Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information:

Ni^{2+} and Pr^{3+} co-doped $CsPbCl_3$ Perovskite Quantum Dots with Efficient Infrared Emission at 1300 nm

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Materials

Ccesium carbonate (Cs_2CO_3, 99.9%, Macklin), octadecene (ODE, 90%, Macklin), oleic acid (OA, 90%) oleylamine (OLA, 70%),nickel(II) chloridehydrate (NiCl2·xH2O, Alfa Aesar, 99.995%) $PbCl_2$(99.99%, Macklin), $PrCl_3$•6H2O (99.99%), toluene (ACS grade, Fischer), tri-n-octylphosphine (TOP, Alfa Aesar, tech.,90%), ODE (>95%,Macklin), cyclohexane (99.5%,Macklin), ethyl acetate (99.8%,Macklin), others were purchased from Sigma-Aldrich and all were used directly.

Characterizations

The HR-TEM images were recorded on a JEOL-2100F high resolution transmission electron microscope (HR-TEM) under a working voltage of 200 kV. The phase structure and purity of the as-prepared samples were characterized by X-ray power diffraction (XRD) with a Rigaku D/max 2550 X-ray diffractometer, using a monochromatized Cu target radiation resource (λ=1.54 Å). The Fourier transform infrared (FTIR) spectra were measured by a Shimadzu DT-40 model 883 IR Spectrophotometer. The excitation and emission spectra were recorded at room temperature using a Hitachi F-4500 spectrophotometer. The luminescent dynamics were pumped by a laser-system consisting of a Nd: YAG pumping laser (1064-nm)， the third-order Harmonic-Generator (355-nm) and a tunable optical parameter oscillator (OPO, Continuum Precision II 8000). It was with a pulse duration of 10 ns, repetition frequency of 10 Hz and line width of 4-7 cm^{-1}.

Photoluminescence quantum yields (PLQY)

The PLQYs of the samples were acquired using an integrating sphere incorporated into a spectrofluorometer (FLS980, Edinburgh Instruments). Absolute photoluminescence quantum yield measurements were performed on colloidal PQD samples dispersed in hexane placed in a sealed 1 cm path length quartz cuvette and positioned in a teflon-based integrating sphere using a custom cuvette holder. The samples were directly excited with a 365 nm Xe lamp and attenuated with neutral density filters, as necessary. Excitation power was measured through a power meter to calculate excitation power.

Quantum yield was then calculated by using the Edinburgh L980 software package, which was calculated based on the following equation:

$$PLQY = \frac{N_{em}}{N_{abs}} = \frac{\int I_{sample}(\lambda) - I_{ref}(\lambda) d\lambda}{\int E_{ref}(\lambda) - E_{sample}(\lambda) d\lambda},$$

where ‘I’ indicates the spectrally corrected intensity of the emitted light, ‘E’ indicates the spectrally corrected intensity of the excitation light, sample indicates measurements of PQD samples, and ref indicates measurements of a reference cuvette containing neat hexane

Our PLQY equipment was calibrated using the recognized dye emission standards, which was in good agreement with literature values: Rhodamine 6G for visible detector Measured (91.1%), Literature (90-92%), the relative error is about 1%; IR140 for near-infrared detector- Measured (19.1%), Literature (20.0%), the relative error is about 4.5%.

UV and water stability

The UDPQDs, NiPQDs and NPPQDs were stored in a UV lamp with 25 ℃ temperature. The luminescence intensities were recorded every day.

The UDPQDs, NiPQDs and NPPQDs were stored in deionized water with 25 ℃ temperature， after the centrifugal. The luminescence intensities were recorded every 7 min.

Table S1: Summary of tolerance factors (TF) after doping with diverse cations.

cations	Pb	Ni	Pr
TF	0.82	0.98	0.88

Table S2: Lifetimes of NPPQDs.

Doping amount	Ni^{2+}: 6.1% Pr^{3+}: 0.8%	Ni^{2+}: 6.1% Pr^{3+}: 1.9%	Ni^{2+}: 6.1% Pr^{3+}: 3.7%	Ni^{2+}: 6.1% Pr^{3+}: 5.2%	Ni^{2+}: 6.1% Pr^{3+}: 7.3%
Life time/ ns (400 nm)	12.4	11.2	10.7	9.6	8.7
Life time/ ns (1300 nm)	766	850	933	1046	992

As the lattice is gradually adjusted and the concentration of doping approaches a appropriate level, the lifetime at 1300 nm becomes longer and eventually decreases due to the quenching of the concentration.

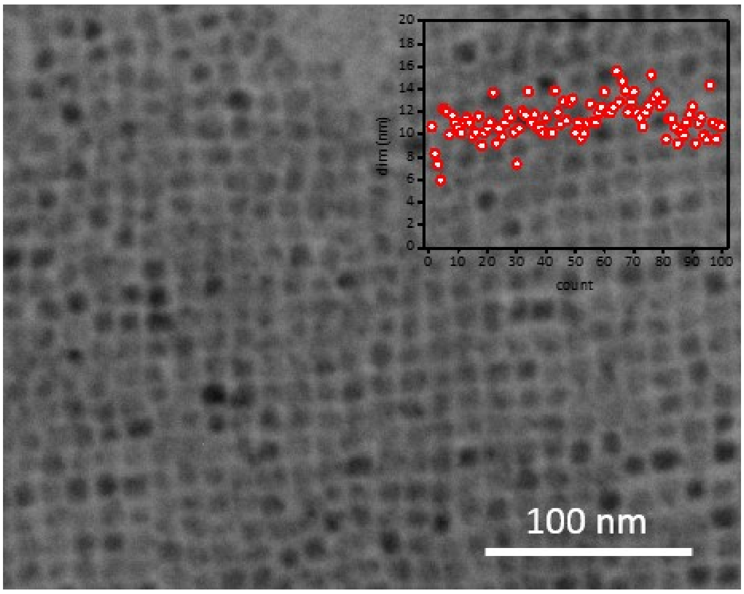

Fig.S1 TEM micrograph of $CsPbCl_3$ PQDs. The illustration shows the diameter statistics of 100 individual quantum dots.

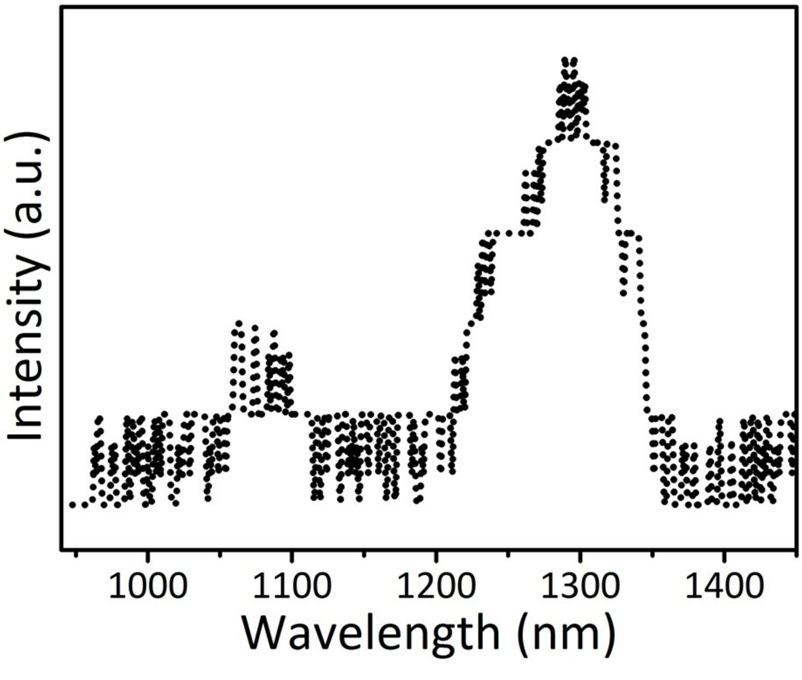

Fig.S2 Emission of Pr^{3+} doped $CsPbCl_3$ PQDs. Limited weak optical signal was observed which excited by 365 nm.

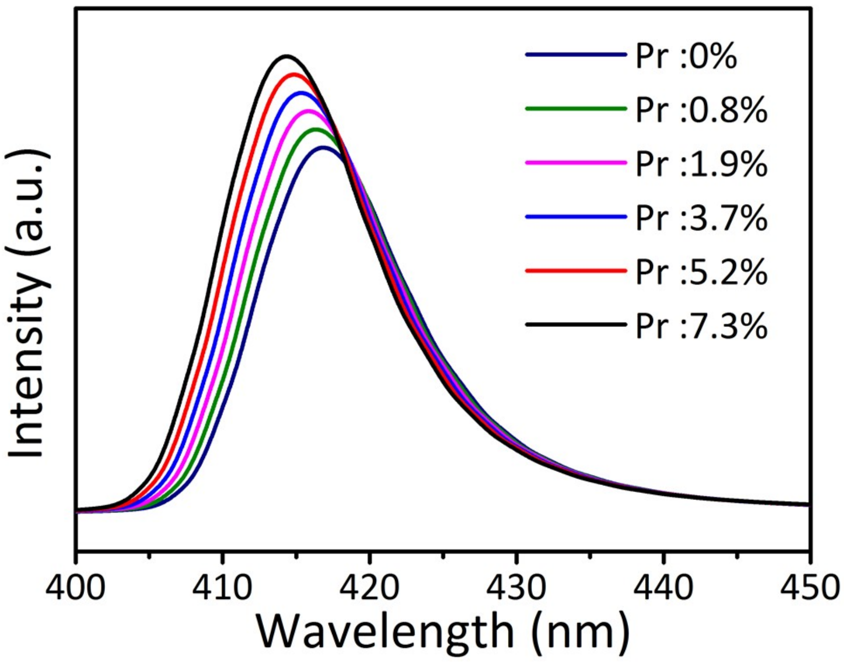

Fig.S3: Emission of PrPQDs. Blue light peaks with different Pr^{3+} doping amounts were observed which excited by 365 nm.

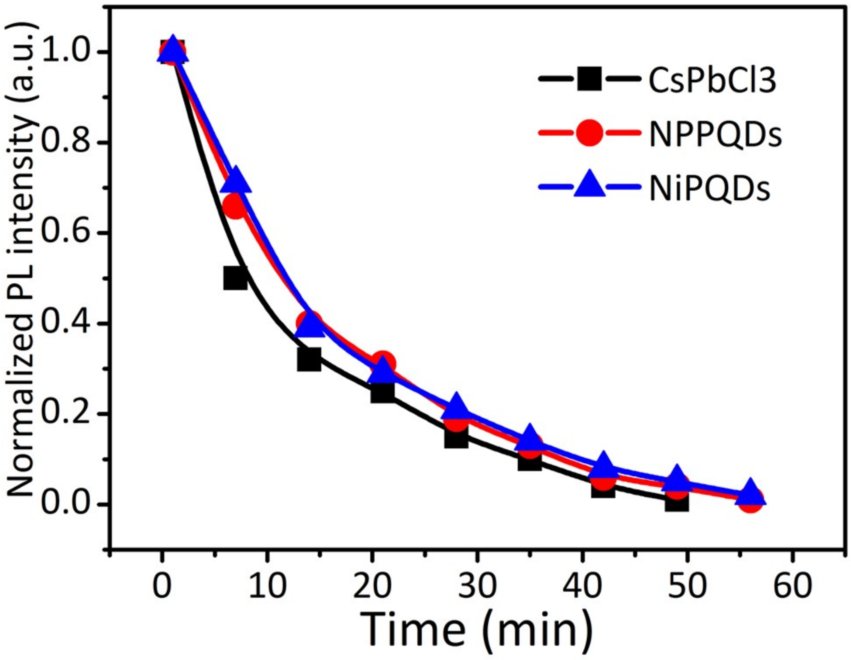

Fig.S4 Stability test of PQDs in water. (Temperature = 25 ℃)

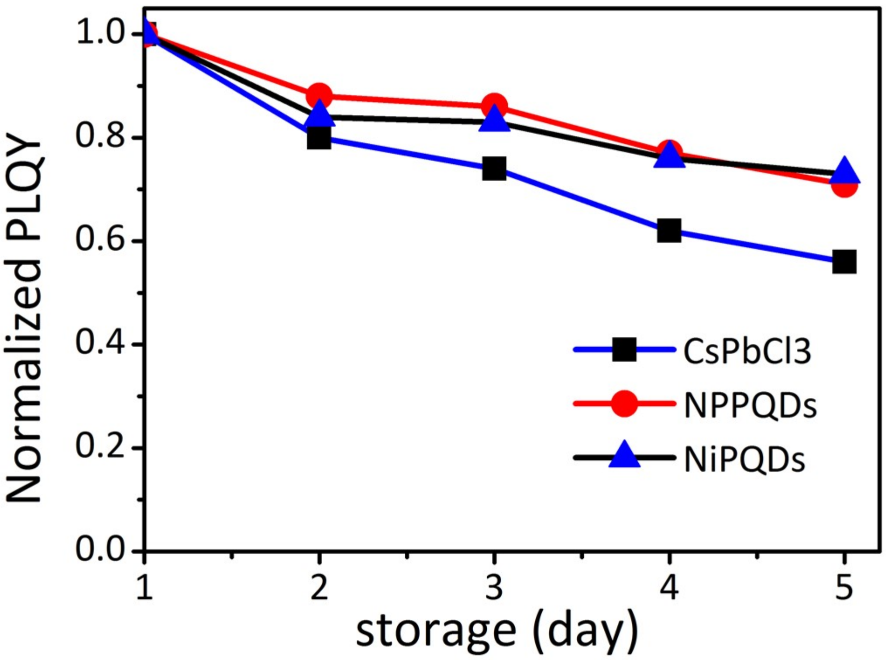

Fig.S5 Stability testing of PQDs under UV lamp conditions. (UV = 365 nm)

The stability of NiPQDs and NPPQDs under UV light is improved due to fewer defects and a more ordered lattice. By contrast, the stability of NiPQDs and NPPQDs in water is not significantly improved due to the inherent properties of ionic crystals