

Supplementary Information

Yongqiang Ji^a, Minqiang Wang*^a, Zhi Yang^a, Shangdong Ji^a, Hengwei Qiu^a, Jinjuan Dou^a,
Nikolai V. Gaponenko^b

^aElectronic Materials Research Laboratory, Key Laboratory of the Ministry of Education International Center for Dielectric Research&Shanxi Engineering Research Center of Advanced Energy Materials and Devices, Xi'an Jiaotong University, Xi'an 710049, China.

^bBelarusian State University of Informatics and Radioelectronics, P. Browki St.6, 220013 Minsk, Belarus.

Experimental details

Materials and chemicals

The cesium carbonate (Cs_2CO_3 , 99.99%), oleic acid (OA, 85%), oleyamine (OLAM, 80-90%), Tri-n-octylphosphine (TOP, 90%), 1-octadecene (ODE, >90%), Tetrabutylammonium chloride (TBA-Cl, 95%) and Tetrabutylammonium iodide (TBA-I, 99%) were purchased from Aladdin. The lead(II) bromide (PbBr_2 , 99.999%) was purchased from Xi'an Polymer Light Technology Corp, and the n-hexane and ethyl acetate purchased from Shanghai Chemical Industrial Company. All the reagents were used without further purification.

Synthesis of CsPbBr_3 NWs

All syntheses were performed in air and without any pre-dried chemicals or solvents. In a typical synthesis, PbBr_2 (1 mmol) was dissolved in 10 mL ODE, 0.5 mL TOP, 1 mL OA and 1 mL OLAM in a 30 mL vial on a hotplate set at 120 °C. After the PbBr_2 was completely dissolved, 1 mL of Cs-OA (0.4 g Cs_2CO_3 dissolved in 1.25 mL OA and 15 mL ODE in a 30 mL vial on a hotplate set to 100 °C) was swiftly injected, the reaction immediately turned pale yellow, depending on the required length and width, was quickly cooled down after 0-60 min to RT with a cold water bath.

Isolation and Purification

First, equal volume ethyl acetate was added to the crude solution of nanowires (NWs). The solutions were first centrifuged at 5000 rpm for 5 min to remove excess by-products. Then, the supernatant was discarded and the aggregated QDs were redispersed in toluene.

Anion exchange of CsPbBr_3 NWs

The anion exchange reaction was performed by using TBA-Cl and TBA-I as the anion

source. 1 g of TBA-Cl or 1 g of TBA-I was mixed with 5 ml OLA in a 100 ml three-neck flask, degassed under Ar flow at 10 min for 120 C and reacted at 200 C for 1 h. After reaction, the mixture was diluted by CHCl₃ with 1:3.

0.25 ml of crude CsPbBr₃ QDs were dispersed in 0.75 ml of CHCl₃, and different amounts (Cl ranging from 50 to 400 μL, and I ranging from 50 to 400 μL) of anion resource solutions were quickly injected. The color of solution changed immediately, and extra 2 min was given to guarantee total ion exchange reaction. After reaction, the QDs were precipitated by adding ethyl acetate (1:1 v/v) and then centrifuged at 5000 rpm for 5 min. The obtained precipitate was re-dispersed in hexane for further characterization.

Measurement and characterization

The transmission electron microscopy (TEM) studies were carried out using JEOL JEM-2100 at 200 kV. The photoluminescence (PL) spectra, quantum yields (QYs) and fluorescence lifetimes were recorded on an Edinburgh Instruments FLS9 spectrometer. The ultraviolet-visible (UV-Vis) absorption spectra were recorded by PE Lambda 950. The x-ray diffraction (XRD) patterns were obtained using the DB-ADVANCE X-ray diffraction analyzer diffractometer.

Introduce and discuss some equations

There are four main equations corresponding to the reaction, Firstly, the Gibbs-Thomson equation, which can be written as

$$C_n = C_b \exp\left(\frac{2\sigma V_m}{rRT}\right) \quad (1)$$

In which C_n and C_b are the solubility of the nanoparticle and the corresponding bulk solid; σ is the specific surface energy; V_m is the molar volume of the material; R is the gas constant and T is the absolute temperature.

According to the Tauc method, For this purpose, a plot of $(\alpha h\nu)^{1/2}$ versus $h\nu$ was formed according to the following equation

$$\alpha(\nu)h\nu = B(h\nu - E_{\text{gap}})^m \quad (2)$$

where E_{gap} , B , and $h\nu$ are the optical gap, constant, and incident photon energy, respectively; $\alpha(\nu)$ is the absorption coefficient, m is the index which can have different values of $1/2$, $3/2$, 2 , and 3 .

Equation is a tri-exponential fitting function:

$$I = A_1 \exp\left(-\frac{t}{\tau_1}\right) + A_2 \exp\left(-\frac{t}{\tau_2}\right) + A_3 \exp\left(-\frac{t}{\tau_3}\right) \quad (3)$$

Where A_1 , A_2 and A_3 are constants, t is time, and τ_1 , τ_2 , τ_3 represent the decay lifetimes.

The average lifetime (τ_{ave}) can be calculated as follows

$$\tau_{\text{ave}} = \frac{A_1 \tau_1^2 + A_2 \tau_2^2 + A_3 \tau_3^2}{A_1 \tau_1 + A_2 \tau_2 + A_3 \tau_3} \quad (4)$$

Table S1. Fitting parameters and average lifetimes for the produced CsPbBr₃ with morphology evolution from nanoparticles (NPs) to s-NWs, l-NWs and ul-NWs.

	$A_1(\%)$	$\tau_1(\text{ns})$	$A_2(\%)$	$\tau_2(\text{ns})$	$A_3(\%)$	$\tau_3(\text{ns})$	$\tau_{avg}(\text{ns})$
5 s	3.54	1.3885	28.37	7.6944	68.09	14.3217	11.9836
10 s	3.15	1.3796	27.48	7.2771	69.37	16.1623	13.2549
30 s	3.53	1.5534	22.90	7.2401	73.57	17.2832	14.4280
60 s	3.75	1.7271	17.78	7.8954	78.47	17.8943	15.5102
120 s	4.17	1.6893	18.34	7.6942	77.49	18.5421	15.8494
300 s	4.54	1.7531	16.53	7.8953	78.93	19.6521	16.8960

Supplementary Figures:

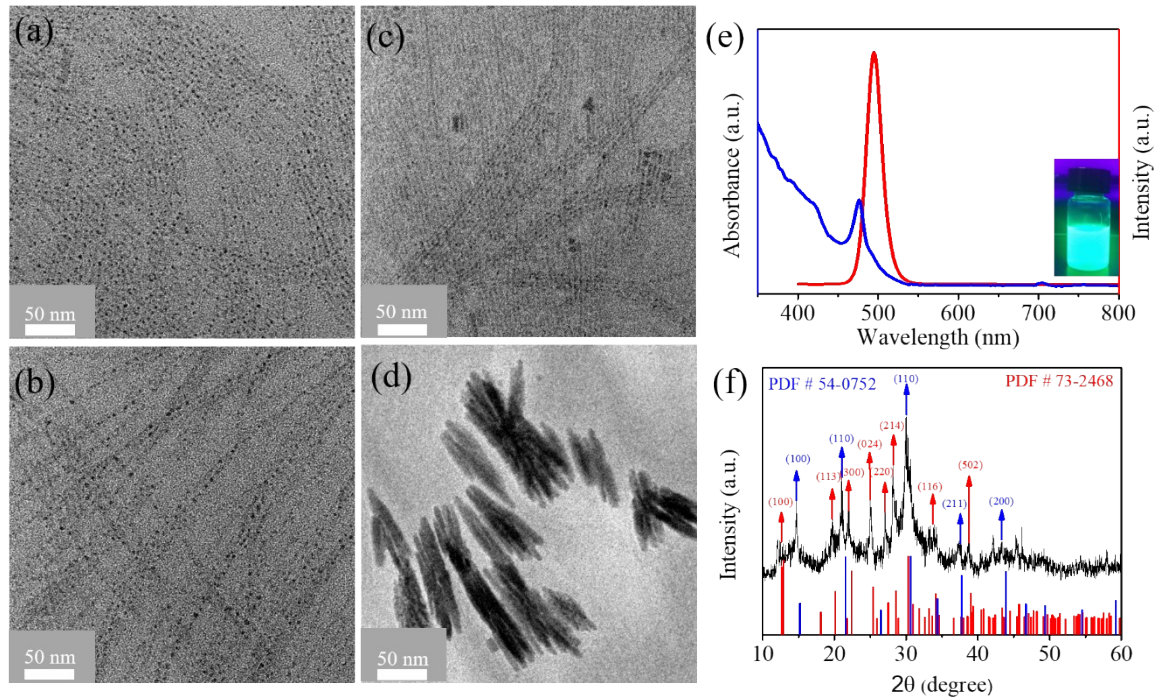


Figure 1. TEM images of CsPbBr₃ NWs: (a) Low concentration. (b) Medium concentration. (c) High concentration. (d) Excess concentration (e) UV-visible absorption (blue line) and photoluminescence (red line) spectra of CsPbBr₃ NWs. (Inset) Digital image of the solution illuminated with a 365 nm UV source. (f) The XRD pattern of CsPbBr₃ NWs.

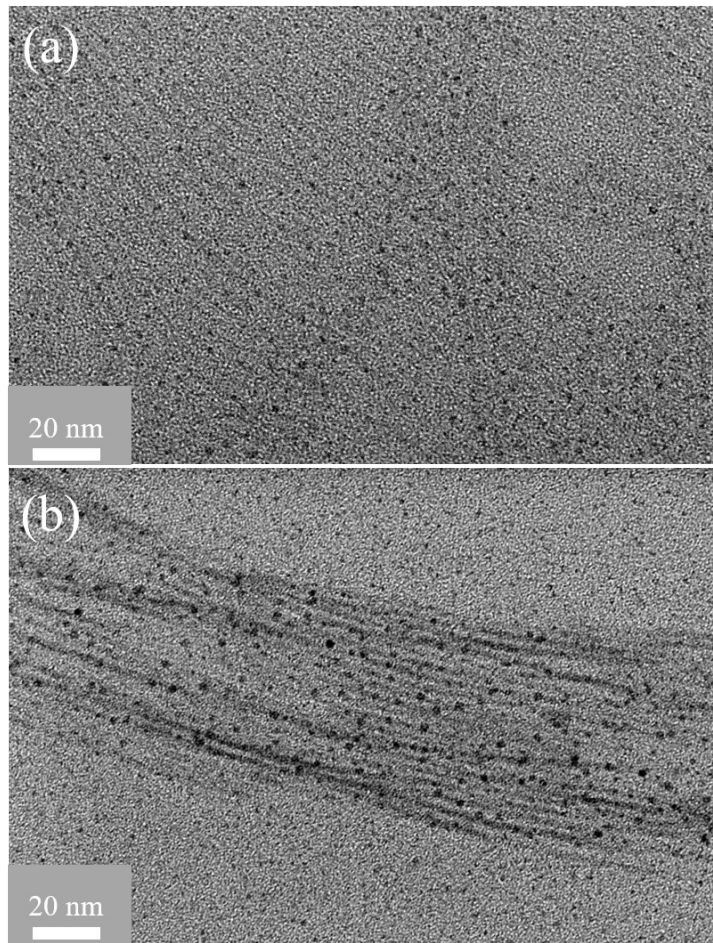


Figure 2. Enlarge TEM images of NWs: (a) Low concentration. (b) High concentration.

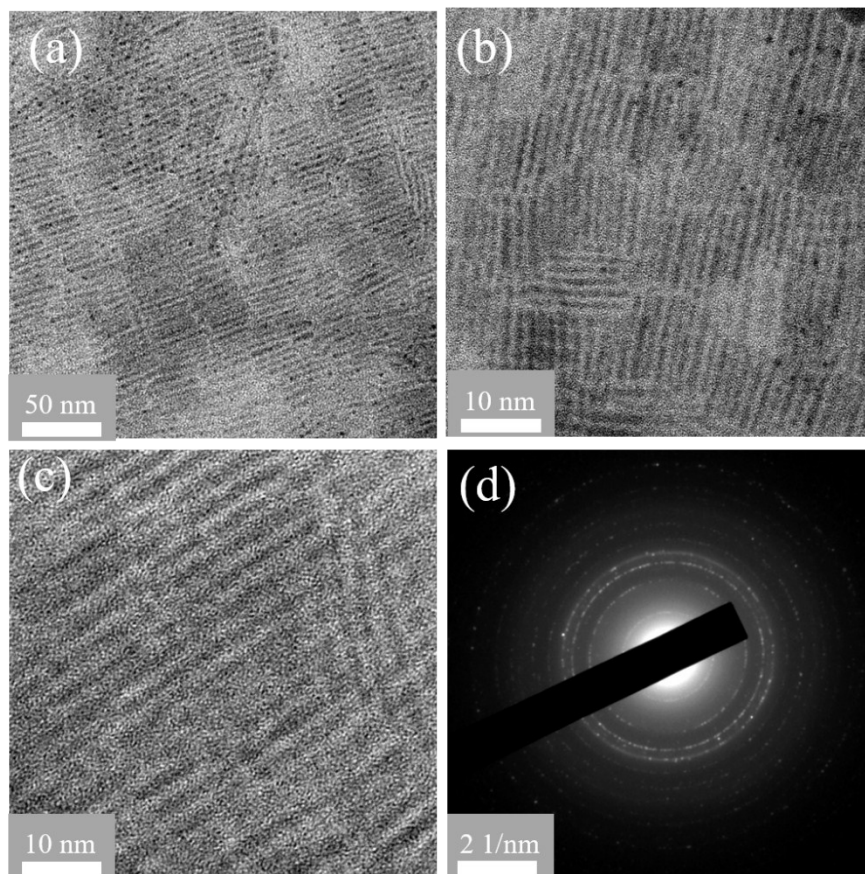


Figure 3. (a) TEM image of short NWs. (b) and (c) Enlarge images of NWs. (d) SAED image of short NWs.

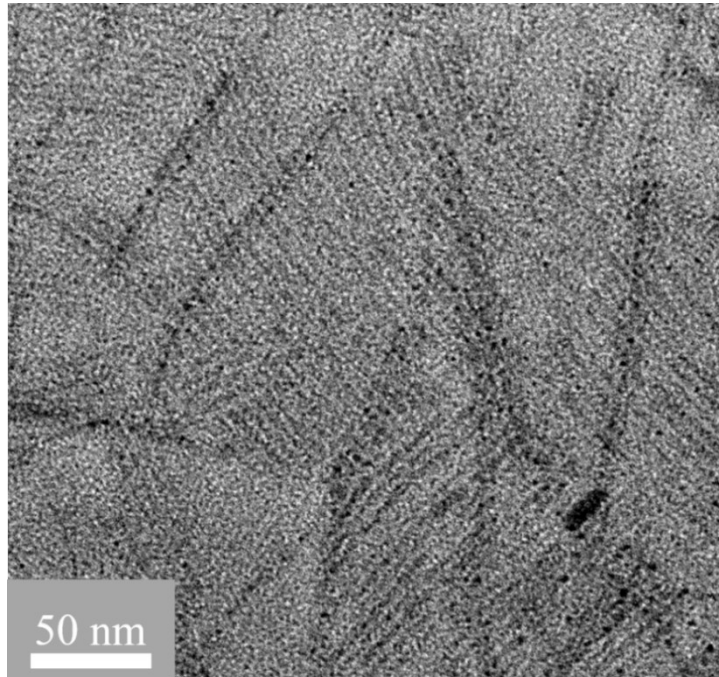


Figure 4. TEM image of comb-like nanostructures.

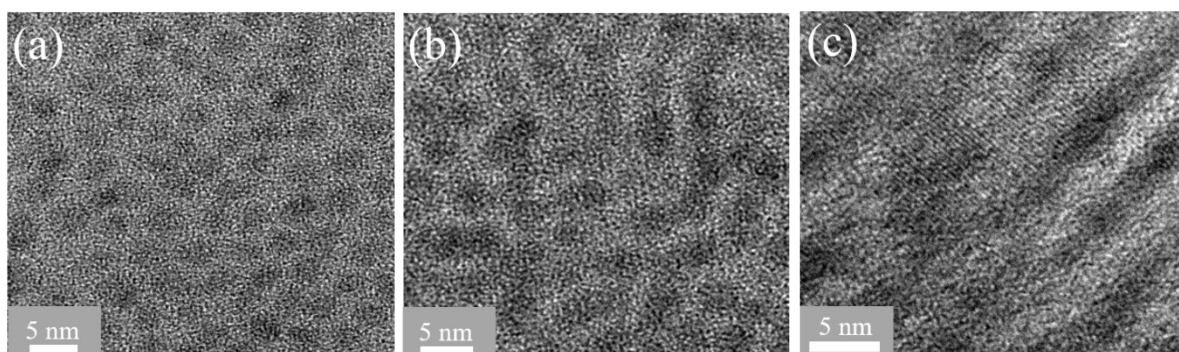


Figure 5. High-resolution TEM images showing three different stages of the NWs formation process from NPs to NWs. The length of the NWs changes but there is no significant change in the diameter.

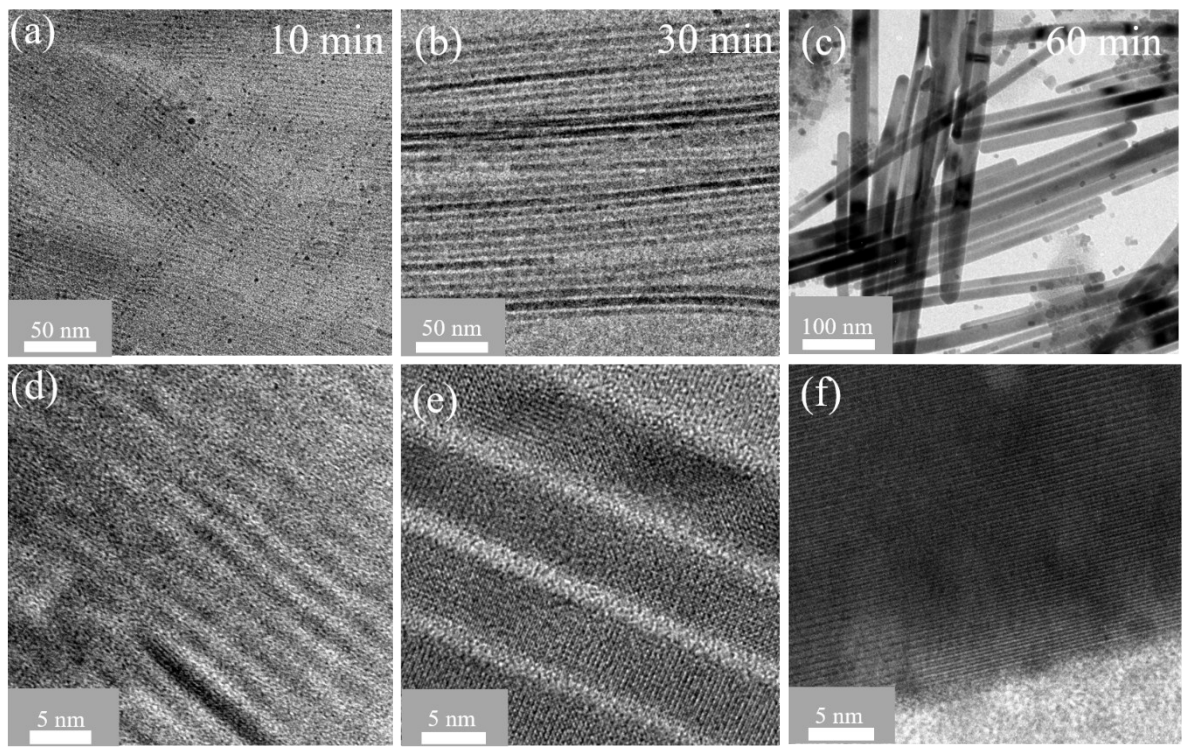


Figure 6. The TEM and high resolution TEM images of CsPbBr₃ NWs with different reaction time: (a, d) 10 min. (b, e) 30 min. (c, f) 60 min.

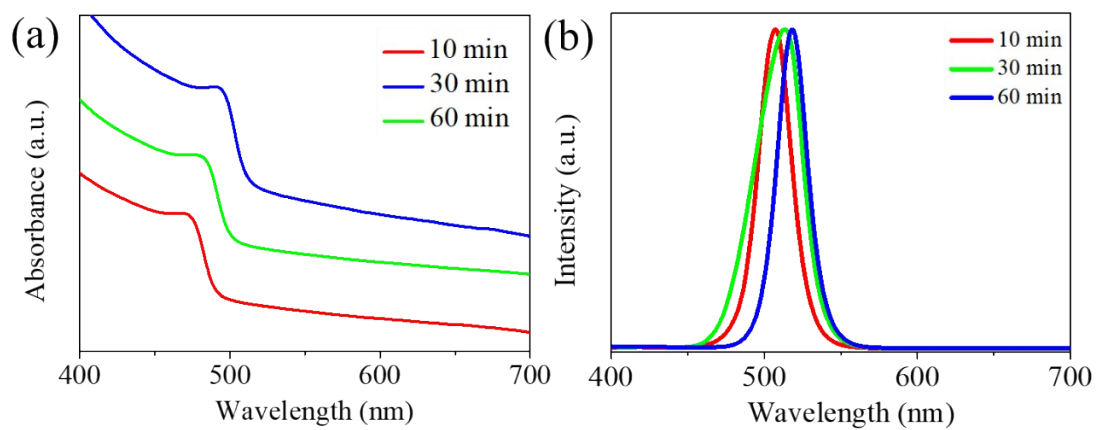


Figure 7. Normalized UV absorption and PL emission spectra of the CsPbBr₃ NWs with different reaction time.

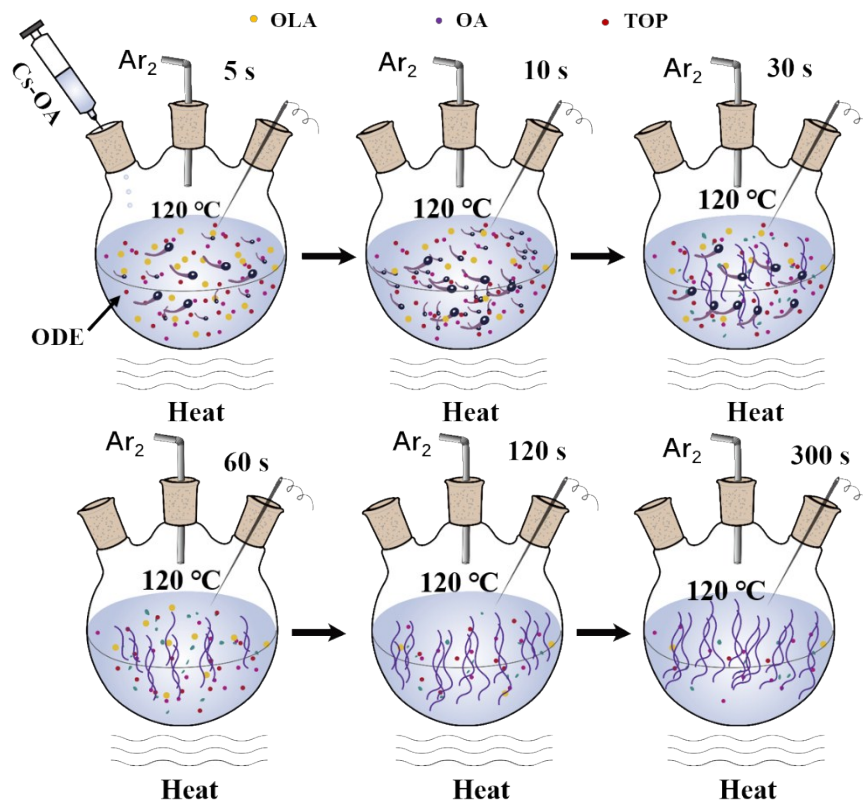


Figure 8. Schematic diagram of NPs self-assembly into NWs.

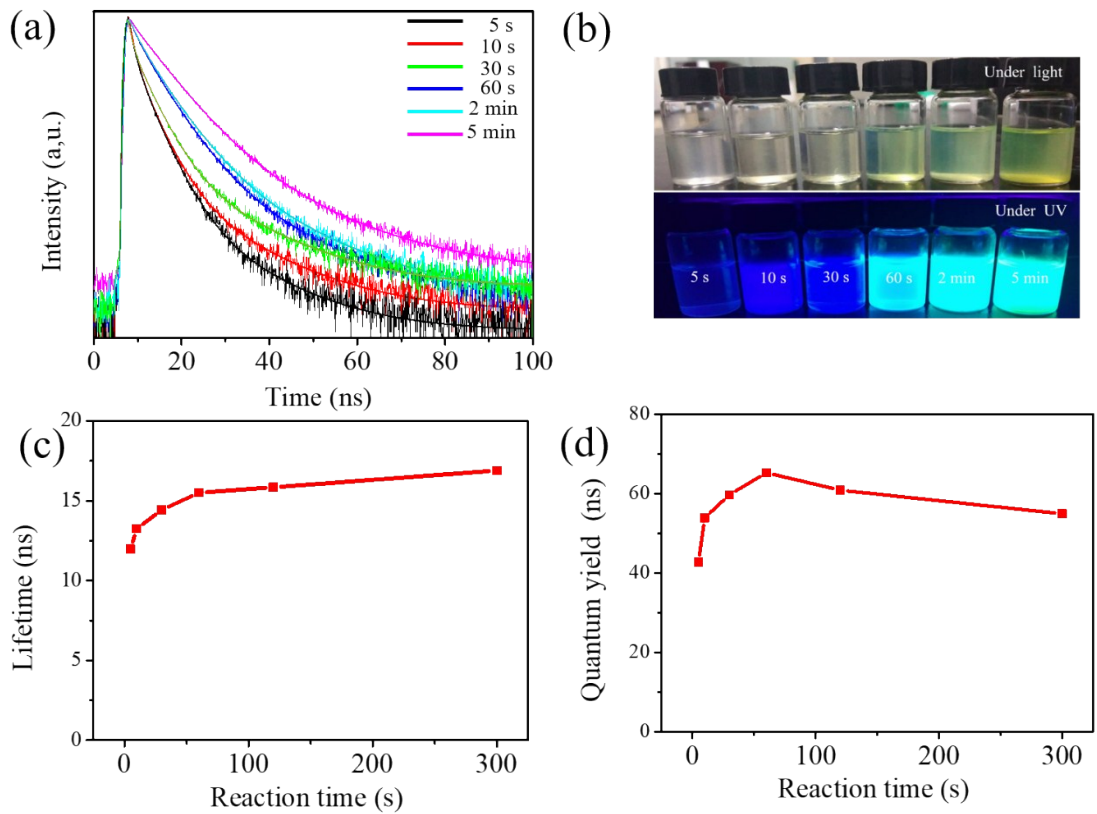


Figure 9. (a) and (c) average lifetime of the CsPbBr₃ NWs with different reaction time. (b) Digital image of the solution illuminated with daylight (Top) and a 365 nm UV source (Down), respectively. (d) PLQYs of the CsPbBr₃ NWs with different reaction time.

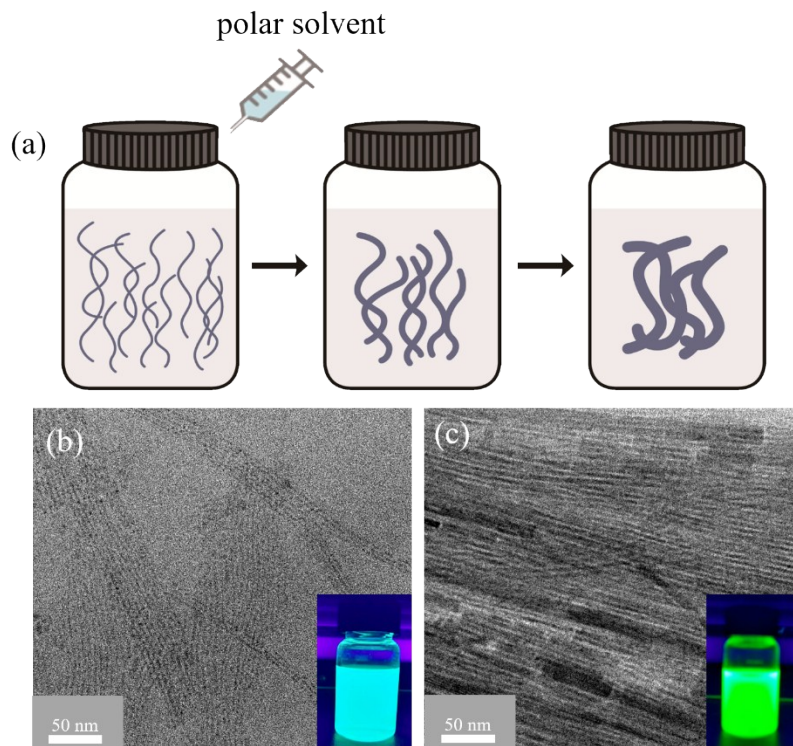


Figure 10. (a) Schematic diagram of ethanol-induced self-assembled NWs. (b) TEM images of initial NWs. (c) TEM images of ethanol-induced NWs. (Inset) Digital image of the solution illuminated with a 365 nm UV source.

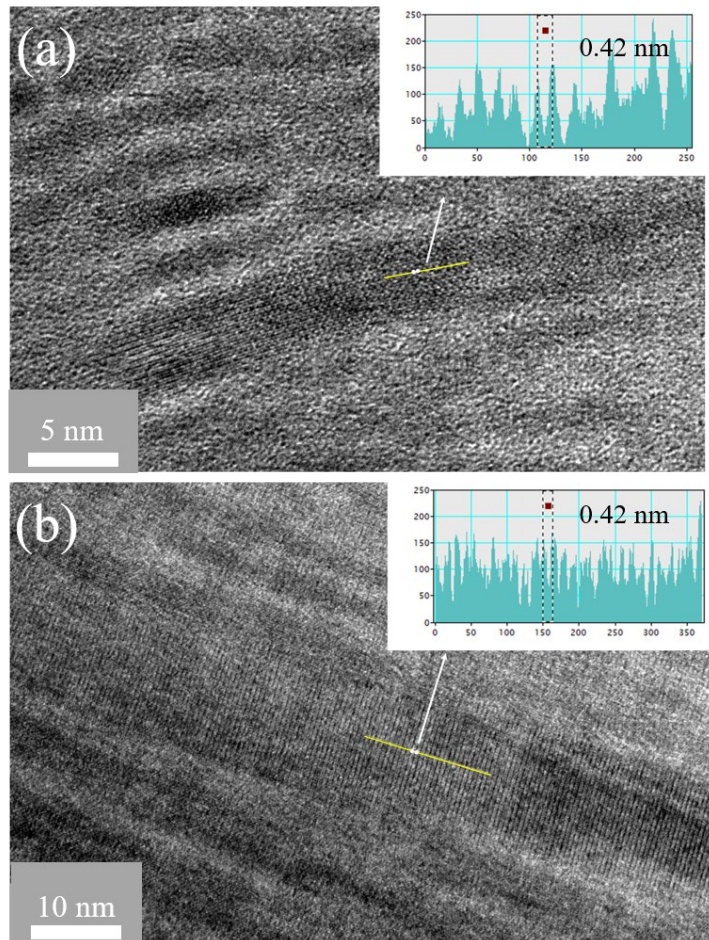


Figure 11. HRTEM images of ethanol-induced self-assembled NWs. (a) Before. (b) After. The lattice fringes exactly match with 110 lattice spacing of cubic phase CsPbBr₃.

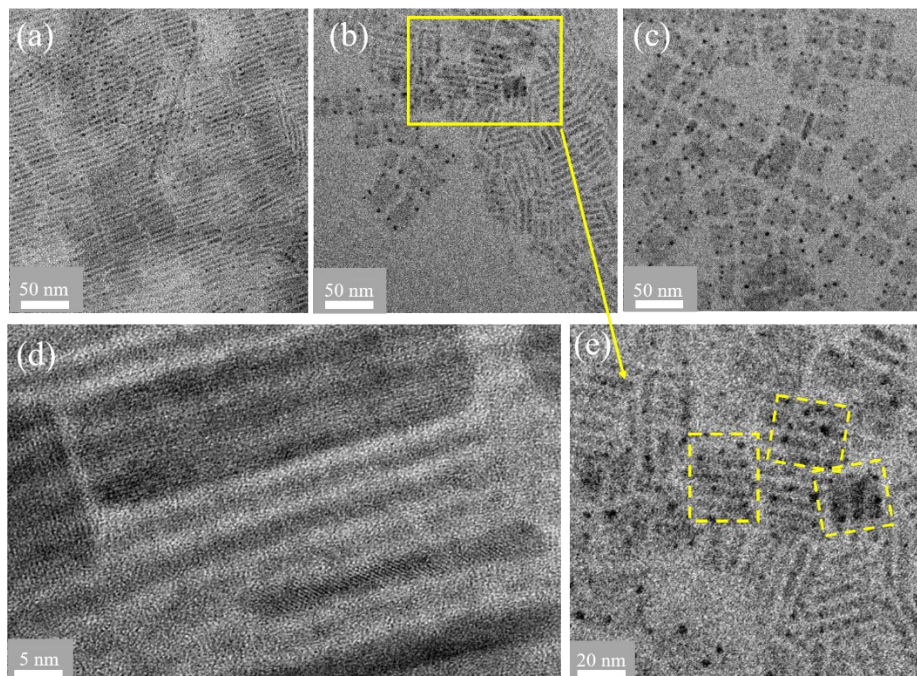


Figure 12. (a-c) Representative TEM images of samples showing transformation from s-NWs to nanosheets (NSs). (d) HRTEM images of NSs consisting of s-NWs. (e) Partially enlarged image of Figure b.

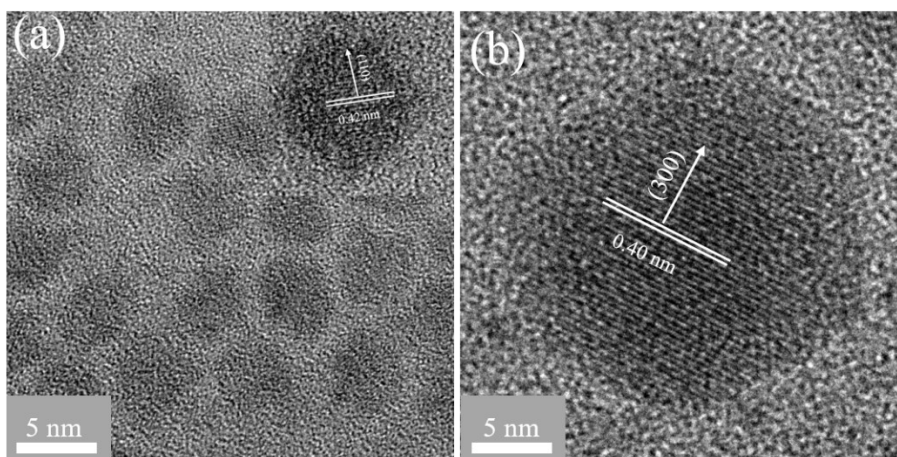


Figure 13. (a) HRTEM images of CsPbBr_3 NPs. (b) HRTEM images of Cs_4PbBr_6 NPs.

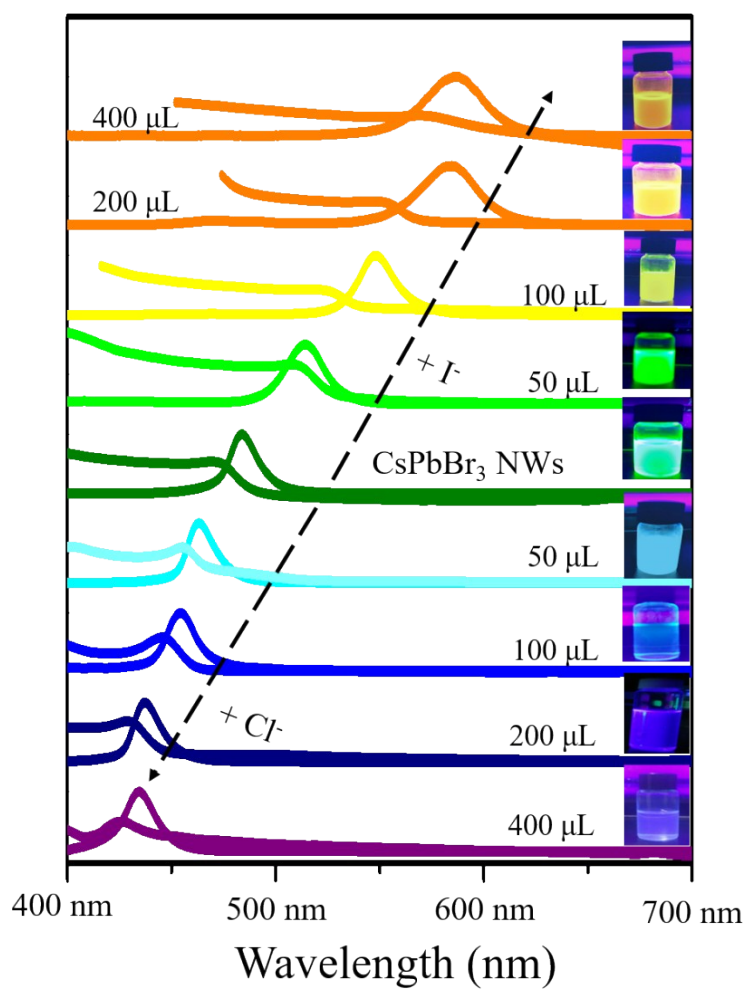


Figure 14. Normalized UV absorption and PL emission spectra of the CsPbBr₃ NWs after halide anion exchange with different halide compositions. (Inset) Digital image of the solution illuminated with a 365 nm UV source.