

Thickness-Controlled Synthesis and Characterization of Wide-Bandgap Perovskite-Related Crystals for Nanophotonics



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- ☐ Reflection-Based Thickness Estimation
- ☐ Conclusion and Perspectives





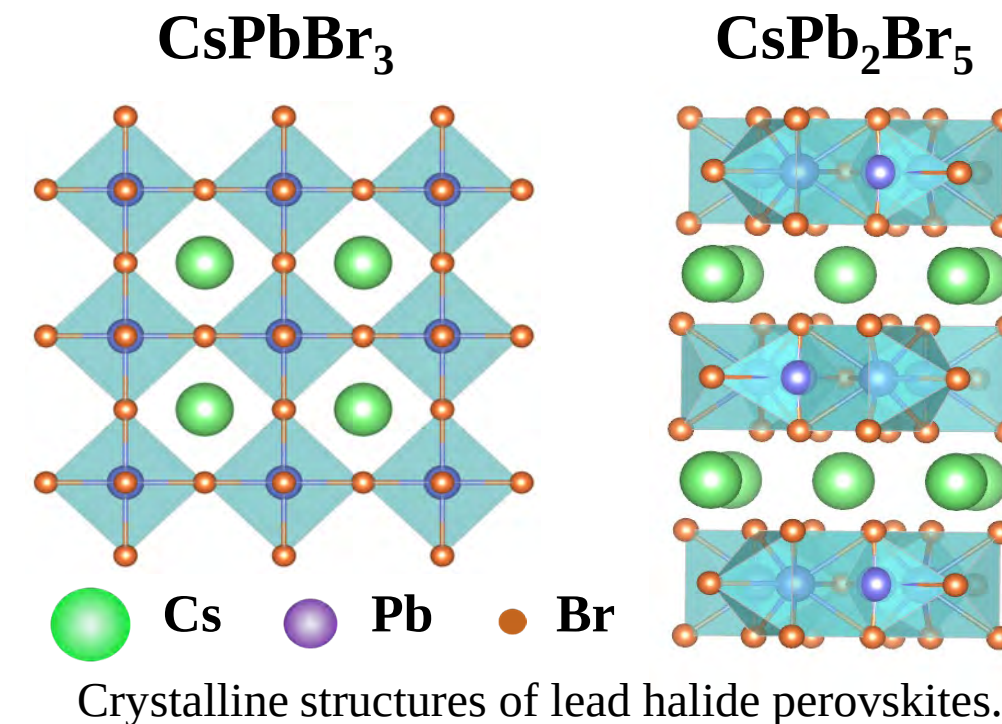
Terminology

- ❑ **Lead Halide Perovskites:** a class of semiconductors with a crystalline structure, typically of the chemical formula of ABX_3
- ❑ **Reflection spectroscopy:** the light intensity of a sample is measured using a halogen white light source, and taken over the wavelength of the light reflected
- ❑ **Atomic Force Microscopy (AFM):** scanning probe microscopy that results in a high-resolution image by using a sharp tip to measure the surface of the material on atomic and nanometer scale
- ❑ **Polydimethylsiloxane (PDMS):** transparent silicone-based polymer which is utilized to confine the crystals growing on the substrate more evenly



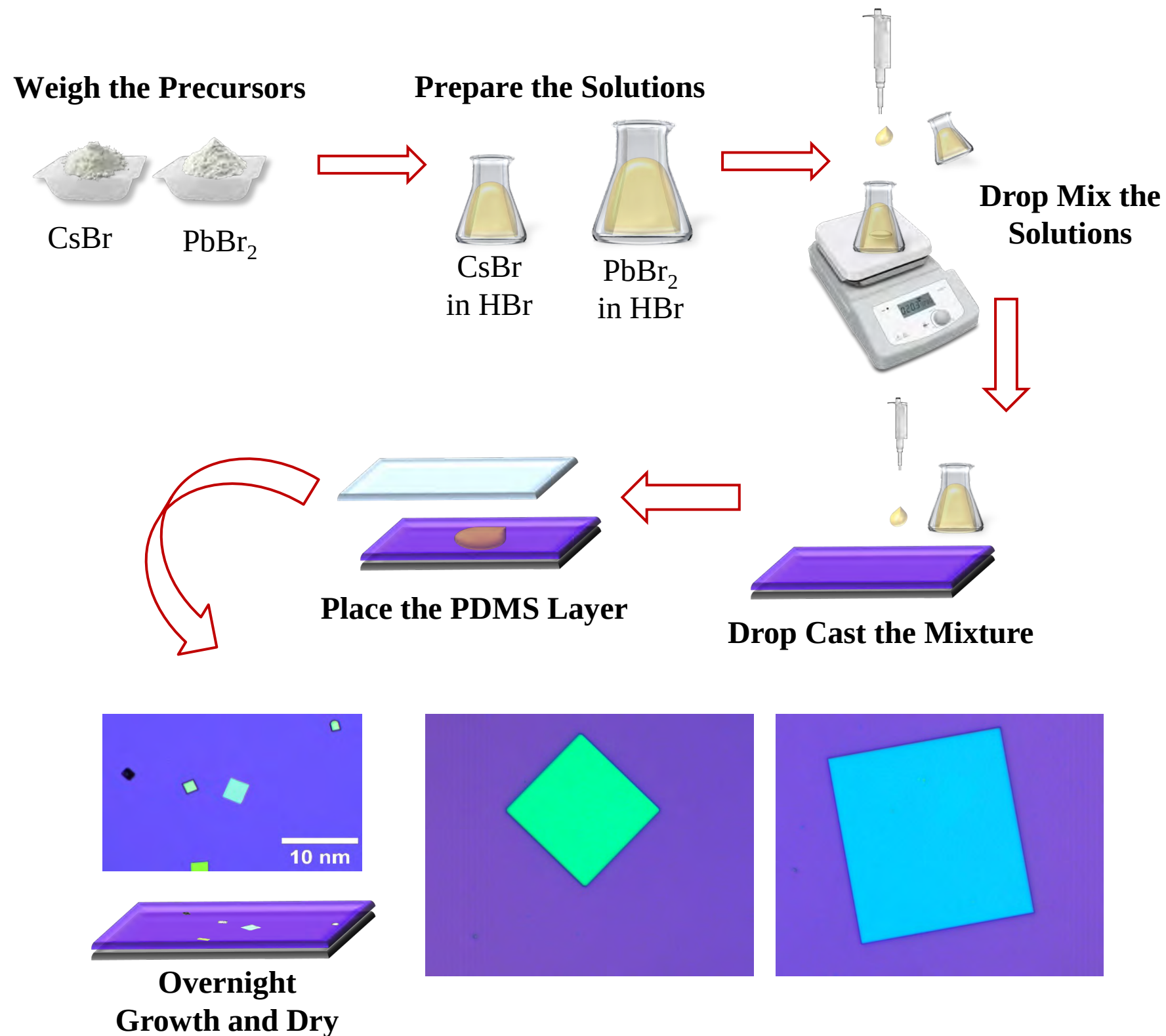
Introduction and Motivation

- ❑ Lead halide perovskites and related materials are particularly important for **nanophotonic applications**, due to their **unique photonic emissions** and **tunable optoelectronic properties**.
- ❑ They have been widely applied in solar cells, light emitters, and photodetectors.
- ❑ This research aims to address the difficulty of synthesizing perovskite-related crystals, CsPb_2Br_5 , with **controlled thickness** and **fast thickness determination**.



Exemplary applications in solar cells and lasers. [1]

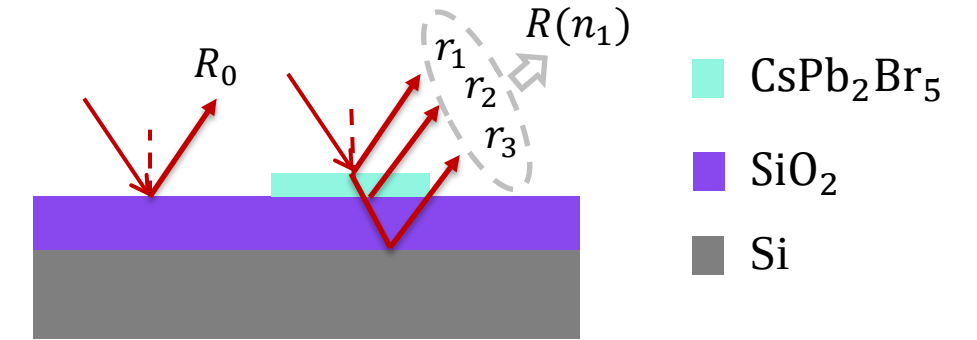
- ❑ **Hydrothermal synthesis** of perovskites using CsBr and PbBr₂ on SiO₂/Si substrate.
- ❑ **PDMS stamps** are used to confine the crystal growth.
- ❑ **Uniform nanometer-thick crystals** have been achieved.



□ Optical contrast calculation is based on the **Fresnel's equation**.

- $C(\lambda)$ is the optical contrast.
- $R(n_1)$ is the reflected light intensity of the crystals.
- r_1, r_2, r_3 are the relative refractive indices at each interface,
- n_0, n_1, n_2, n_3 are the refractive indices.
- The phase differences (Φ_1, Φ_2) represent the change thickness from the CsPb_2Br_5 to the SiO_2 . [2]

□ A **MATLAB code** was developed to investigate how optical contrast depends on the substrate and perovskite thickness.



Schematics of a CsPb_2Br_5 flake on oxidized silicon substrate.

$$R(n_1) = \left| \frac{r_1 e^{i(\Phi_1 + \Phi_2)} + r_2 e^{-i(\Phi_1 - \Phi_2)} + r_3 e^{-i(\Phi_1 + \Phi_2)} + r_1 r_2 r_3 e^{i(\Phi_1 - \Phi_2)}}{e^{i(\Phi_1 + \Phi_2)} + r_1 r_2 e^{-i(\Phi_1 - \Phi_2)} + r_1 r_3 e^{-i(\Phi_1 + \Phi_2)} + r_2 r_3 e^{i(\Phi_1 - \Phi_2)}} \right|^2;$$

$$r_1 = \frac{n_0 - n_1}{n_0 + n_1}, r_2 = \frac{n_1 - n_2}{n_1 + n_2}, r_3 = \frac{n_2 - n_3}{n_2 + n_3};$$

$$\Phi_1 = \frac{2\pi n_1 d_1}{\lambda}, \Phi_2 = \frac{2\pi n_2 d_2}{\lambda}.$$

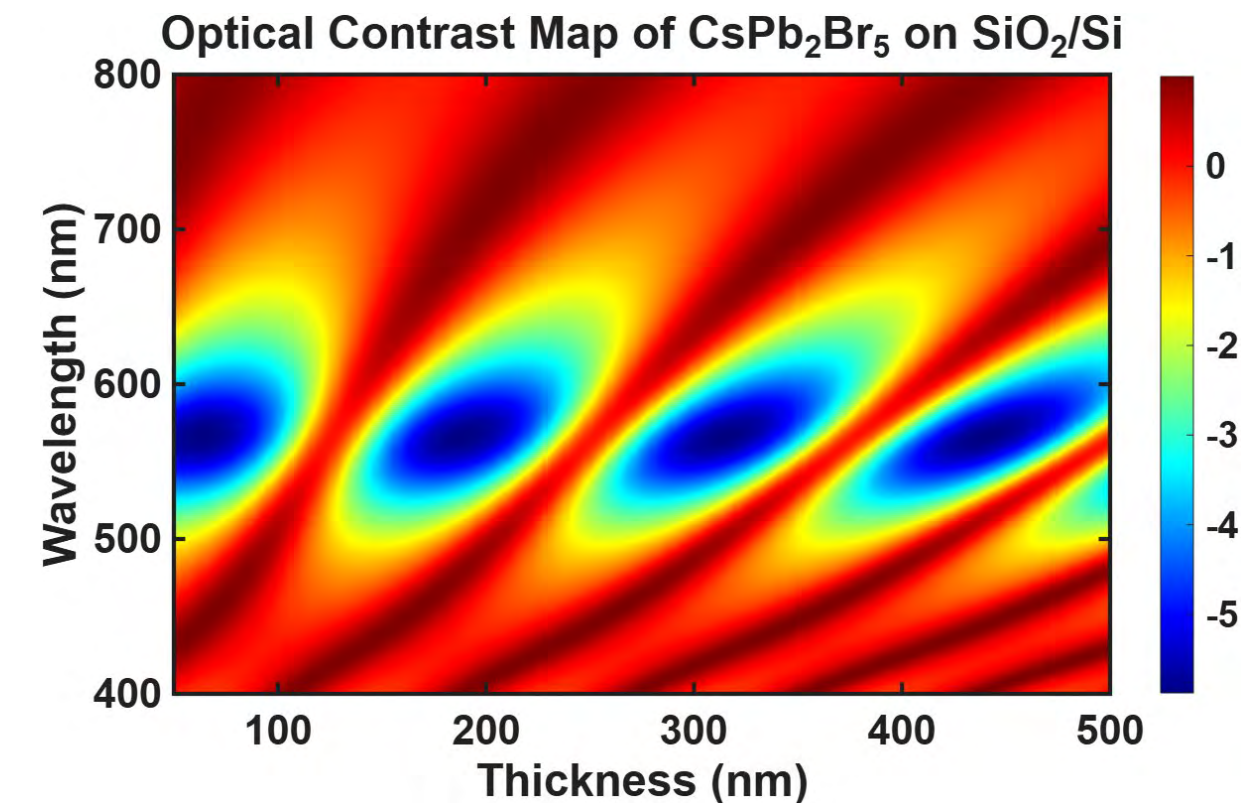
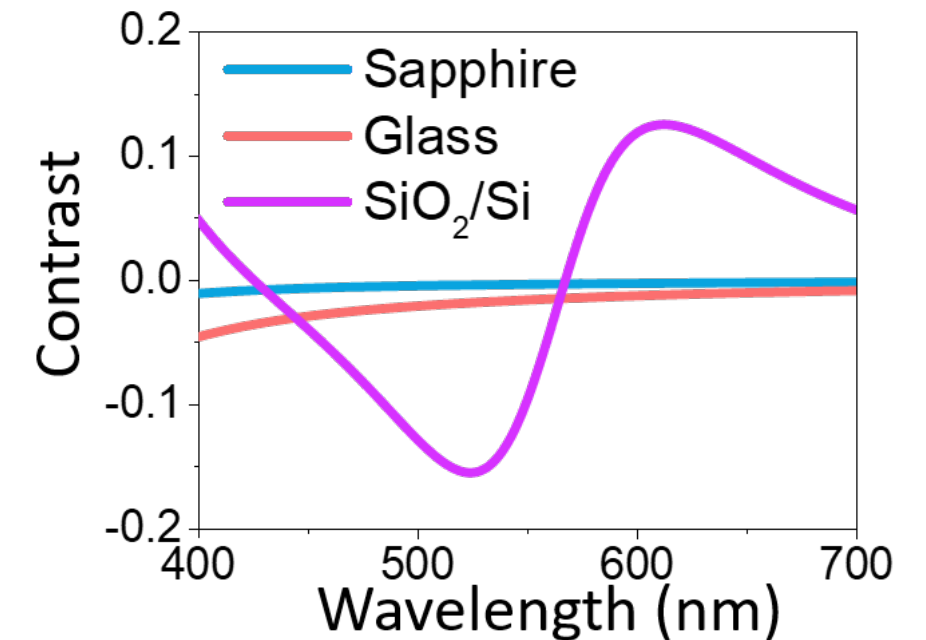
$$C(\lambda) = \frac{R(n_1 = n_0) - R(n_1)}{R(n_1 = 1)};$$

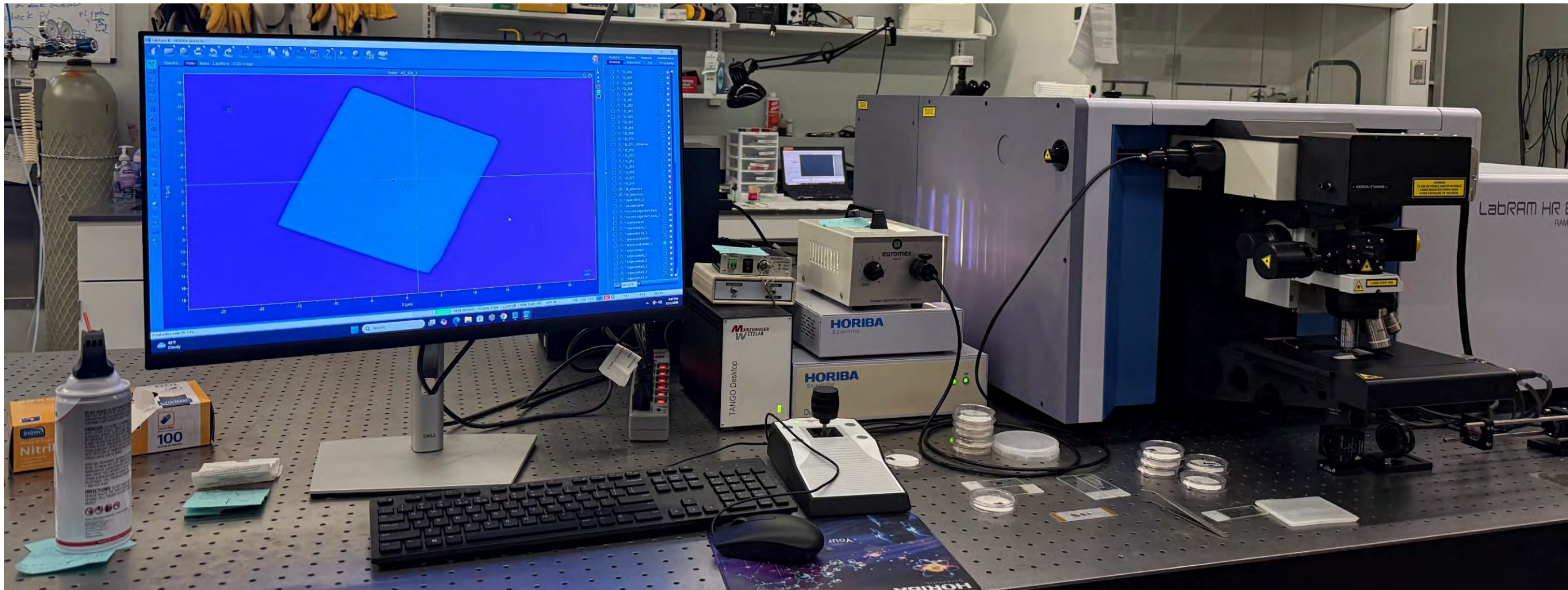


Optical Contrast Calculation



- ❑ **Substrate dependence:** Enhanced contrast for SiO_2/Si is observed compared to other transparent substrates, due to multilayer interference.
- ❑ **Thickness dependence:** The optical contrast map shows the relationship of the thickness of the CsPb_2Br_5 crystals with the wavelength of light reflected. Periodic enhancement in the optical contrast can be observed due to constructive interference.

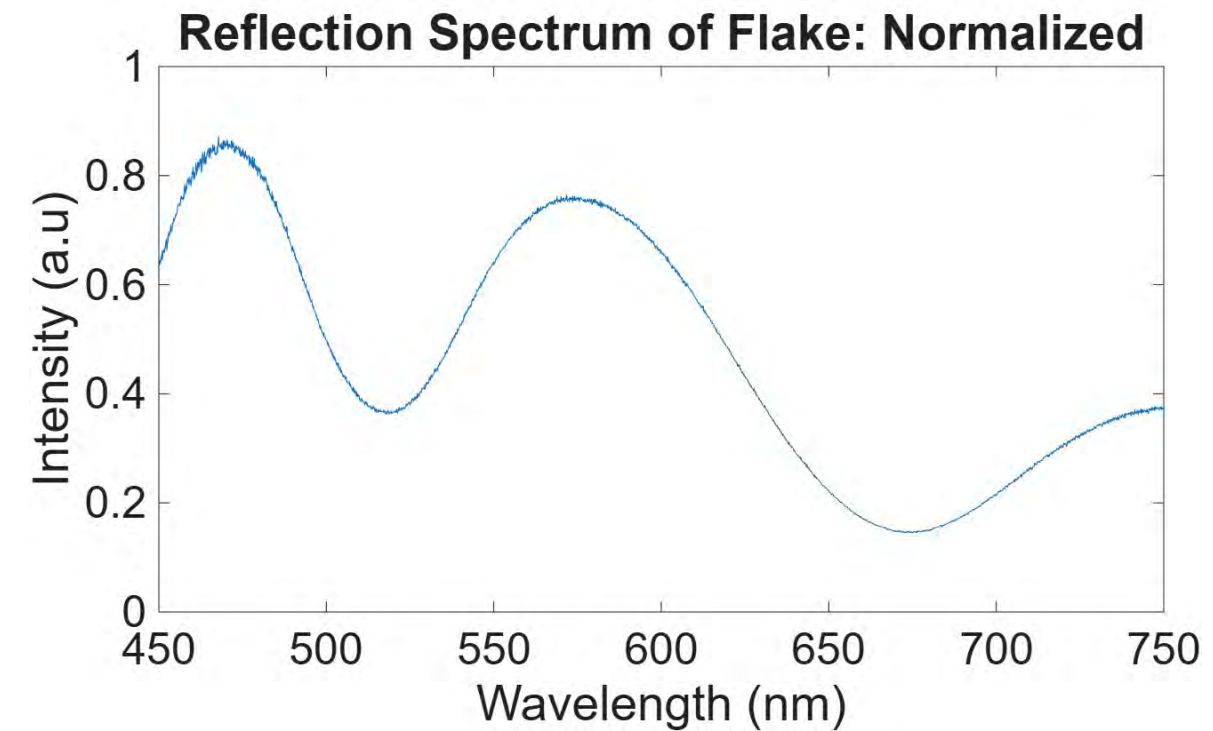
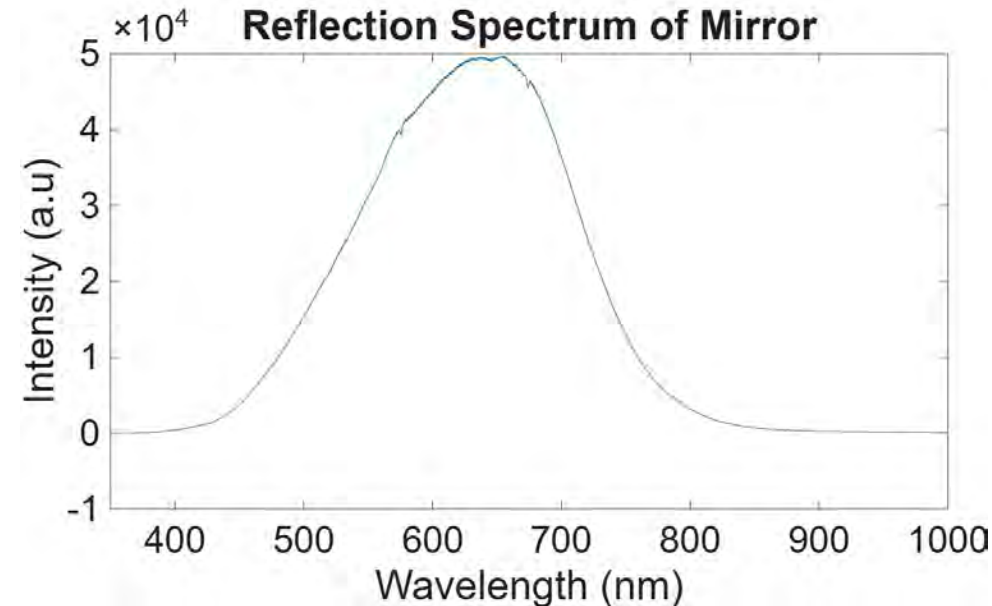
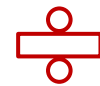
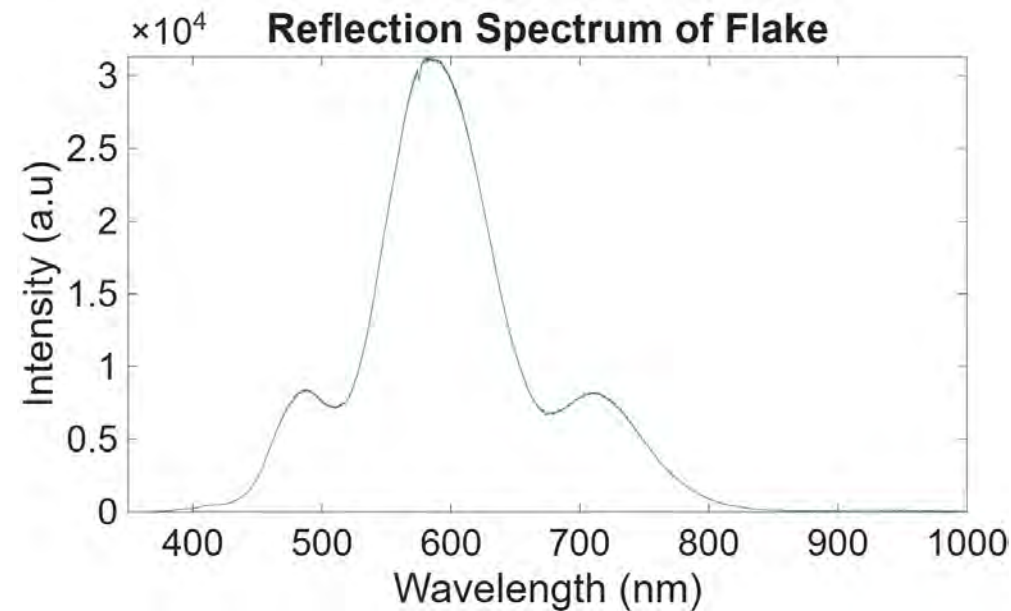




- ❑ The reflection spectra are measured using a **custom-built confocal optical spectrometer** in a **back-reflection configuration**, with **white-light illumination** from a halogen lamp focused through a **50× objective**.

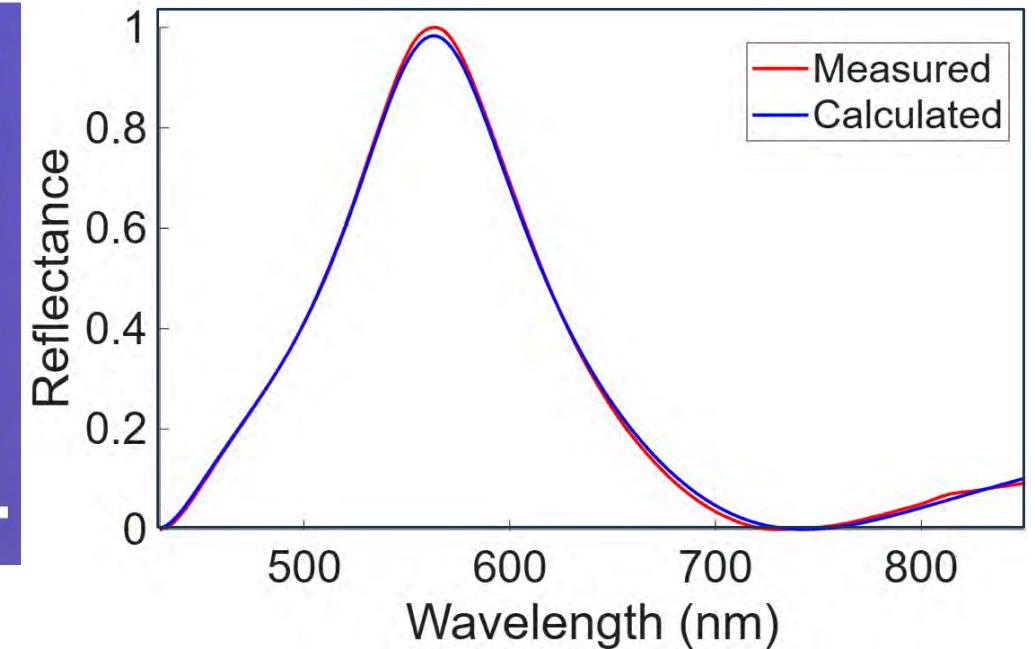
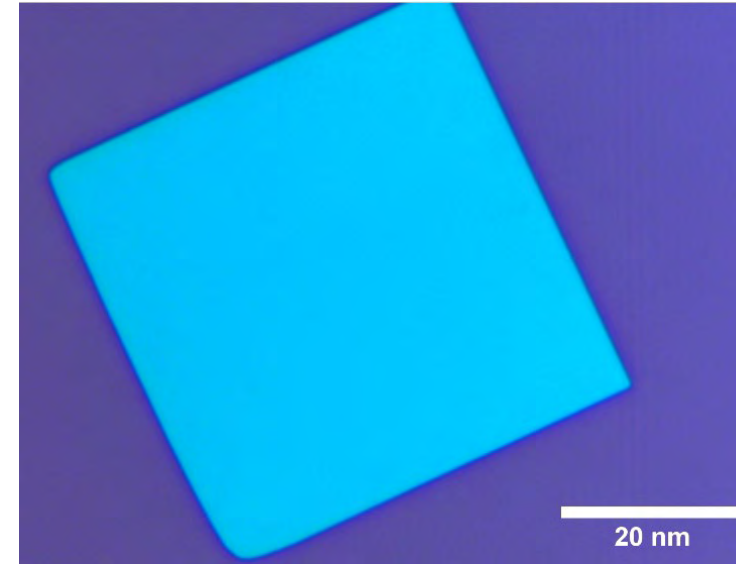


Reflection Spectrum Measurement

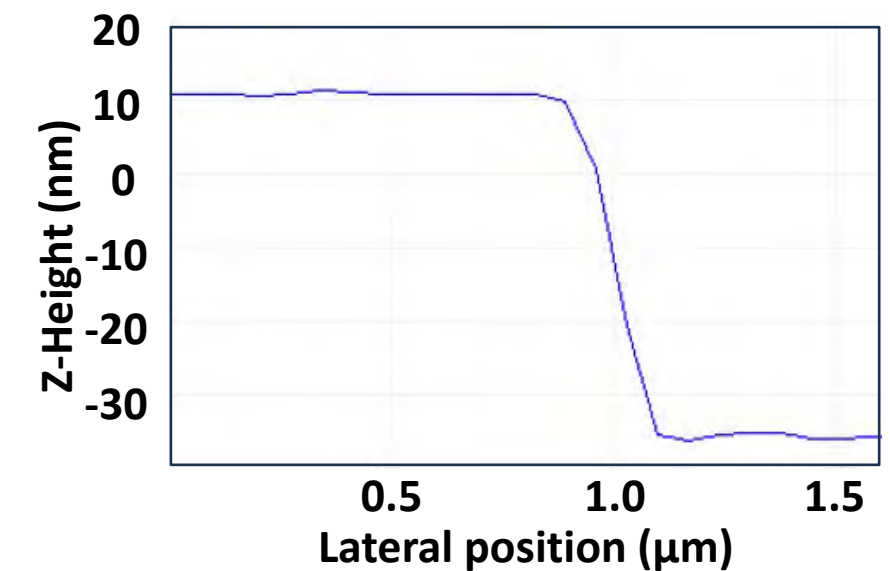
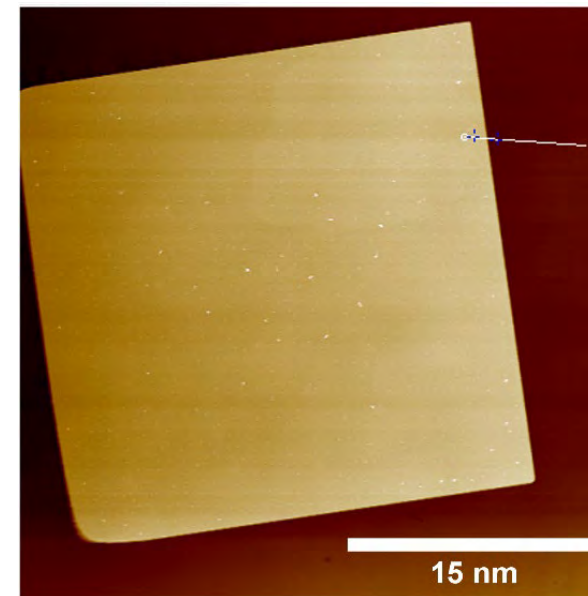


- ❑ A **silver-coated mirror** was used as a reference. Normalized reflectance is calculated by dividing the flake's reflection spectrum by the mirror's one under the **same lighting and measurement conditions**.

- ❑ First, we estimated the thickness of the flakes by matching the measured and calculated reflectance spectra by multiple iterations.
- ❑ **The best fit in the visible part of the spectra achieved at the thickness of ~48 nm.**
- ❑ Then we used atomic force microscope (AFM) measurement to validate the thickness as 48 nm.



Example of a CsPb_2Br_5 flake and the corresponding reflection spectra.



AFM image and the height profile of the same CsPb_2Br_5 flake.



Conclusions and Perspectives

- ❑ We have successfully synthesized high-quality CsPb_2Br_5 crystals with **controlled thickness in nanoscale**.
- ❑ Our experimental results and optical contrast modeling demonstrate the strong relationship between flake thickness and optical properties, confirming that reflection spectroscopy provides **a rapid and noninvasive method for estimating flake thickness**.
- ❑ In future work, we will further develop a machine-learning model to automatically estimate flake thickness from the measured spectra with minimal human intervention.

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Questions?

