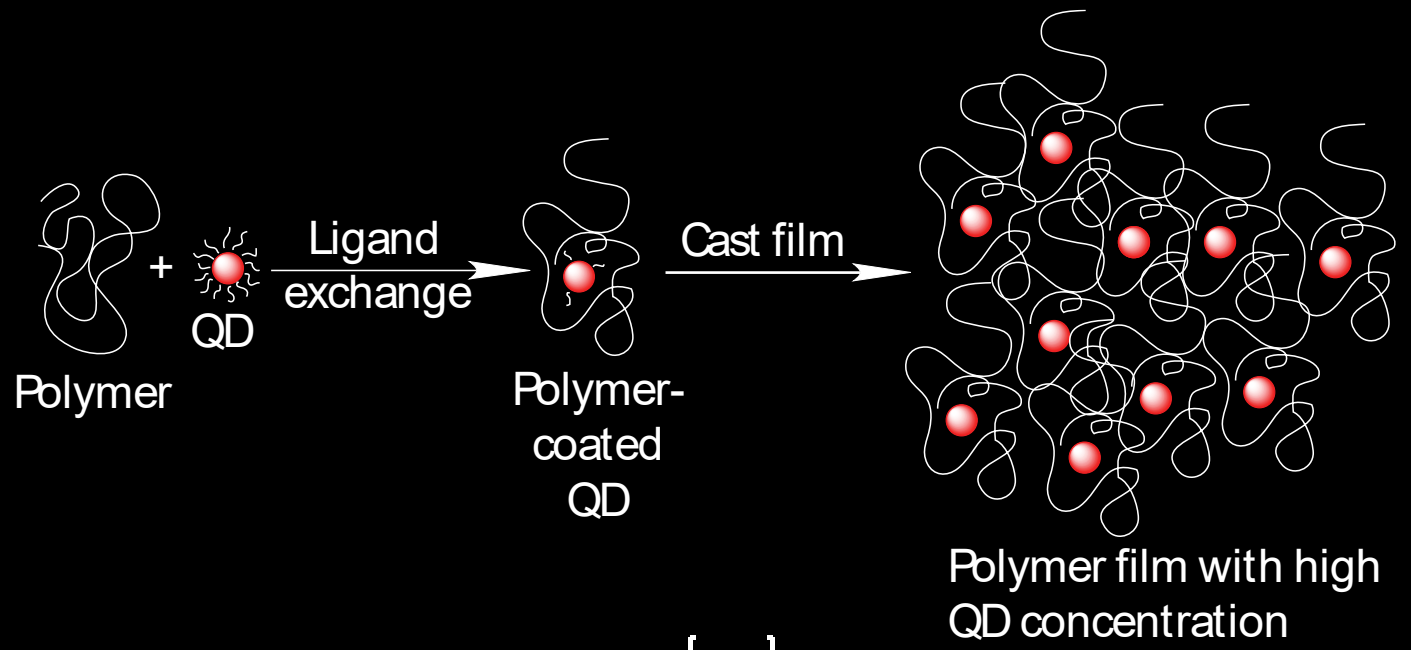


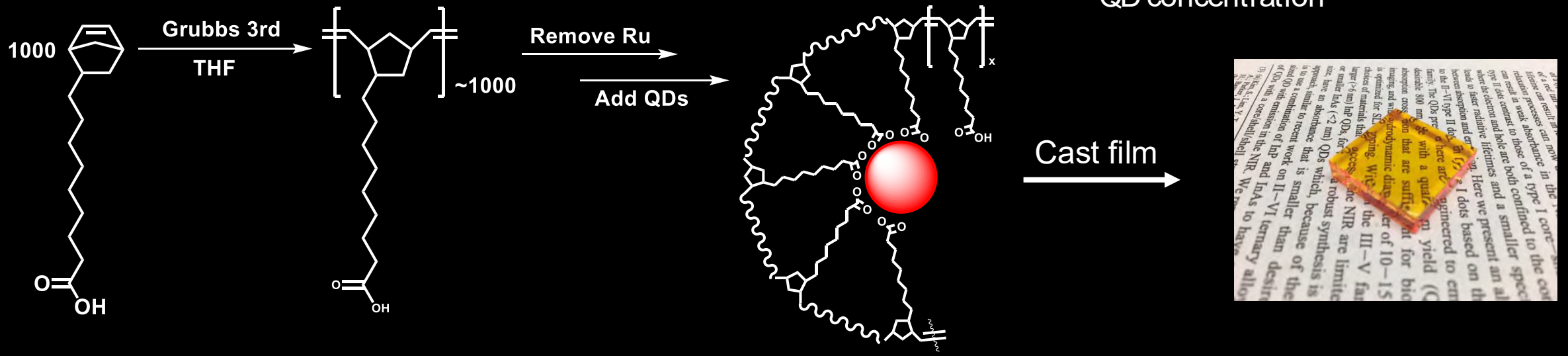
Cadmium selenide/cadmium sulfide

Physical separation of absorption and emission events leads to separation of the corresponding spectra and reduced reabsorption losses

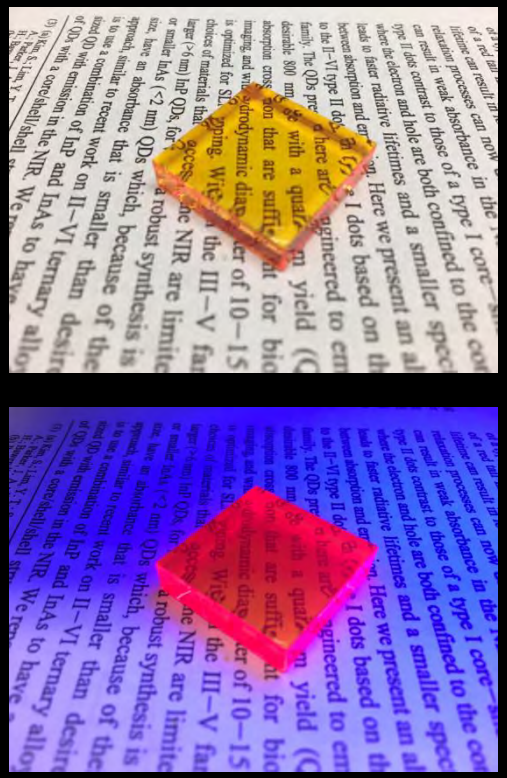


Thin-film LSC: Polymeric Ligand

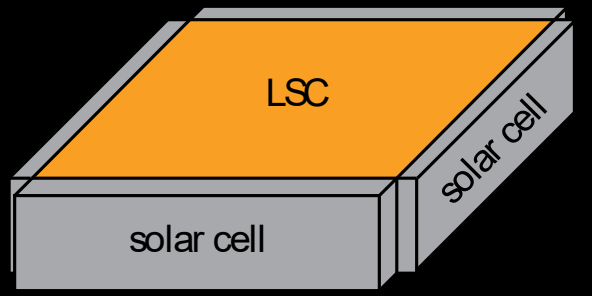




Thin-film LSC: Device Performance



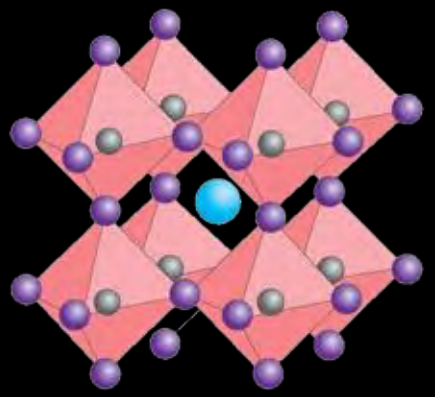
Thin film on 23×23×6 mm
PMMA waveguide



$$\text{Optical power efficiency} = \frac{light\ power\ incident\ on\ solar\ cells}{light\ power\ incident\ on\ LSC}$$

7.5%

Halide Perovskite Materials For Solar PV



A MA^+, FA^+, Cs^+

B Pb^{2+}, Sn^{2+}

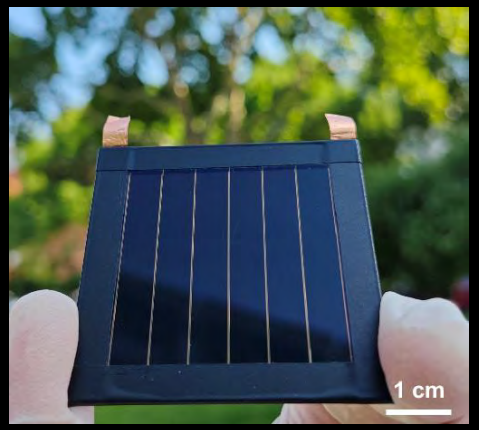
X Cl^-, Br^-, I^-

ABX_3 Halide Perovskites:

- ☑ Tunable bandgap
- ☑ High photon absorption
- ☑ Long carrier diffusion length
- ☑ Low-cost fabrication

Perovskite mini-module PV
5 cm x 5 cm area
22.73% efficiency

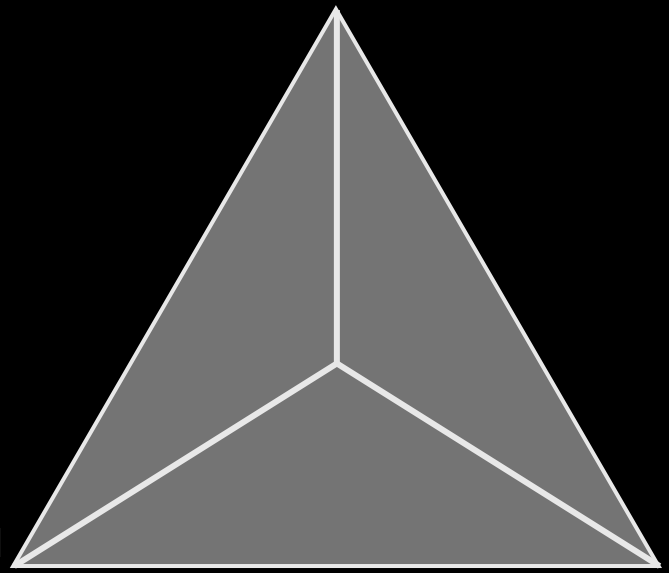
Credit: *Nat. Comm. 15, 6679 (2024)*



The benchmark is Silicon PV:

Performance
(Power Conversion Efficiency)

28.1% (as of 2026)



Operational Stability

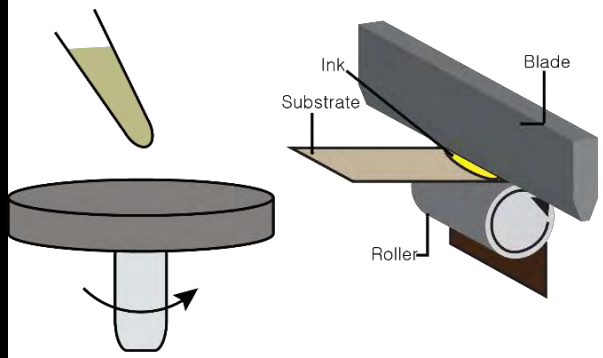
25 year
lifetime warranty

Industrial Scalability

Residential: ~1.0m x 1.7m area
Utility: 1.2m x 2.2m area

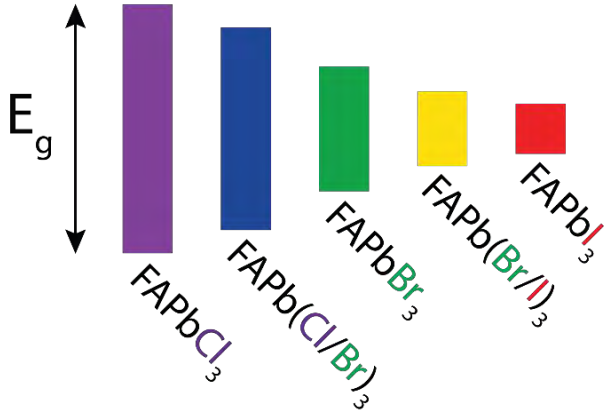
Why Lead Halide Perovskites?

Processing



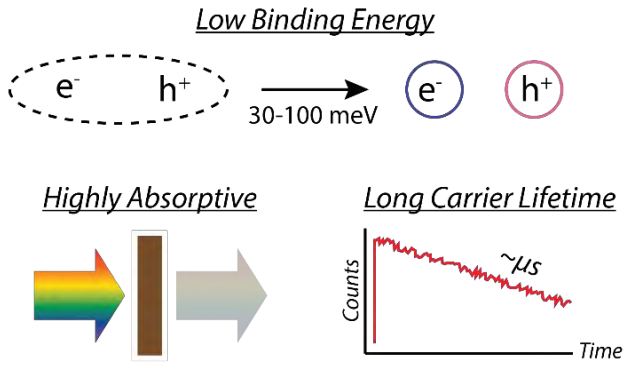
- Low Temperature
- Solution Processable
- Scale-up friendly

Tunable Bandgap



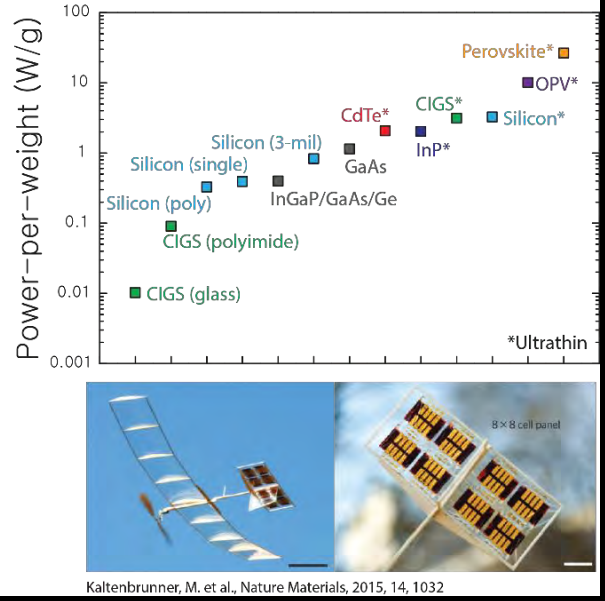
- High tunability
- Wide applications: PVs, LEDs, etc

Opto-electronic Property



- Defect tolerant
- Foundation for high efficiency

Light Weight

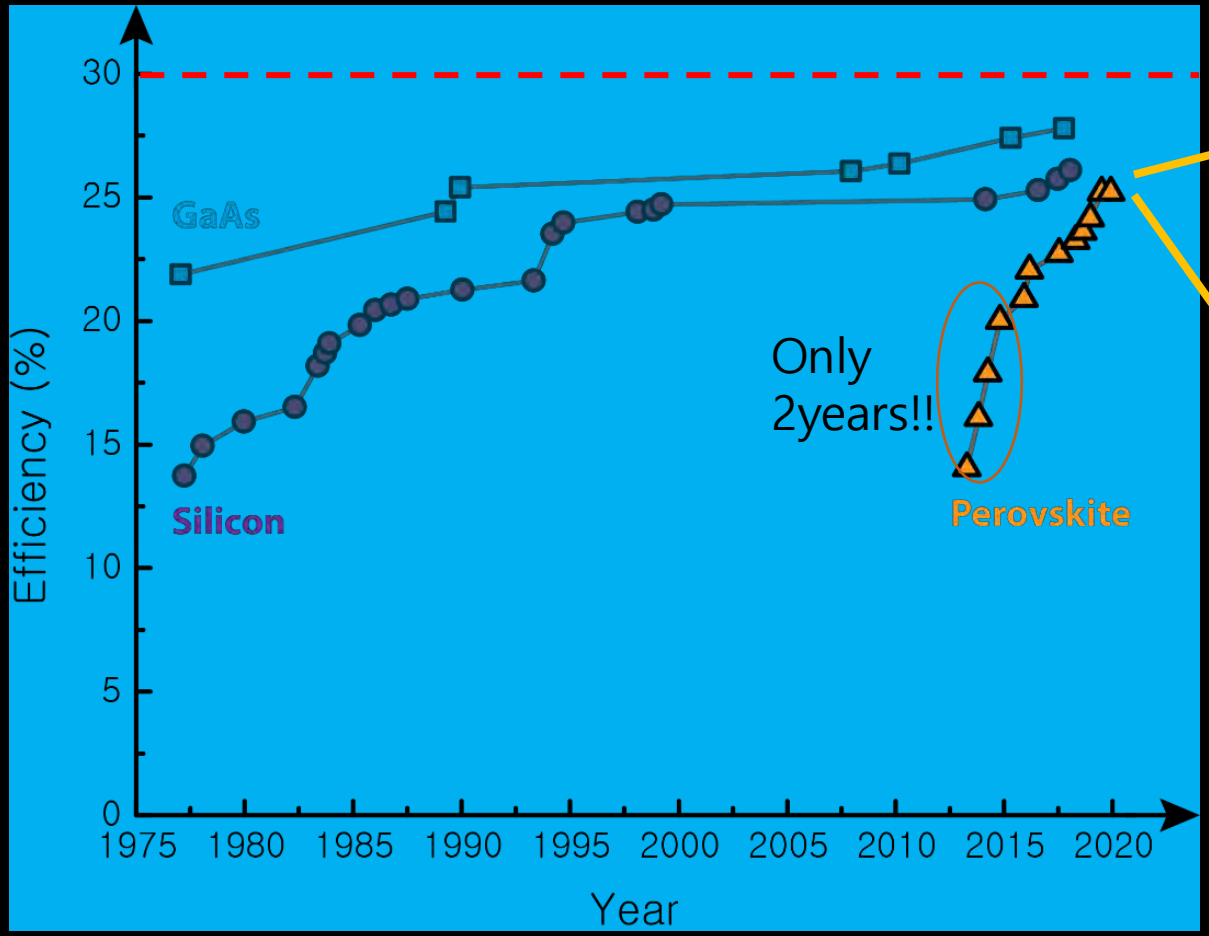


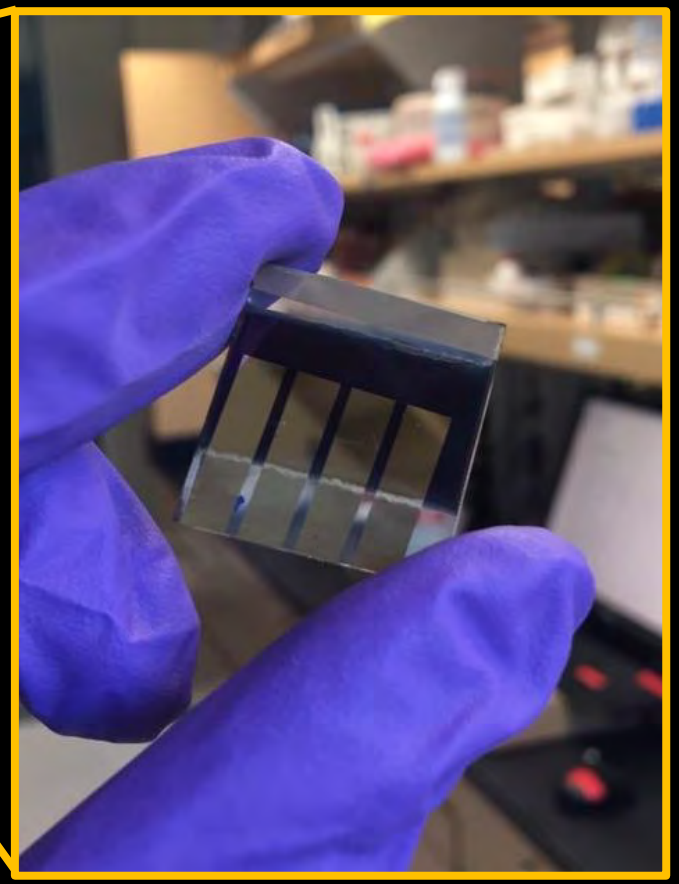
Kaltenbrunner, M. et al., Nature Materials, 2015, 14, 1032

- High specific weight (W/g)
- Diverse applications

Thin Film Lead Halide Perovskite Solar Cells

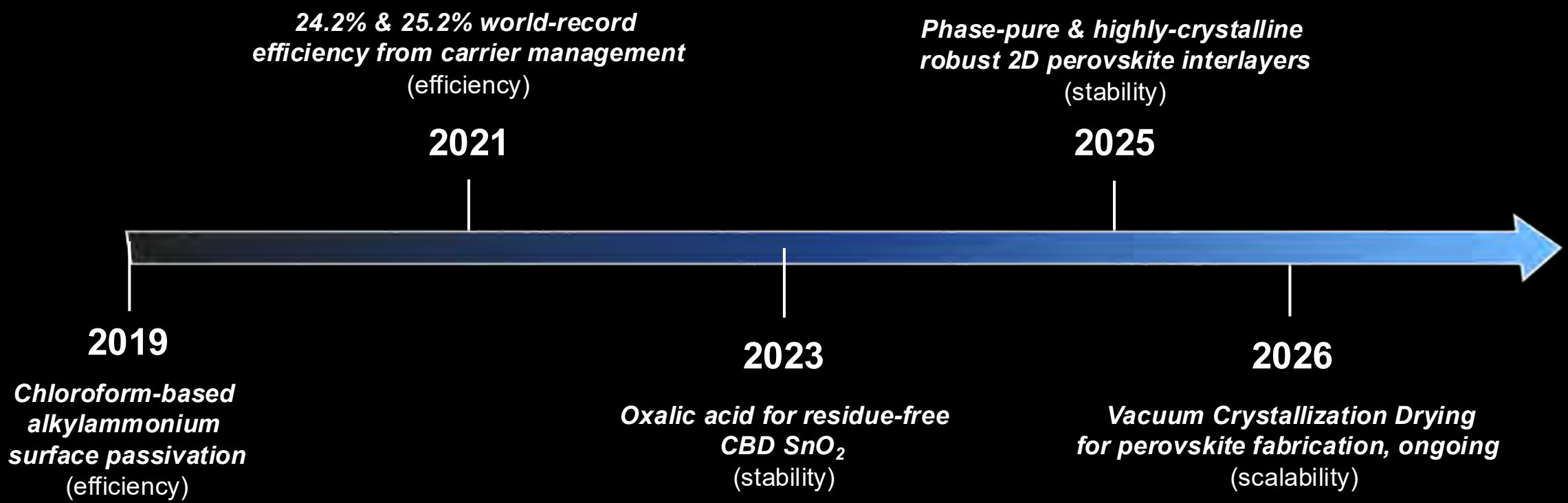
The remarkable rise of a new material for solar energy harvesting



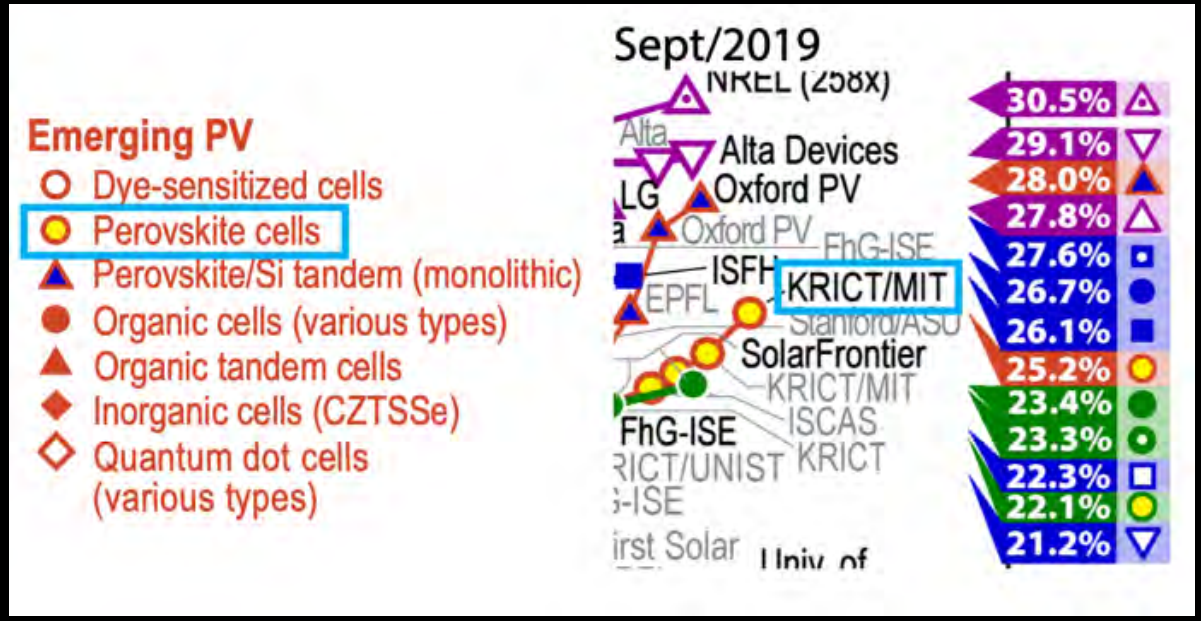


Evolution of Perovskite PV Research from my Laboratory

The focus has evolved from efficiency (2019-2021) to stability (2023-present) and scalability (2026-present)



Some of our contributions

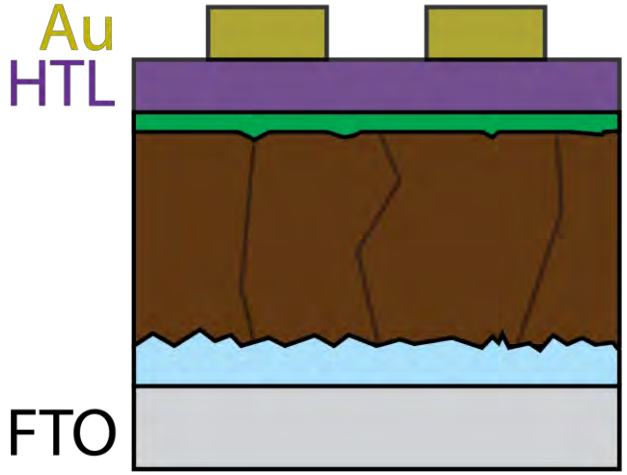


25.2% (MIT)

24.2% (MIT)

22.6% (MIT)

~20%



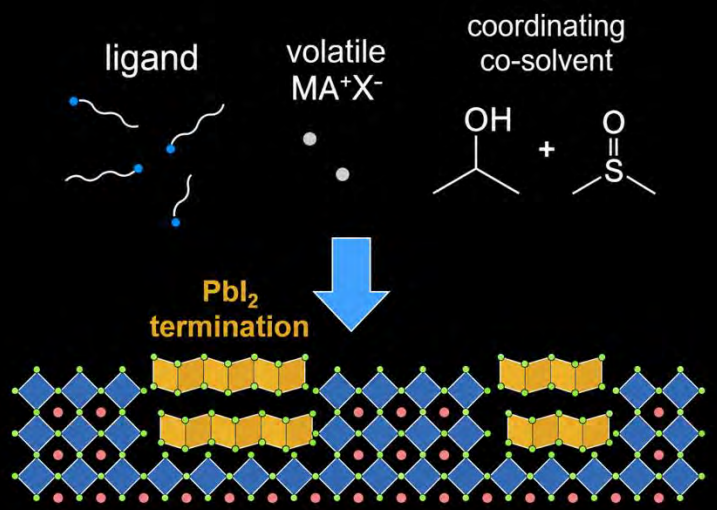
2D Perovskite (SPD Strategy)

$FAPbI_3$+0.8 mol% $MAPbBr_3$

CBD SnO_2 (pH 1.5)

Nature 590, 587–593 (2021)

Stability: Phase-pure & highly-crystalline robust 2D perovskite interlayers

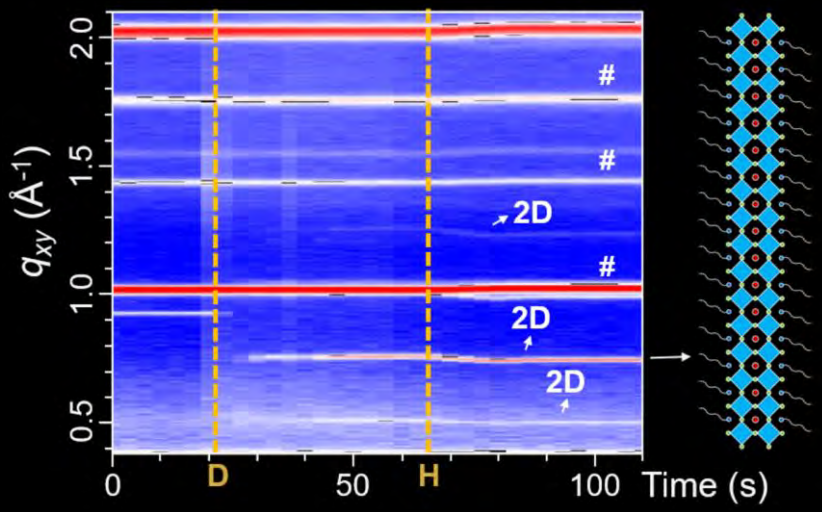


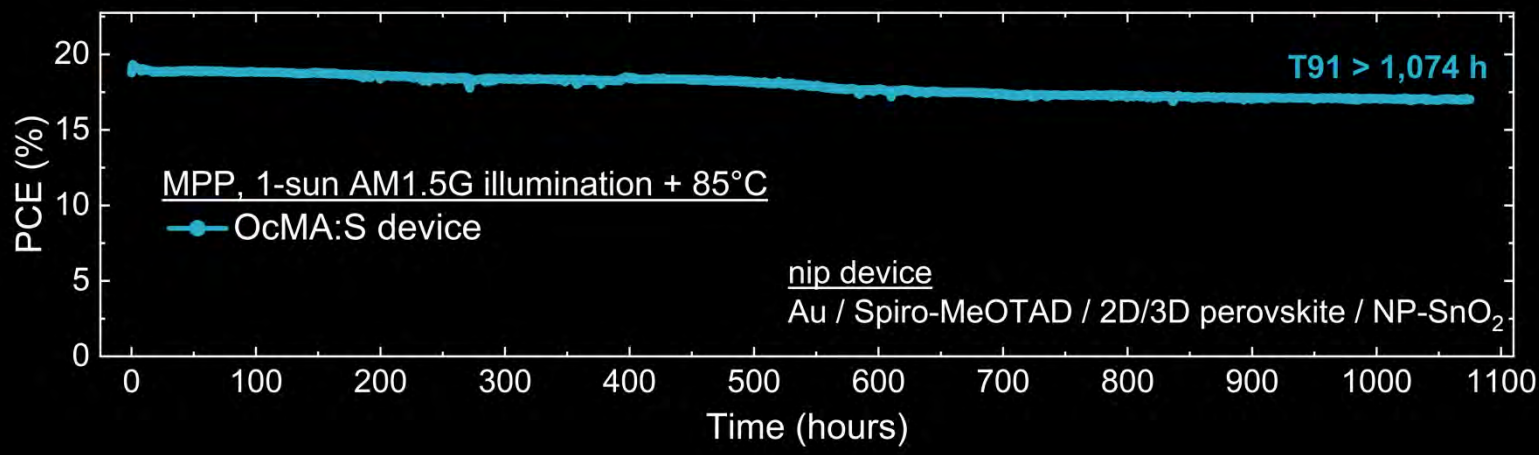
1. Formation of phase-pure, high crystallinity 2D perovskite:

- Volatile methylammonium promotes initial 2D formation
- Coordinating co-solvent partially dissolves underlying 3D perovskite and slows down 2D nucleation

2. Robust 2D interlayer preserves interface protection:

- 2D perovskite retained during PV aging, functioning as a robust barrier to preserve defect passivation and suppress ion migration

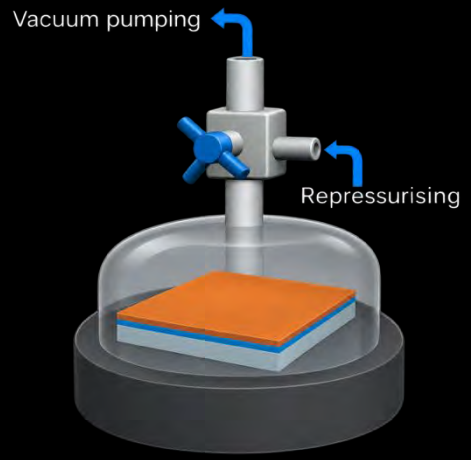




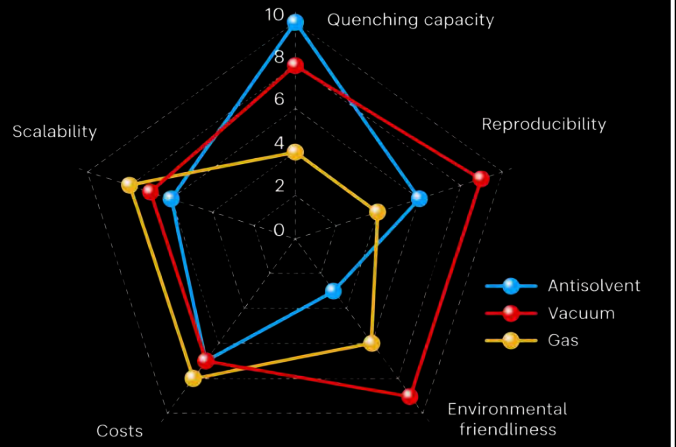
Tan, Bawendi, et al. Science 388, 6747 (2025)

Scalability: Incorporation of Vacuum Crystallization Drying (VCD)

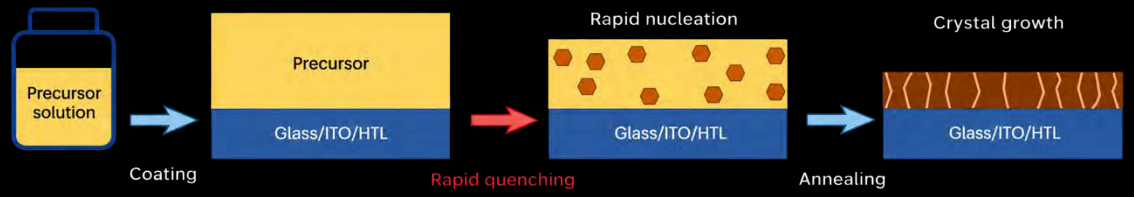
1. Fabrication process & crystallization mechanism:



Credit: *Science 353.6294 (2016)*

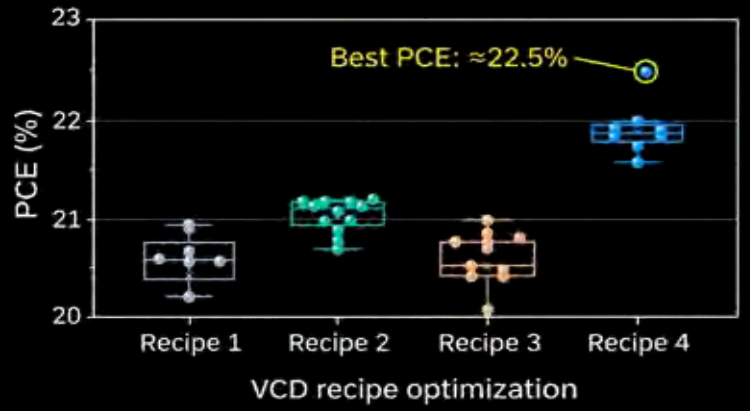


Credit: *Nature Photonics 19, 968-976 (2025)*

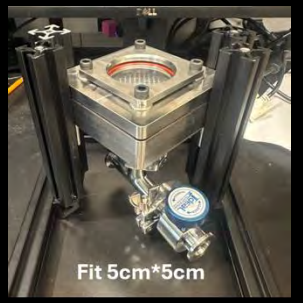


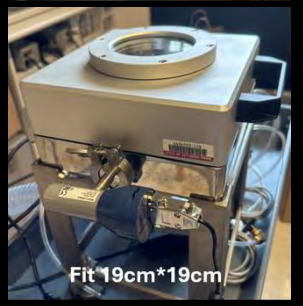
2. Our preliminary results

Efficiency results with VCD perovskite PV:

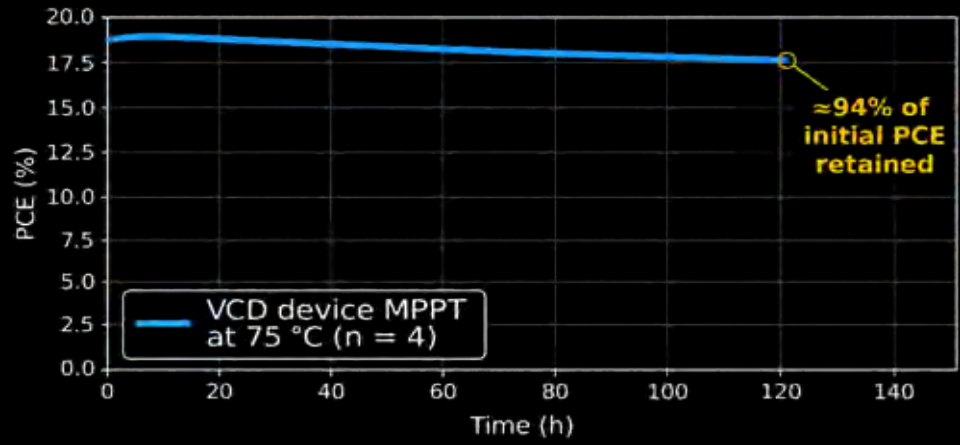


Our setup





Stability results with VCD perovskite PV:



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