Supporting Information

Experimental section

Chemicals

Indium(I) chloride (In(I)Cl, 99.99%, Aladdin), Indium(III) chloride ($InCl_3$, 99.9%, Aladdin), Tri-n-octylphosphine (TOP, 90%, Aladdin), Oleylamine (OLA, 80-90%, Aladdin), Tris(dimethylamino)phosphine ($P(DMA)_3$, 97%, Alfa Aesar)， all chemicals were used directly without any further purification.

Synthesis of InP QDs using In(I)Cl:

Initially, 0.75 g (0.5 mmol) of In(I)Cl, 0.32 mL (0.3 mmol) of TOP, and 7 mL of OLA were loaded into a 50 mL three-neck flask. The mixture was degassed under vacuum at 50 °C for 30 min to remove residual moisture and oxygen. Subsequently, the system was heated to 200 °C under an inert atmosphere, followed by a rapid injection of 0.18 mL (1 mmol) of $P(DMA)_3$. The reaction was maintained for 30 min, during which the solution gradually turned deep red-black, indicating the formation of InP QDs. The reaction was then quenched by cooling the flask to room temperature. The resulting crude product was purified using a sequential centrifugation process. First, the reaction mixture was centrifuged at 4000 rpm for 3 min to remove unreacted precursors and metallic indium byproducts. Next, 30 mL of acetone was added, and the mixture was centrifuged at 8000 rpm for 3 min to collect the InP QD precipitate. The purified QDs were redispersed in 1 mL of anhydrous toluene under a nitrogen atmosphere and transferred to a 50 mL three-neck flask containing a magnetic stir bar. For surface etching, a controlled amount of 2% hydrofluoric acid solution (prepared by dilution with acetone) was introduced into the system.

Synthesis of InP QDs using $InCl_3$:

To synthesize InP QDs using $InCl_3$, $InCl_3$ (0.11 g, 0.5 mmol), TOP (0.32 mL, 0.3 mmol), and OLA (7 mL) were introduced into a 50 mL three-neck flask. The mixture was subjected to vacuum degassing at 50 °C for 30 min to remove residual moisture and oxygen. The flask was then heated to 200 °C under an inert atmosphere. At this temperature, $P(DMA)_3$ (0.18 mL, 1 mmol) was rapidly injected, and the reaction was kept at 200 °C for 30 min before being cooled to room temperature to terminate the reaction. The cooled InP QDs were purified by centrifugation at 8000 rpm for 3 min. After discarding the supernatant, 1 mL of methanol was added to fully dissolve InP precipitate. Subsequently, an appropriate amount of 2% HF solution was introduced to perform HF etching.

Synthesis of InP QDs Uusing In(I)Br:

The same synthetic procedure was applied to prepare InP QDs using In(I)Br instead of In(I)Cl.

Characterization:

Ultraviolet-visible (UV-Vis) absorption spectra were measured using a Shimadzu UV-2600 UV-Vis spectrophotometer. The excitonic absorption peak position (for shoulder peaks) was determined by Gaussian fitting. Emission spectra were acquired using a Tianjin Gangdong F-320 fluorescence spectrophotometer equipped with a 150 W xenon lamp.

PLQY was measured using the steady-state and transient fluorescence spectrometer (FLS1000, Edinburgh Instruments, UK). For the measurement, the etched InP QDs (without further centrifugation) were dispersed in hexane within a quartz cuvette, with the absorbance at the excitation wavelength (365 nm) precisely adjusted to 0.1. PLQY was then determined using the integrating sphere system.

Time-resolved photoluminescence (TRPL) measurements were performed on a high-sensitivity HORIBA Fluorolog-3 spectrofluorometer (HORIBA Instruments Incorporated). The photoluminescence (PL) decay curves were fitted with a biexponential function:

$$Y(t)=A_1\exp(-t/\tau_1) + A_2\exp(-t/\tau_2)$$

whereτ_1 andτ_2 represent the decay time constants, andA_1 and A_2 denote their respective amplitudes [$\chi^2 = 0.99$]. The average lifetime (τ_{avg}) was calculated using the following equation:

$$\tau_{avg}= (A_1\tau_1^2+ A_1\tau_2^2)/ (A_1\tau_1+ A_1\tau_2)$$

XRD measurements were performed using a high-power variable-temperature Rigaku X-ray diffractometer. The sample was prepared by drop-casting a hexane-dissolved InP quantum dot solution onto a dry silicon substrate, followed by complete solvent evaporation prior to testing. XPS analysis was conducted on a Shimadzu KRATOS Axis Supra X-ray photoelectron spectrometer. The sample was prepared by drop-casting a hexane-dissolved InP quantum dot solution onto a dry silicon substrate, followed by complete solvent evaporation prior to testing. ^{31}P NMR spectra were acquired using a Bruker BioSpin AG AVANCE NEO 400 MHz NMR spectrometer. The sample was prepared by mixing 300 μL of the InP quantum dot solution, 5.2 mg (0.02 mmol) of triphenylphosphine (external reference, δ = -5 ppm), and 300 μL of deuterated toluene in an NMR tube for measurement.

Stability Test: Purified InP QDs after HF etching was weighed and thoroughly mixed with lamp-bead glue. The mixture was slowly poured onto a horizontally placed PET film, allowed to flow naturally and spread into a uniform layer, and then rapidly cured under ultraviolet irradiation to obtain composite film materials. The fluorescence properties of the films were subsequently measured using the fluorescence spectrophotometer.

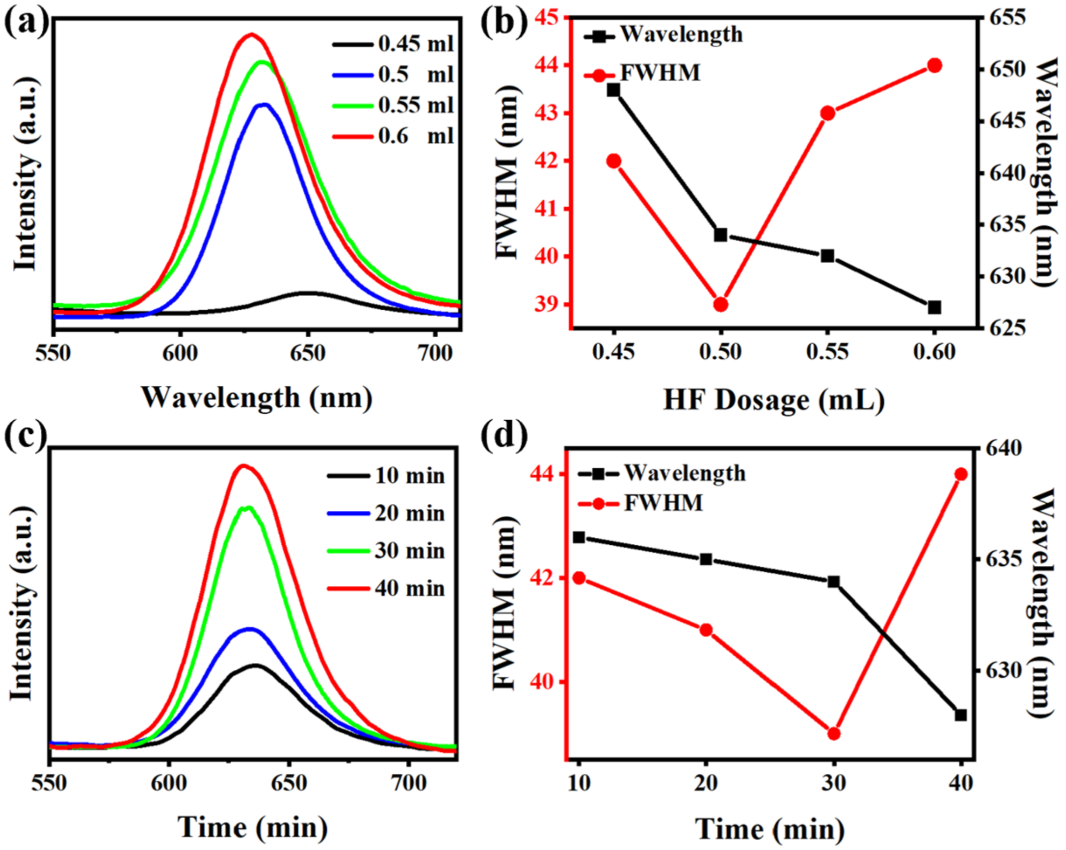


Fig. S1 2% HF concentration (a) PL spectra of InP quantum dots etched with different HF dosages. (b) Variation of emission wavelength and FWHM with HF dosage. (c) PL spectra of InP quantum dots etched for different reaction times. (d) Variation of emission wavelength and FWHM with reaction time.

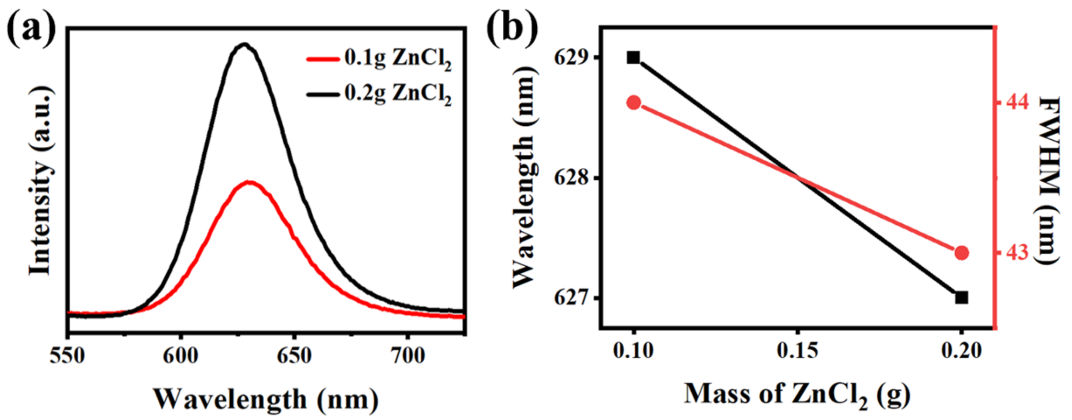


Fig. S2 PL spectra of InP QDs prepared with different amounts of $ZnCl_2$. (b) Schematic diagram of wavelength and FWHM variation with different amounts of $ZnCl_2$.

Table S1. Comparative summary of red-emitting InP QDs synthesized via aminophosphine-based routes reported in recent literature.

Precursors	Year	QDs	PL (nm)	FWHM (nm)	PLQY	Ref
$P(TMS)_3$	2019	InP	630	35	100%	Nature, 2019 575, 634-638
	2022	InP	620	36	90%	Nano Letters,2022, 22 (10), 4067-4073
	2023	InP	614	37	90%	Nano Letters, 2024, 24 (49), 15781-15787
$P(DMA)_3$	2022	InP	607	45	95%	ACS Nano, 2022, 16, 9701-9712
	2022	InP	621	44	86%	Journal of Materials Chemistry C, 2022, 10(6): 2213-2222
	2022	InP	617	45	85%	ACS Energy Letters, 2022, 7(7): 2247-2255
	2023	InP	670	43	40%	Journal of the American Chemical Society, 2023, 145(10): 5970-5981
	2023	InP	632	43	74%	ACS omega, 2023, 8(42): 39690-39698
	2024	InP	609	48	70%	Inorg. Chem. 2024, 63, 6396-6407
	2025	InP	615	44	96%	Adv. Funct. Mater. 2025, e21226
	This work	**InP**	**634**	**38**	**80%**	

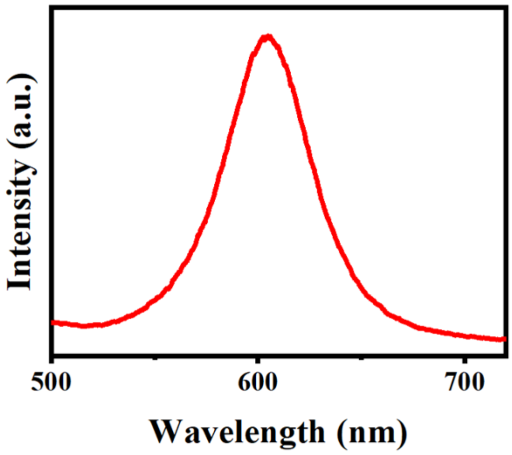


Fig. S3 PL spectra of InP core QDs synthesized using In(I)Br.

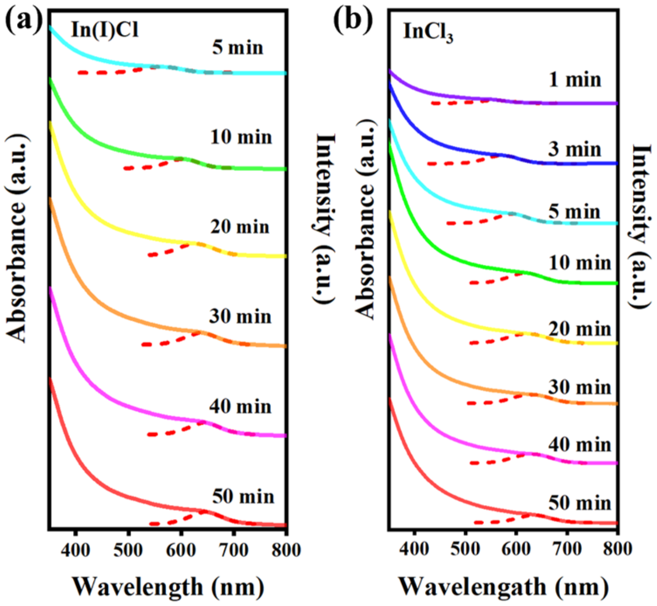


Fig.S4 Evolution of absorption spectra and their Gaussian-fitted curves for InP QDs synthesized from InCl$_3$ and In(I)Cl precursors.

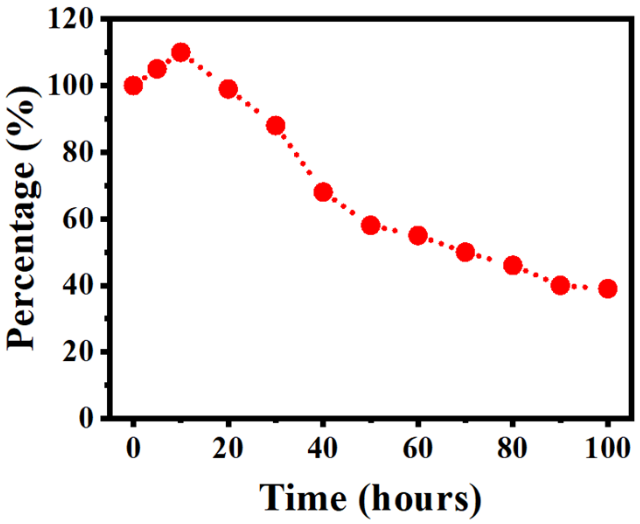


Fig. S5 Stability testing spectra of InP QDs after HF etching.

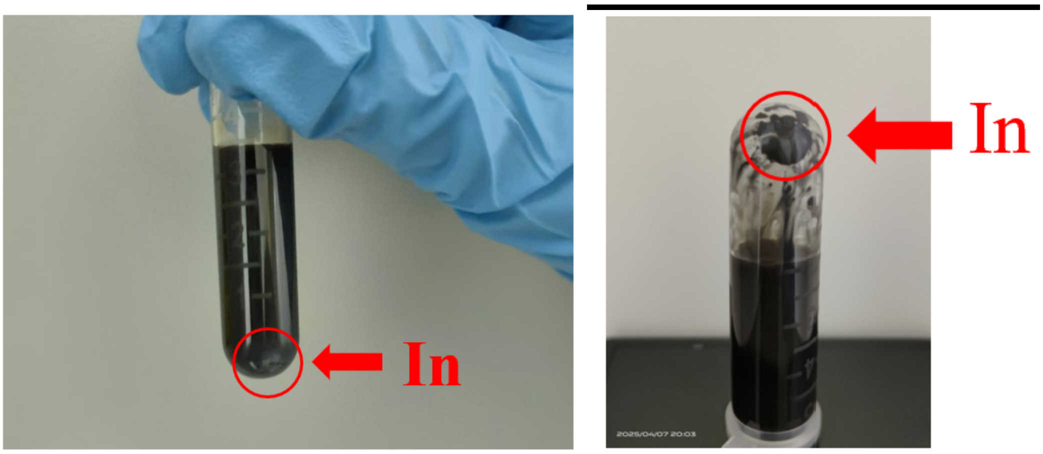


Fig. S6 Schematic illustration of the precipitation behavior observed during centrifugation purification of InP QDs.

Table S2. Comparative analysis of PL lifetime characteristics for InP QDs before and after HF etching treatment.

Sample	τ_{av} [ns]	A_1 [counts]	τ_1 [ns]	A_2 [counts]	τ_2 [ns]
InP QD solution	16.8	5837.8	4.6	1350.8	26.0
HF-treated InP QD solution	37.2	4956.8	13.8	2863.0	48.7

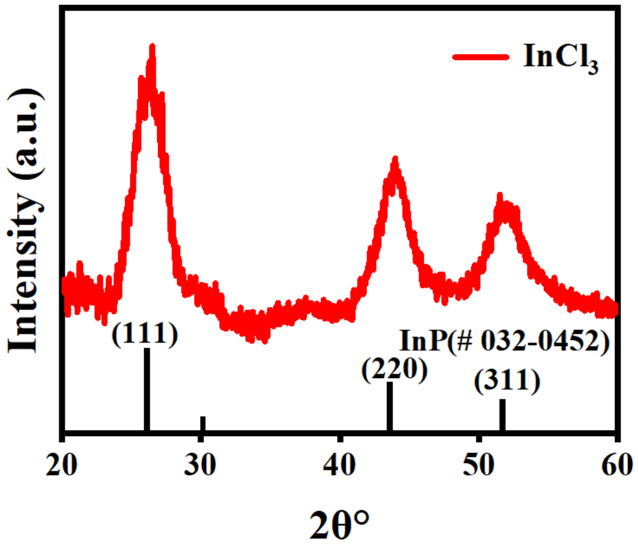


Fig. S7 XRD pattern of InP QDs synthesized using InCl$_3$.

The average crystallite size of InP QDs is analyzed based on XRD data, and the main calculation procedure is as follows:

K is the Scherrer constant, D is the average size of crystal, B is the FWHM of the measured diffraction peak, θ is the diffraction angle, and γ is the X-ray wavelength.

For InP QDs synthesized using In(I)Cl

$$D = \frac{K\lambda}{B cos\theta}$$

$$= (0.89\times0.15406)/(0.0517\times\cos 0.2271)$$

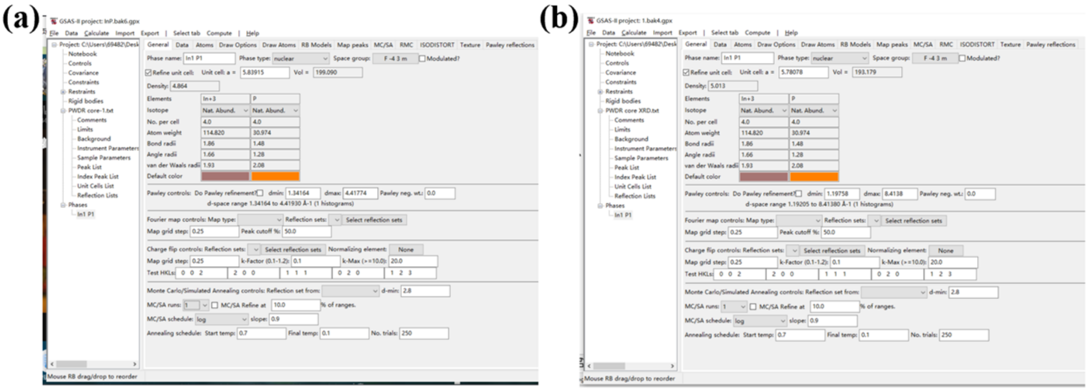
$$=2.72 \text{ nm}$$

For InP QDs synthesized using InCl$_3$

$$D = \frac{K\lambda}{B cos\theta}$$

$$= (0.89\times0.15406)/(0.0532\times\cos0.2289)$$

$$=2.65 \text{ nm}$$



(a)

Phase name: In1 P1 Phase type: nuclear Space group: F -4 3 m ☐ Modulated?

☑ Refine unit cell: Unit cell: a = 5.83915 Vol = 199.090

Density: 4.864

Elements	In+3	P
Isotope	Nat. Abund.	Nat. Abund.
No. per cell	4.0	4.0
Atom weight	114.820	30.974
Bond radii	1.86	1.48
Angle radii	1.66	1.28
van der Waals radii	1.93	2.08
Default color	🟫	🟧

Pawley controls: Do Pawley refinement? ☐ dmin: 1.34164 dmax: 4.41774 Pawley neg. wt.: 0.0
d-space range 1.34164 to 4.41930 Å-1 (1 histograms)

Fourier map controls: Map type: Reflection sets:
Map grid step: 0.25 Peak cutoff %: 50.0

Charge flip controls: Reflection sets: Normalizing element: None
Map grid step: 0.25 k-Factor (0.1-1.2): 0.1 k-Max (>=10.0): 20.0
Test HKLs: 0 0 2 | 2 0 0 | 1 1 1 | 0 2 0 | 1 2 3

Monte Carlo/Simulated Annealing controls: Reflection set from: d-min: 2.8
MC/SA runs: 1 ☐ MC/SA Refine at 10.0 % of ranges.
MC/SA schedule: log slope: 0.9
Annealing schedule: Start temp: 0.7 Final temp: 0.1 No. trials: 250

(b)

Phase name: In1 P1 Phase type: nuclear Space group: F -4 3 m ☐ Modulated?

☑ Refine unit cell: Unit cell: a = 5.78078 Vol = 193.179

Density: 5.013

Elements	In+3	P
Isotope	Nat. Abund.	Nat. Abund.
No. per cell	4.0	4.0
Atom weight	114.820	30.974
Bond radii	1.86	1.48
Angle radii	1.66	1.28
van der Waals radii	1.93	2.08
Default color	🟫	🟧

Pawley controls: Do Pawley refinement? ☐ dmin: 1.19758 dmax: 8.4138 Pawley neg. wt.: 0.0
d-space range 1.19205 to 8.41380 Å-1 (1 histograms)

Fourier map controls: Map type: Reflection sets:
Map grid step: 0.25 Peak cutoff %: 50.0

Charge flip controls: Reflection sets: Normalizing element: None
Map grid step: 0.25 k-Factor (0.1-1.2): 0.1 k-Max (>=10.0): 20.0
Test HKLs: 0 0 2 | 2 0 0 | 1 1 1 | 0 2 0 | 1 2 3

Monte Carlo/Simulated Annealing controls: Reflection set from: d-min: 2.8
MC/SA runs: 1 ☐ MC/SA Refine at 10.0 % of ranges.
MC/SA schedule: log slope: 0.9
Annealing schedule: Start temp: 0.7 Final temp: 0.1 No. trials: 250

Fig. S8 Refined lattice parameters of InP QDs synthesized from (a) In(I)Cl and (b) $InCl_3$.