Color by Composition: Halide-Controlled Emission in $CsPbX_3$ Quantum Dots

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Introduction

Quantum dots (QDs) are semiconductor nanocrystals that measure only a few nanometers in size. Their importance was highlighted by the 2023 Nobel Prize in Chemistry, awarded for their discovery and synthesis. A key feature of QDs is their size-dependent optical behavior: the emission color can be precisely tuned by adjusting the particle size.

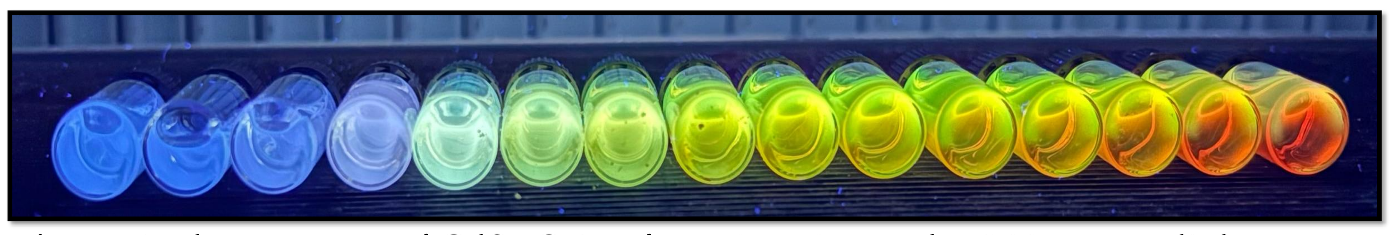

Figure 1. Fluorescence of CdSe QDs of varying size under 366 nm UV light.

In this project, $CsPbX_3$ perovskite QDs were synthesized and characterized. Upon excitation, QDs emit visible light, with both halide composition and particle size determining the emission color: smaller QDs emit blue light, while larger QDs shift toward red (Figure 1). This study demonstrates how these parameters influence the optical properties of QDs.

Materials and methods

$CsPbX_3$ (X = Cl, Cl/Br, Br, Br/I, I) QDs were synthesized using a hot- injection method under a nitrogen atmosphere.

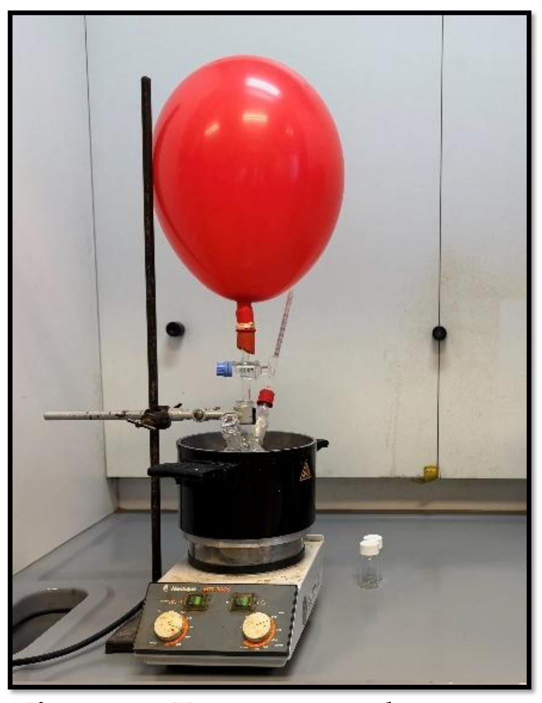

Figure 2. Experimental setup for the $CsPbX_3$ QDs synthesis.

Lead halides (PbX_2) were first prepared by precipitating $Pb(NO_3)_2$ and the corresponding potassium halide (KCl, KBr, or KI) in water, followed by filtration and drying. Next, a Cs precursor (Cs oleate) was prepared by dissolving Cs_2CO_3 in ODE and OA under N_2. In a separate setup, the growth medium was prepared by dissolving PbX_2 in ODE, OAm and OA under N_2. Both solutions were heated in an oil bath.

Minor adjustments in temperature or reagents were necessary depending on the halide composition. After heating the growth medium to 170 °C, the preheated Cs-oleate solution was rapidly injected, initiating nucleation and growth of the QDs. The resulting colloidal suspension was characterized under UV light (λ = 366 nm) and by fluorescence spectroscopy.

Results and discussion

Under UV light (λ = 366 nm), the samples exhibit different colors corresponding to their halide composition. The normalized fluorescence spectra show a systematic red-shift in emission with increasing halide size: $CsPbCl_3$ (411 nm, blue), $CsPb(Cl/Br)_3$ (445 nm, light green), $CsPbBr_3$ (516 nm, yellow), $CsPb(Br/I)_3$ (567 nm, orange), $CsPbI_3$ (668 nm, red). This trend indicates a gradual bandgap reduction as smaller halide ions (Cl^-) are replaced by larger ones (Br^- and I^-), shifting the emission toward longer wavelengths. $CsPbCl_3$ has the largest bandgap and therefore requires higher excitation energy. Excitation at 418 nm lies too close to the emission band, causing peak broadening and a red-shift. Excitation at 380 nm ensures proper excitation. Unlike CdSe quantum dots, where the emission shifts as growth progresses, the emission of $CsPbX_3$ QDs is mainly determined by the halide composition.

Figure 3. Fluorescence of $CsPbX_3$ perovskite quantum dots under normal light. Samples are arranged from left to right by halide composition: X = Cl, Cl/Br, Br, Br/I, I.

Figure 4. Fluorescence of $CsPbX_3$ perovskite quantum dots under UV light (λ = 366 nm) from a UV flashlight. Samples are arranged from left to right by halide composition: X = Cl, Cl/Br, Br, Br/I, I.

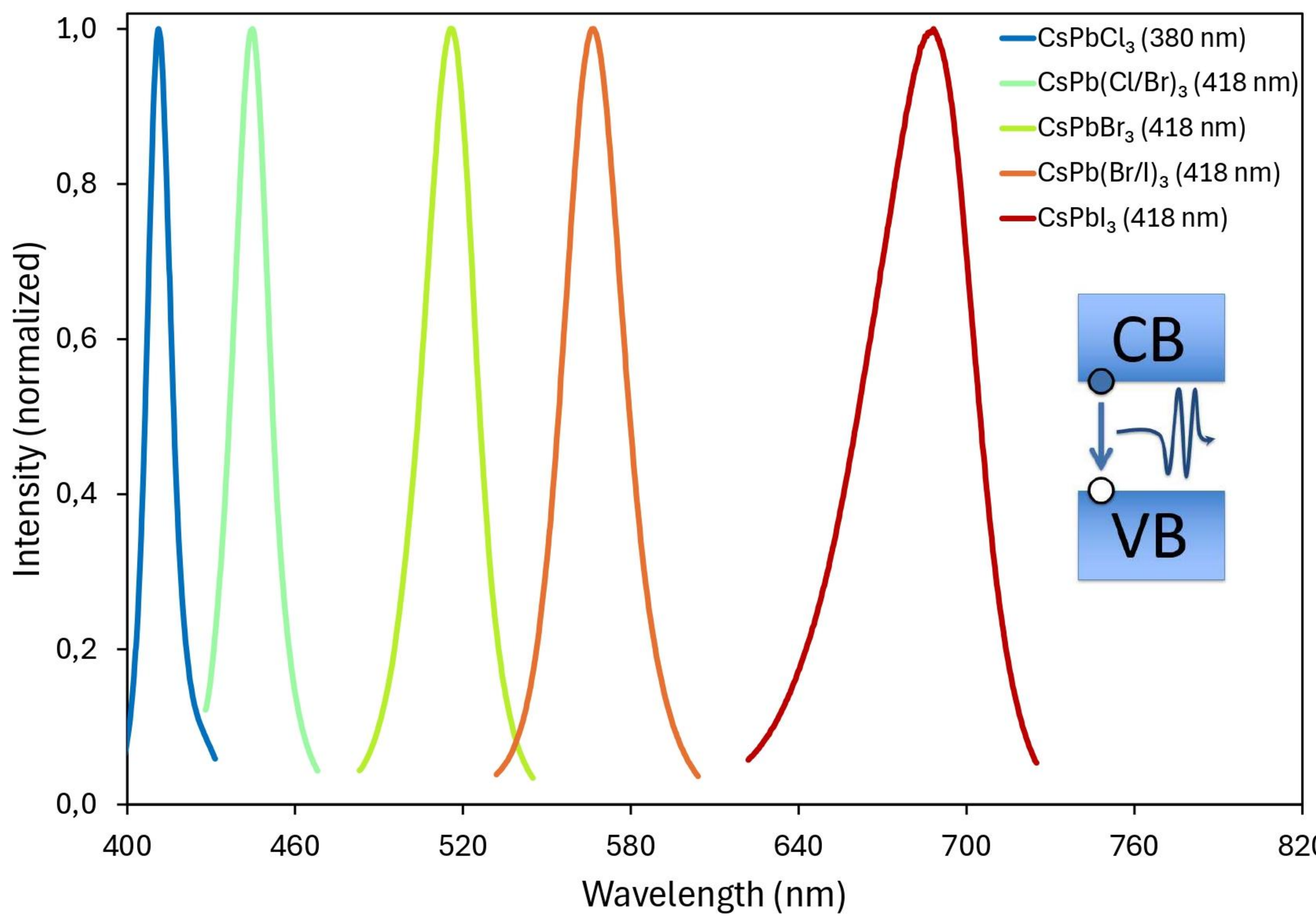

Figure 5. Normalized emission spectra of synthesized $CsPbX_3$ perovskite quantum dots. $CsPbCl_3$ was excited at 380 nm, while $CsPbCl_3$, $CsPbCl_3$ and mixed halides were excited at 418 nm.

Conclusion

$CsPbX_3$ perovskite quantum dots are successfully synthesized and characterized under UV light and fluorescence spectroscopy. The results confirm that optical properties are primarily determined by halide composition, while growth has minimal influence. A systematic red-shift in emission with increasing halide size reflects bandgap reduction, highlighting the role of crystal structure and chemical composition. This enables precise and reproducible color tuning.

Reference

Shekhirev M, Goza J, Teeter JD, Lipatov A, Sinitskii A. Synthesis of Cesium Lead Halide Perovskite Quantum Dots. Journal Of Chemical Education [Internet]. July 24, 2017;94(8):1150–6.