Study of photoluminescence and photophysical properties of halide perovskite nanocrystals on single-particle level

Material science and engineering

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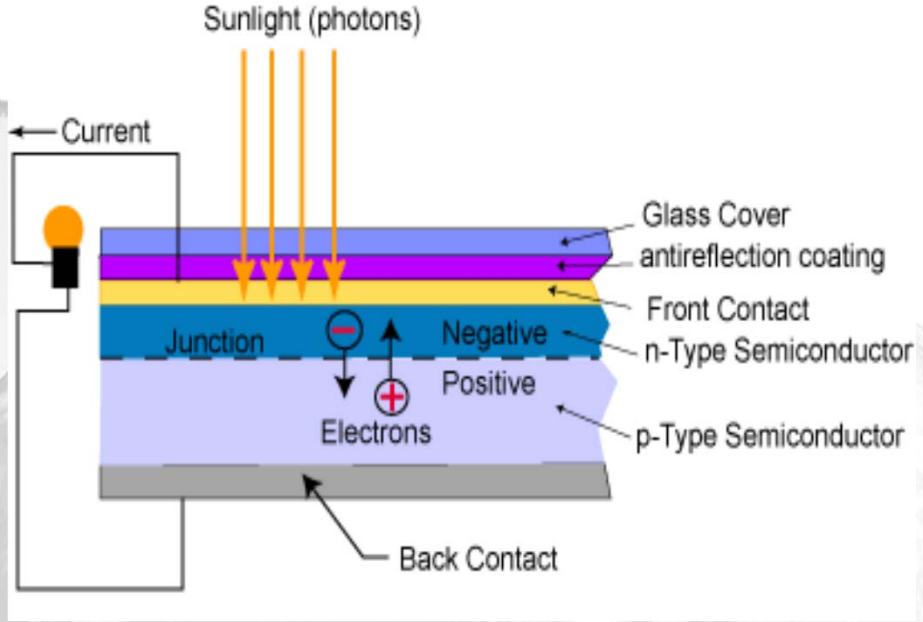
- Outline
- What is perovskite ?
- Aim of the project
- Idea for the work
- Single particle experiment setup
- Results
- Conclusion

Basic structure of a photovoltaic cell

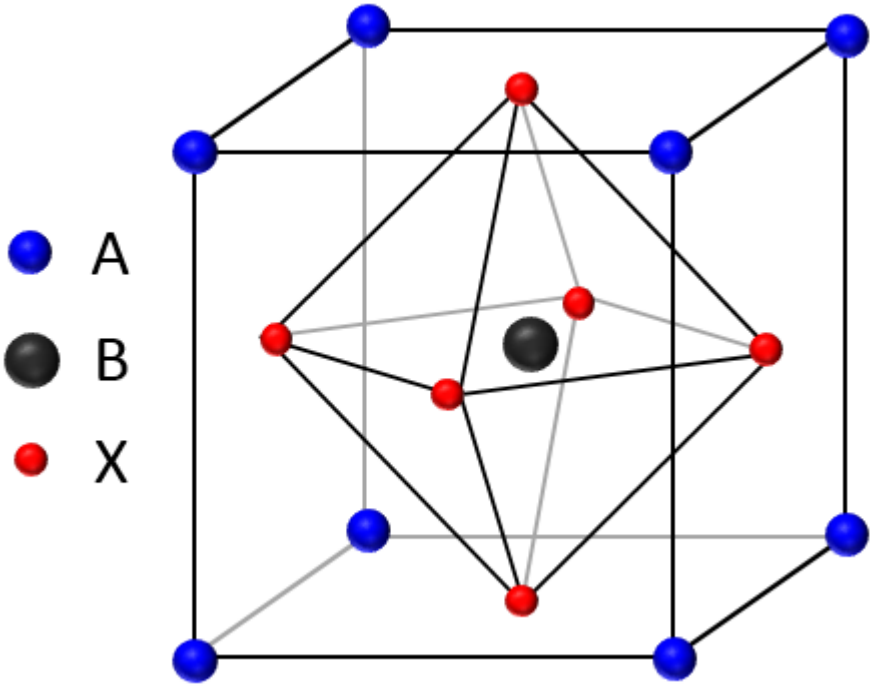
- A photovoltaic solar cell is made of three main part:
- **Light Absorber**: converting incident photons to electron and holes
- **Carrier Collector**: capturing the carriers – electrons and holes (TiO2, ZnO, Spiro-OMeTAD)
- **Metal Contacts**: transferring the carriers to the circuit (Ag, Au)



The heart of a solar cell is the absorber layer : Cd-Te, Organic Dye, Quantum dots(QD's), Perovskite

What is perovskite ?

- A perovskite structure is any material with the same type of crystal structure as ABX_3, known as the perovskite structure where 'A' and 'B' are two cations and X is halide.



ABX_3

$A = CH_3NH_3^+, HC(NH_2)_2^+$

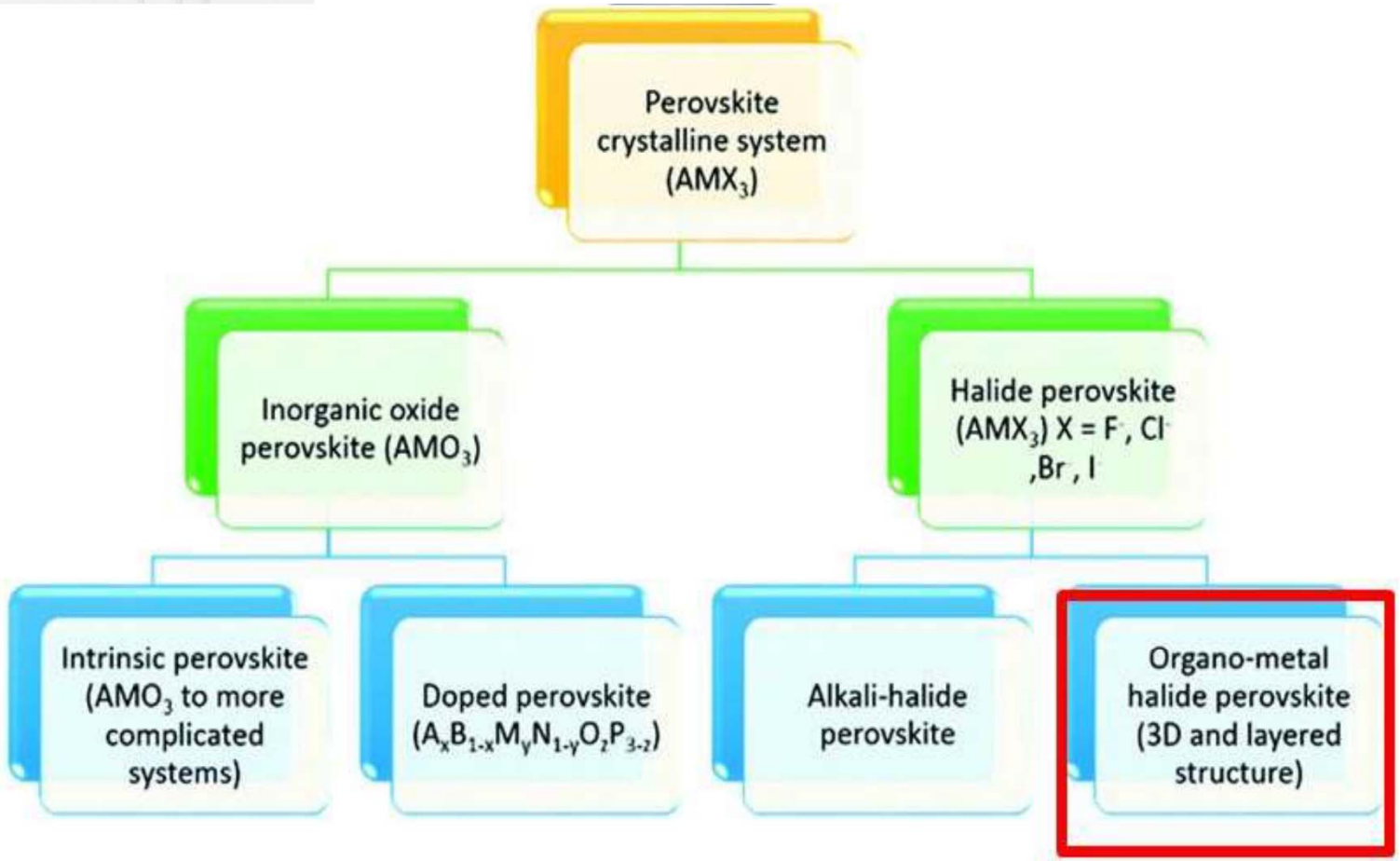
$B = Pb^{2+}, Sn^{2+}$

$X = I^-, Br^-, Cl^-$

- Efficiency jump in photovoltaics research from 3.8% in 2009 to 22% in 2016.

❖ First discovered by Gustav Rose in 1839 and named after Russian mineralogist L. A. Perovski

Classifications of perovskite



Organic–Inorganic hybrid perovskites

- Hybrid Organic Inorganic Semiconductor
- Inorganic – Lead (Strong light absorption, Provide high efficiencies, even above 20% as per NREL).
- Organic– Methyl Ammonium (Soluble in Polar Solvents, Provides low temperature processing – low cost and energy saving)
- First three–dimensional organic–inorganic hybrid perovskite, discovered by replacing cesium in $CsPbX_3$ (X = Cl, Br or I) with methyl ammonium cations (MA =$CH_3NH_3^+$) by Dieter Weber, in 1978

Source: National Renewable Energy Laboratory (NREL)

Why?

- Halide perovskites is a solution-processable low-cost alternatives to silicon in photovoltaic devices.
- Halides have excitonic properties and have narrow-band emission
- Halides are promising for electroluminescence devices, light-emitting and sensing applications

What are the Challenges?

- Device Stability and Lifespan
- Spectral Instability and Micro phase Separation in Mixed-Halide Perovskite.

How to resolve?

- Mixed-halide perovskite have emerged as promising materials for optoelectronics due to their tunable band gap in the entire visible region.

Source!: Xiaofei Zhao, Jun De Andrew Ng et al., ACS Photonics, 2018, 5, "Opportunities and Challenges in Perovskite Light-Emitting Devices"
Source!!: Xiaofeng Tang, Marius van den Berg et.al, Nano Lett. 2018, 18, 2172−2178, ≪Local Observation of Phase Segregation in Mixed-Halide Perovskite≫

Way ahead…

1. Study the suppression of blinking in both electroluminescence(EL) and photoluminescence(PL) using microscopy.

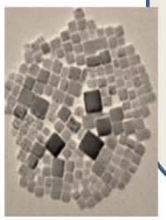
2. Study of spectral diffusion and spectral shifts, in relationship with structural/compositional stability.

3. Study the effect of surface, surface functionalization and nanocrystal orientation on the effectivity of charge transport and charge recombination.

Source: Holly F. Zarick, Naiya Soetan et. al, J. Mater. Chem. A, 2018, 6, 5507–5537 | 5507, Mixed halide hybrid perovskites: a paradigm shift in photovoltaics

How to proceed ?

Single-molecule detection
Single-particle spectroscopy
Atomic-force microscopy



Halide **perovskite nanocrystals** (CsPbX3, MAPbX3, novel materials) *vs.* semiconductor quantum dots, conjugated polymers

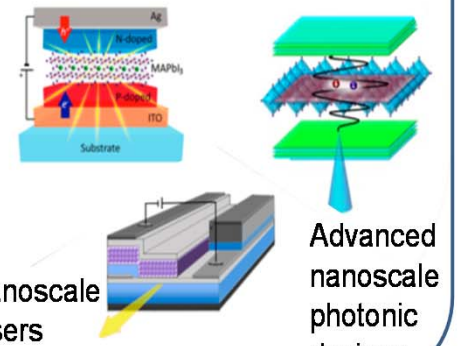
PHOTOLUMINESCENCE

- origin and suppression of blinking
- surface functionalization vs. charge transport
- maximizing emission quantum yield in EL & PL
- spectral diffusion and spectral shifts
- interactions with organic semiconductors

ELECTROLUMINESCENCE

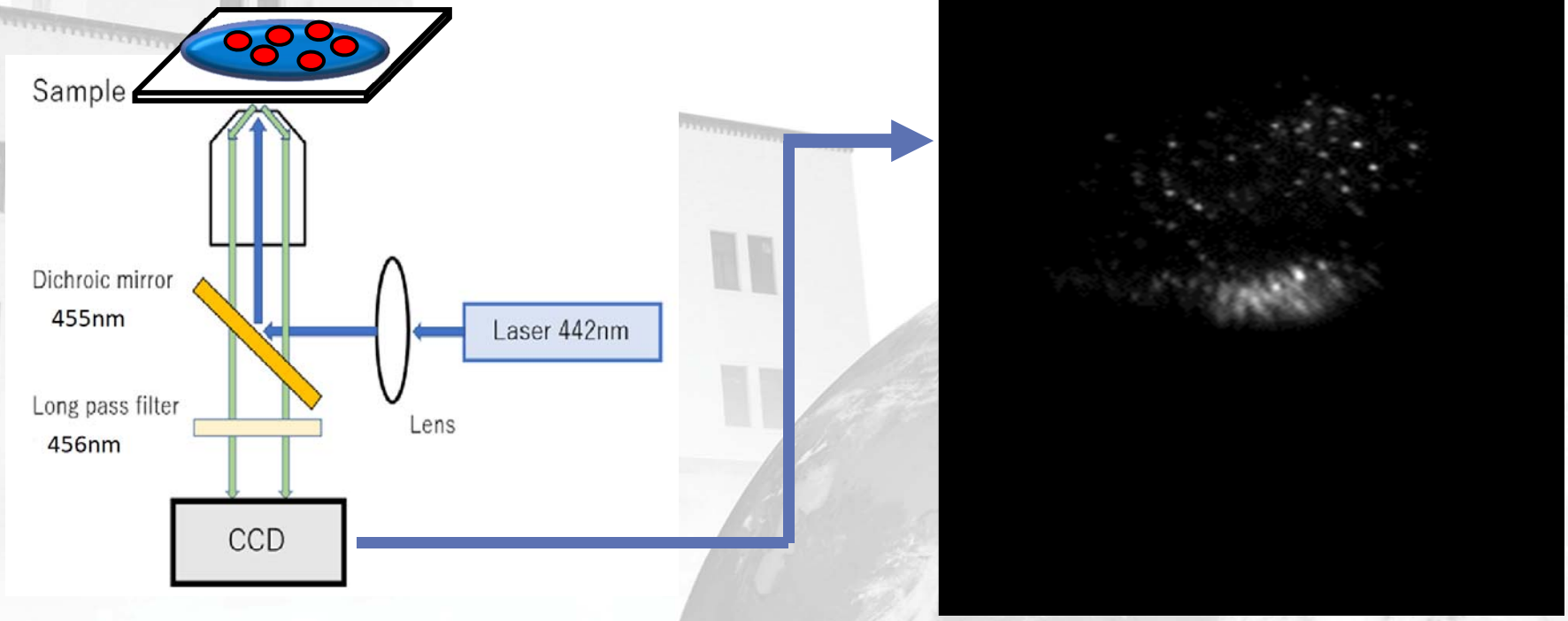
Nanoscale devices

Light-emitting devices
→ single-photon sources



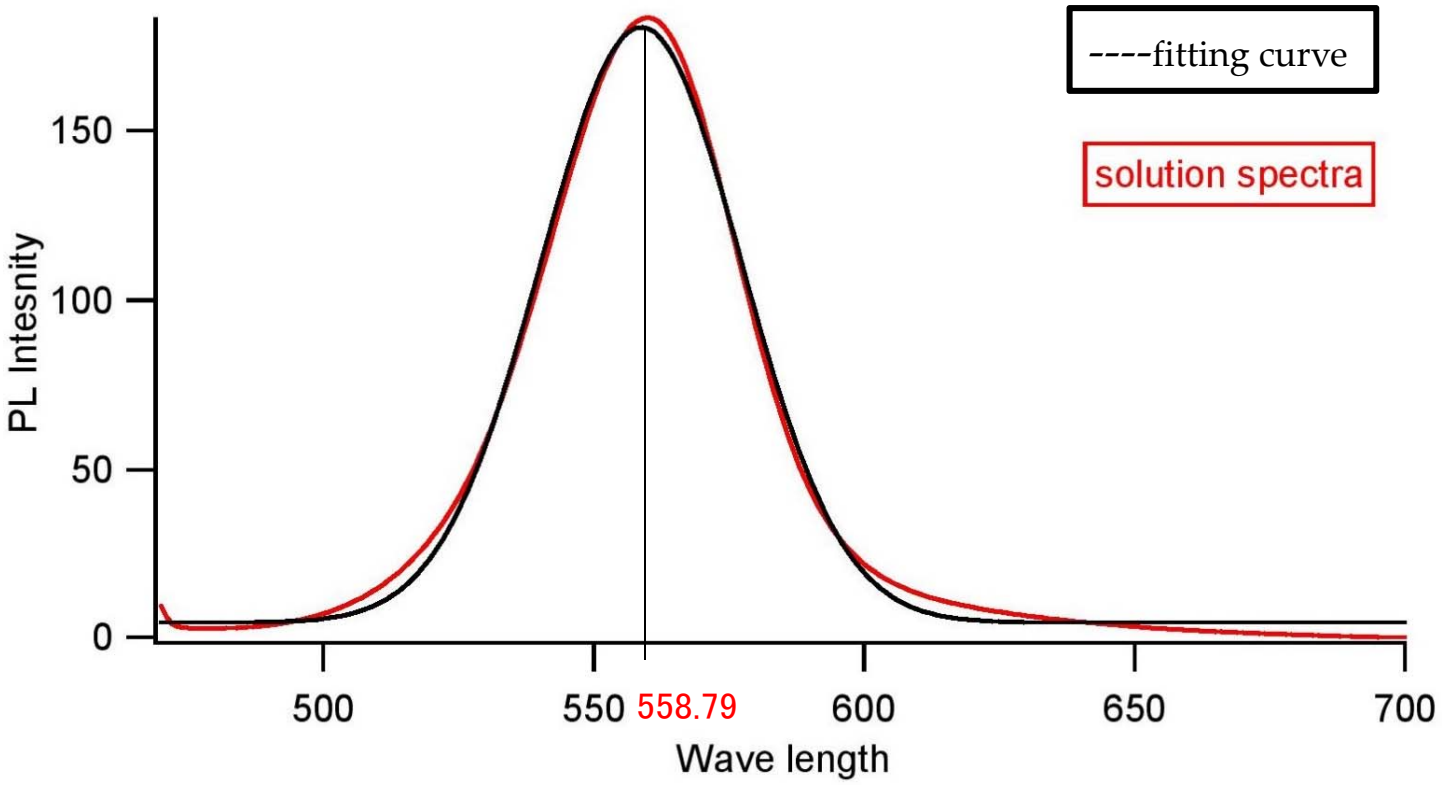
Schematic Diagram of the work

Single particle experiment setup



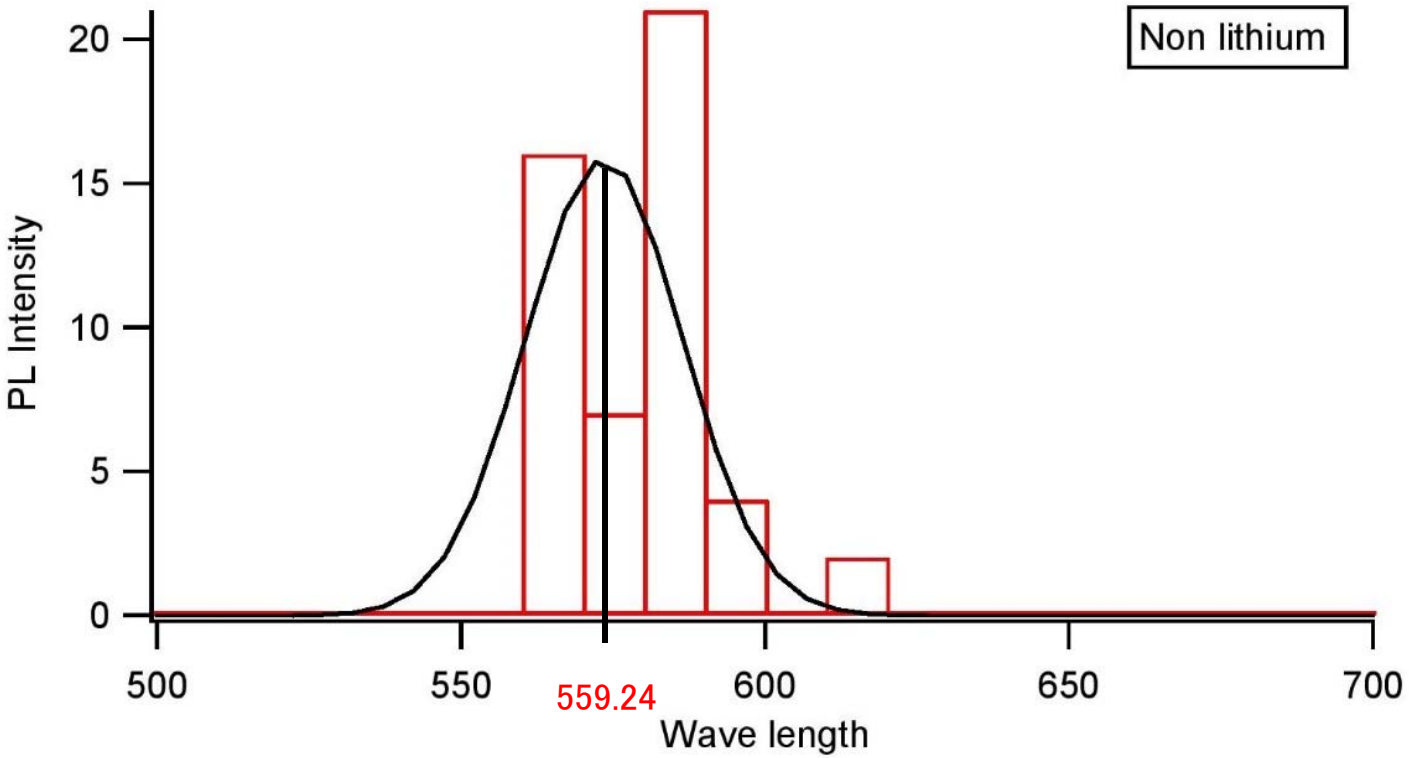
Source: "Single-particle spectroscopy of I-III-VI semiconductor nanocrystals: spectral diffusion and suppression of blinking by two-color excitation", Nanoscale, 2016, 8, 13687

Theoretical results :



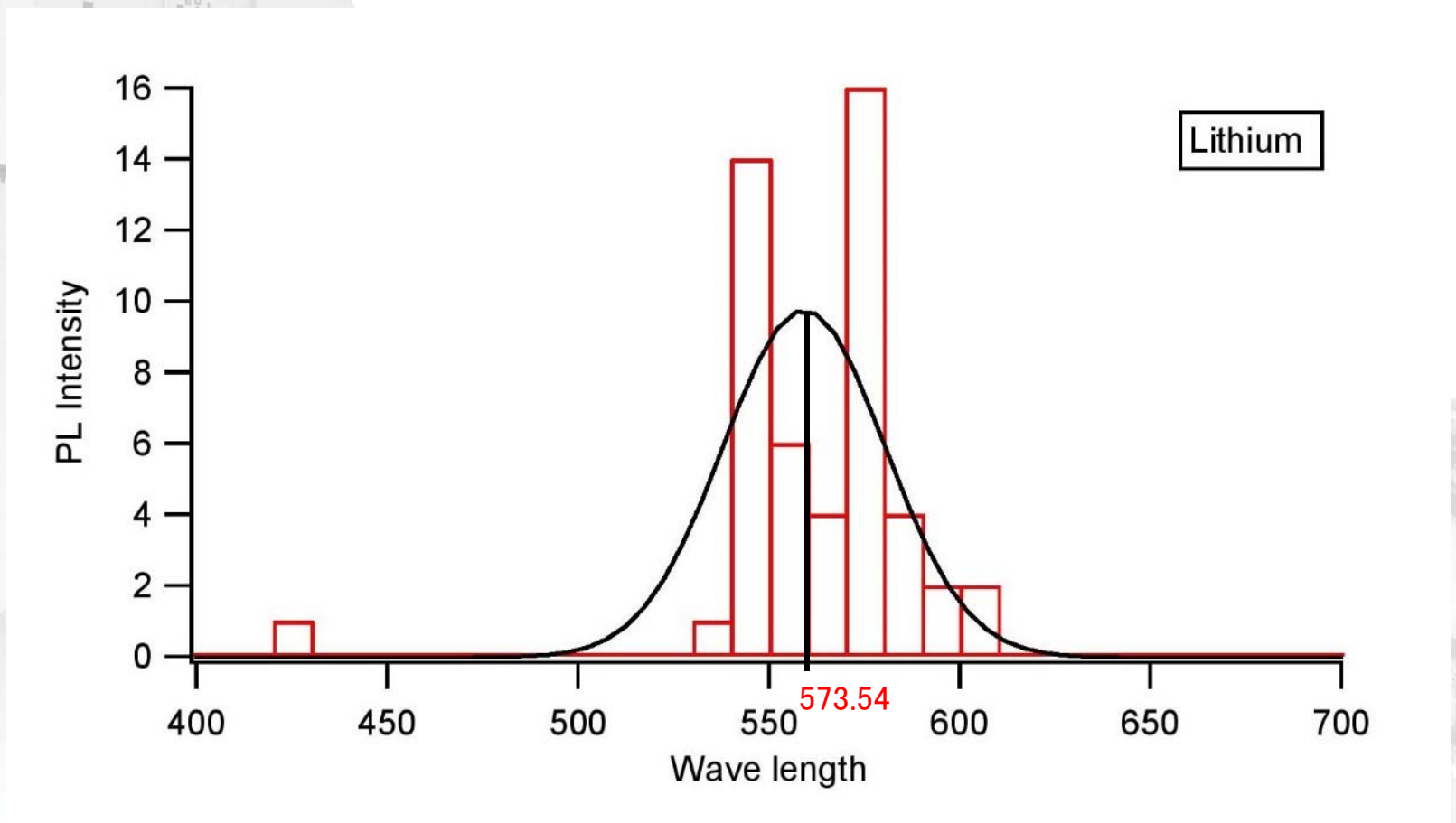
Solution spectra of non lithium based quantum dot material

Experimental result :



Non lithium quantum dot's Spectra analysis

Experimental result :



lithium quantum dot's spectra traces

Source: D K Sharma, S. Hirata, Nanoscale, 2016, 8, 13687"Single-particle spectroscopy of I–III–VI semiconductor nanocrystals: spectral diffusion and suppression of blinking by two-color excitation"

Conclusion

- The experimental results are very similar to theoretical data.
- The spectral analysis and the blinking spot looks quite promising in single particle analysis.
- PL studies gives a good support for unstable materials.

Future plan

- Need to study the spectral shift and the effect of ON/OFF time of exposure.
- Explore spectroscopy studies of new materials with unique composition.

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“The sun will be the fuel of future .”
Thank You