Supporting Information

Atomically Thin Cesium Lead Bromide Perovskite Quantum Wires with High Luminescence†

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Experiment section

Materials

All chemicals were used as received without further purification. Cesium carbonate (Cs_2CO_3, 99.5%) and n-hexane (⩾97.0%) were purchased from Sinopharm Chemical Reagent Co., Ltd (Shanghai, China). 1-octadecene (ODE, 90%), lead bromide ($PbBr_2$, 98%), oleic acid (OA, 90%), and oleylamine (OAm, 70%) were obtained from Sigma-Aldrich. Ultrapure Millipore water (18.2 MΩ•cm) was used as the solvent throughout.

Synthesis of $CsPbBr_3$ NWs

The Cs-oleate solution was prepared through a reported method developed by Protesescu and co-workers. Specifically, 0.814 g of Cs_2CO_3 and 2.5 mL of OA were loaded into 100-mL 3-neck flask together with 40 mL of octadecene, followed by degassing and drying at 120 ^oC for 1h. Then the mixture was heated under N_2 to 150 ^oC until all Cs_2CO_3 was reacted with OA. Since the Cs-oleate complex can precipitate out of ODE at room temperature, they have to be preheated to 100 ^oC before injection. In a standard procedure, 69 mg of $PbBr_2$, 0.5 mL of OA, and 0.5 mL of OAm were dissolved in 5 mL of ODE in a 20-mL vial at 120 ^oC. After magnetic stirring for 15 min, a uniform mixture solution was formed. The mixture solution was then cooled down to room temperature (25 ^oC) naturally. Afterwards, 0.4 mL of Cs-oleate solution was quickly injected into the above mixture solution under magnetic stirring. The solution was then reacted at room temperature for 2 h with vigorous stirring. The produced $CsPbBr_3$ quantum wires were directly precipitated by centrifugation at 15000 rpm for 10 min in an original ODE solution and then washed with hexane for one more time. To improve the quantum yield of the produced $CsPbBr_3$ quantum wires, the produced $CsPbBr_3$ quantum wires reaction solution was further treated at a 120 ^oC oil bath for 2 min.

Characterization

Transmission electron microscopy (TEM) images were taken using a Hitachi HT7650 microscope operated at 120 kV. To avoid the damage to $CsPbBr_3$ quantum wires by intense electron beams, high-angle annular dark-field scanning TEM (HAADF-STEM) images were collected on a JEOL ARM-200F field-emission transmission electron microscope operating at 80 kV. Synchrotron radiation X-ray diffraction (XRD) was performed at the BL19U station of Shanghai Synchrotron Radiation Facility (SSRF). The used X-ray photon energy is 12 keV. The diffraction patterns were recorded by a two-dimension detector (Pilatus, 1M) using a transmission geometry. Ultraviolet-visible (UV-vis) absorption spectra were collected on an Agilent Cary 60 UV-Vis Spectrometer. The steady-state, time-resolved photoluminescence (PL) and quantum yields were measured on a FLS920 fluorescence spectrometer (Edinburgh Instruments). The quantum yields were measured using an integrating sphere and determined by the following equation:[1]

$$\mathrm{QY} = \frac{\int I_{em}\mathrm{d}\lambda}{\int I_O\mathrm{d}\lambda - \int I\mathrm{d}\lambda} \qquad (1)$$

where I_{em} is the PL intensity, and I_0, I are the excitation light intensity transmitted through the solvent and sample, respectively. The excitation source is 365 nm light of a Xe lamp. In the experiments, we used standard quartz cuvette (10mm length x10mm width, four-plane transparent) as the sample container. We used integrating sphere from Edinburgh Instruments Ltd, and the measuring geometry is shown in Figure S4B. The absorption of the sample is obtained by subtracting the excitation light transmitted through sample from that transmitted from solvent. The PL decay data were recorded using time-correlated single photon counting (TCSPC) technique, using pulsed laser diodes with a wavelength of 404.2 nm and pulse width of 58.6 ps as the excitation source. The temperature-dependent measurements were performed with a closed-cycle helium cryostat. For excitation-density dependent measurements, the light fluence was tuned by neutral attenuators.

References

1 L. Protesescu, S. Yakunin, M. I. Bodnarchuk, F. Krieg, R. Caputo, C. H. Hendon, R. X. Yang, A. Walsh, M. V. Kovalenko, *Nano L*ett., 2015, **15**, 3692.

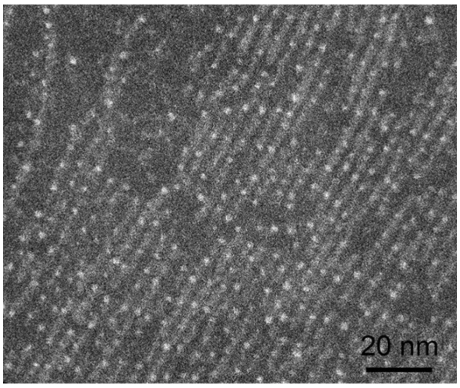

Fig. S1 High-magnification HAADF-STEM image of the few-unit-cell-thick $CsPbBr_3$ QWs obtained by using the standard procedure.

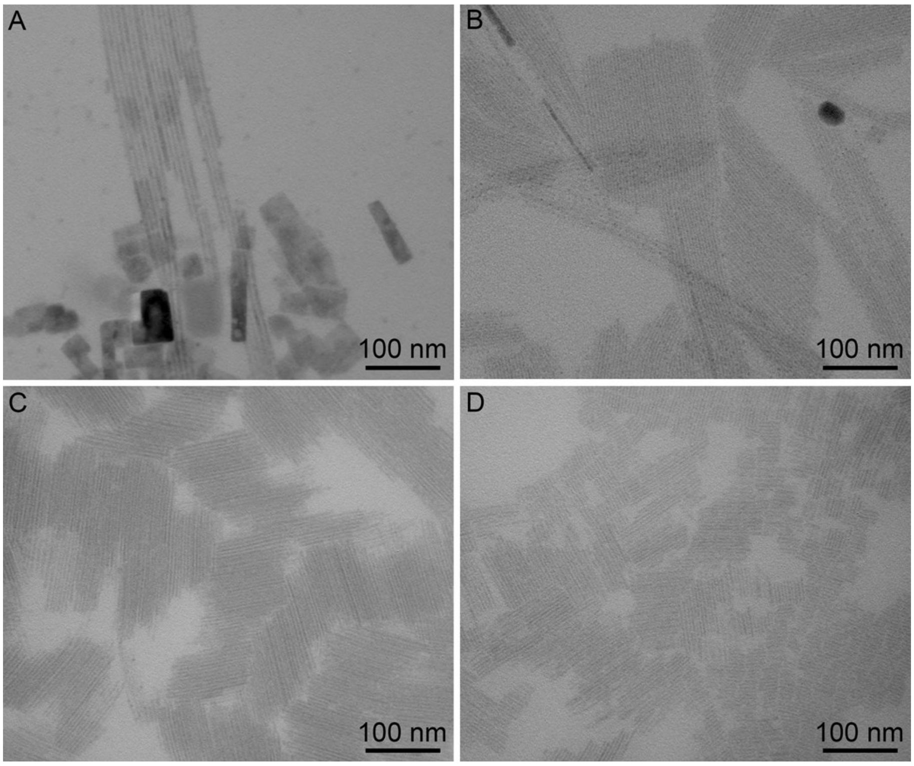

Fig. S2 TEM images of the products obtained through the standard procedure except for the addition of different amounts of OAm: (A) 0.25 mL and (B) 1.00 mL. TEM images of the products obtained through the standard procedure except for the addition of different amounts of OA: (C) 0.25 mL and (D) 1.00 mL.

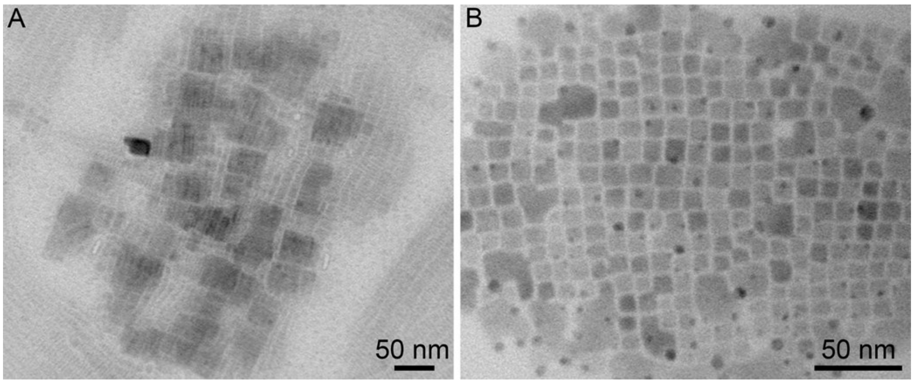

Fig. S3 TEM images of the products obtained by using the standard procedure except for different reaction temperatures in the first step: (A) 60, and (B) 150 ^{o}C.

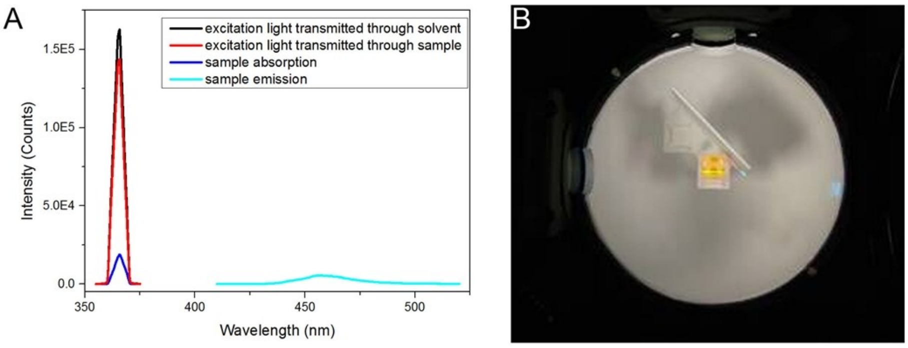

Fig. S4 PLQY measurement of the 120 ^{o}C-treated sample. (A) Measuring results. The absorption of the sample (blue line) is obtained by subtracting the excitation light transmitted through sample from that transmitted from solvent. We note that there is concentration quenching effect in our samples, which is normal for fluorescence materials in solution. In this regard, we restricted our PLQY measurements in low concentration regime to avoid such effect. (B) Measuring geometry of the samples.

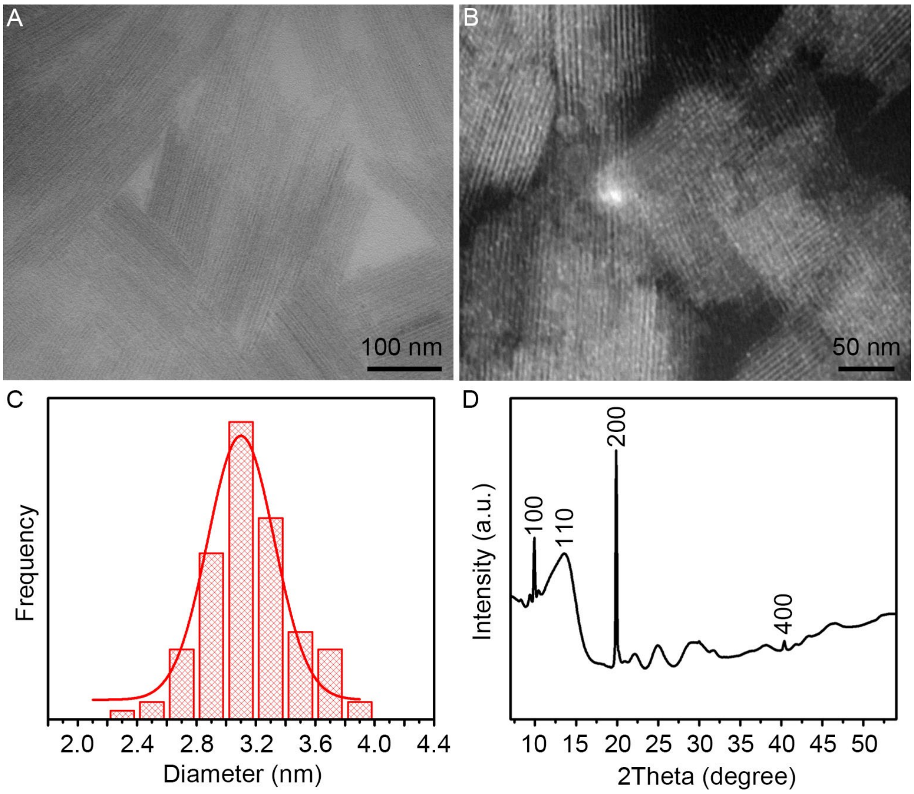

Fig. S5 (A) TEM image, (B) HAADF-STEM image, (C) histogram of diameter distribution, and (D) XRD pattern of the products obtained by treating the standard few-unit-cell-thick $CsPbBr_3$ QWs at 120 ^{o}C for 2 min.

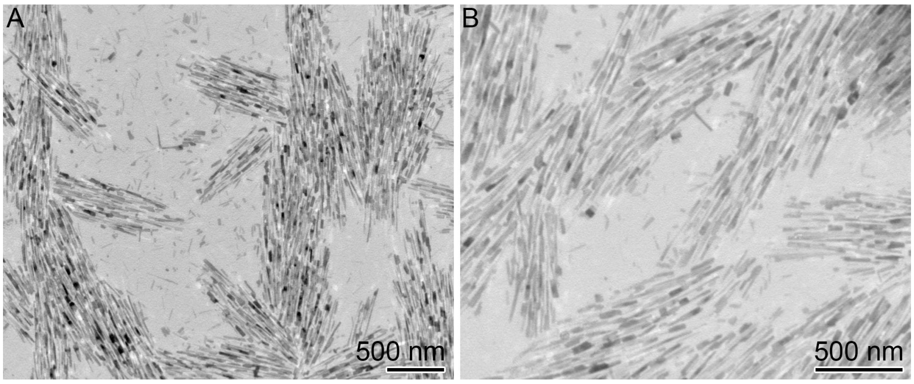

Figure S6. TEM images of the sample obtained by washing the 120^{o}C-treated $CsPbBr_3$ QWs with hexane for 5 times.

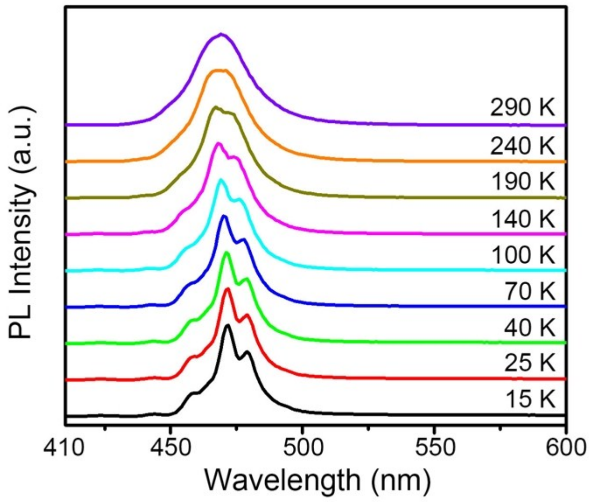

Fig. S7 Temperature-dependent PL spectra collected from the120 ^{o}C-treated $CsPbBr_3$ QWs.

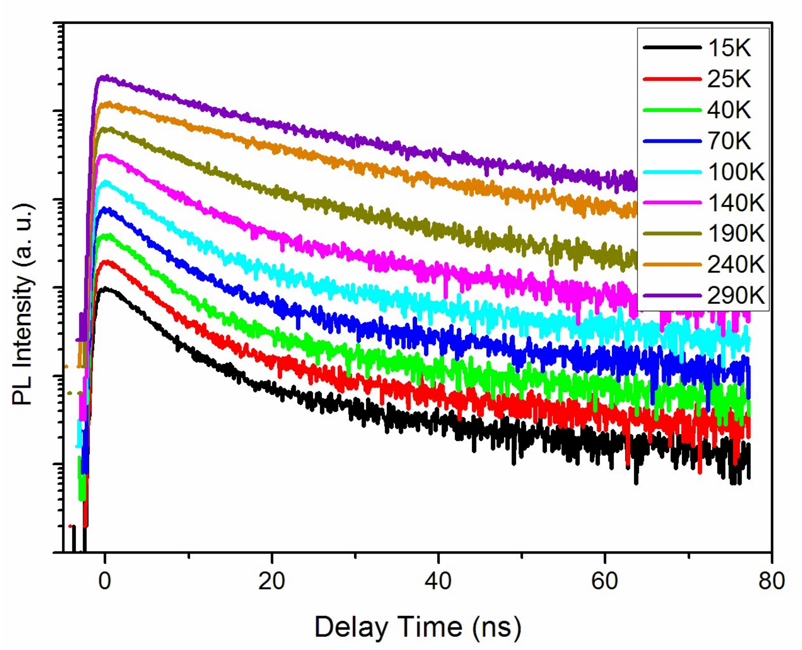

Fig. S8 Temperature-dependent PL decay spectra collected from the 120 ^{o}C-treated $CsPbBr_3$ QWs.