Electronic Supplementary Material (ESI) for Chemical Communications

Supplementary Information

A General and Reversible Phase Transfer Strategy Enabling Nucleotides Modified High-Quality Water-Soluble Nanocrystals

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EXPERIMENTAL SECTION

Chemicals. Adenosine 5'-monophosphate (AMP), adenosine, adenine, guanosine 5'-monophosphate (GMP), guanosine, cytidine 5'-monophosphate (CMP), and cytidine were purchased from Sigma. (MPA, >99%), tetramethylammonium hydroxide pentahydrate (TMAH, >95%), oleylamine (OAm, 70%), 1-hexadecylamine (98%), 1-dodecylamine (>99%), oleic acid (99%), 1-octadecene (ODE, >95%) were obtained from Aldrich and used without further purification. All organic solvents such as hexane, dichloromethane, ethanol, methanol were of analytical grade and obtained from commercial sources and used as received. Deionized water was used throughout.

Nanocrystals Synthesis.

Synthesis of CdSe/CdS/ZnS Core/Shell/Shell QDs

Synthesis of CdSe core QDs. CdSe core nanocrystals were prepared via a modified literature method.[1] Typically, 25.6 mg (0.2 mmol) of CdO, 1.2 g of TOPO, 1.0 ml of oleic acid and 4.0 ml of ODE were loaded in a 50 mL three-neck flask clamped in a heating mantle. The mixture was heated to 320-330 ^{o}C under argon flow and resulted in a colorless clear solution, which was then cooled to 315 ^{o}C. At this temperature, 2.4 mL of the Se precursor solution, which was made by dissolving selenium (79.0 mg) in TOP (4.0 ml) and ODE (6.0 ml) by sonication, was quickly injected into the reaction flask. After the injection, the reaction temperature was set at ~270 ^{o}C for the growth of the nanocrystals with different periods of time (10 s – 3 min) to get nanocrystals with desired size. The reaction mixture was then allowed to cooled to ~ 60 ^{o}C and 10.0 ml of hexane/CH_3OH (v/v, 1:1) was used as the extraction solvent to separate the nanocrystals from byproducts and unreacted precursors. The as-prepared CdSe solution was further purification by centrifugation and decantation with the addition of acetone and then the CdSe NPs were redispersed in hexane.

Stock solutions preparation. The Zn precursor solution (0.1 M) was prepared by dissolving 219.5 mg (1 mmol) $Zn(OAc)_2.2H_2O$ in 10.0 mL ODE at 160 ^{o}C. The sulfur precursor solution (0.1 M) was obtained by dissolving sulfur in ODE at 120 ^{o}C. The Cd precursor solution (0.1 M) was prepared by dissolving 128.4 mg (1 mmol) CdO in 2.0 ml oleic acid and 8.0 mL ODE at 160 ^{o}C. Each stock solution was stored at room temperature.

Synthesis of CdSe/CdS/ZnS Core/Shell/Shell QDs. The successive ion layer adsorption and reaction (SILAR) technique was adopted for the growth of CdSe/CdS/ZnS core/shell/shell nanocrystals.[2] In a typical procedure, a chloroform solution of purified 3.5 nm CdSe QDs containing 0.1 mmol of CdSe, 1.0 mL of oleylamine and 4.0 mL of ODE were loaded in a 50 mL flask. The flask was then pumped down at room temperature for 20 min to remove the chloroform and at 100 ^{o}C for another 20 min while flushing the reaction system twice with a flow of argon. Subsequently, the reaction mixture was further heated to 230 ^{o}C for the overgrowth of the CdS shell. The Cd precursor stock solution was added into the reaction flask, after 10 min when the Cd precursor was fully deposited around the CdSe surface, an

equimolar amount of S precursor stock solution was added into the reaction system. When the first monolayer of CdS was deposited around the CdSe cores, another Cd/S precursor solution was added alternately at approximately 10 min intervals. The volume of the precursor stock solution added in each cycle was the amount needed for a whole monolayer of CdS shell. The amount was calculated from the respective volumes of concentric spherical shells with 0.35 nm thickness for one monolayer (ML) of CdS (e.g. 0.7, 1.0, 1.3 mL for the 1st, 2nd, and 3rd ML, respectively). Then the reaction temperature was set at 200 ^{o}C for the overgrowth of ZnS shell. The Zn/S precursor stock solution was added into the reaction flask at intervals of 20 min. To monitor the reaction, aliquots were taken before a new cycle of injection and their corresponding UV-vis and PL spectra were recorded. The reaction was terminated by allowing the reaction mixture to cool down to room temperature. The purification procedure was similar to that for CdSe core nanocrystals.

References:

(1) L. Qu and X. Peng, *J. Am. Chem. Soc*. **2002**, *124*, 2049.

(2) (*a*) J. J. Li, Y. A. Wang, W. Guo, J. C. Keay, T. D. Mishima, M. B. Johnson and X. Peng, *J. Am. Chem. Soc*. **2003**, *125*, 12567; (*b*) R. Xie, U. Kolb, J. Li, T. Basche and A. Mews, *J. Am. Chem. Soc.* **2005**, *127*, 7480.

Synthesis of Bi_2S_3 Nanorods

31.5 mg (0.1 mmol) of BiCl3 powder was added to a flask containing 2.0 mL of OAm followed by degassing at 70°C for 5 min under vacuum to remove the moisture and oxygen. The reaction vessel was then filled with nitrogen and the temperature was increased to 150 °C with a heating rate of 10 °C/min and the vessel maintained at this temperature until the complete dissolution of BiCl3 powder to give a white milky solution. Then 2.0 mL of OAm containing 11.3 mg (0.15 mmol) of thioacetamide was injected into the reaction system. After the addition of thioacetamide, the temperature of the reaction system was further increased to 180 °C and the vessel maintained at this temperature for 5-10 min. The reaction mixture was cooled to room temperature and the resulting nanostructures were precipitated by anhydrous ethanol, The Bi2S3 NPs were redispersed in hexane to give a brown dispersion.

References:

T. Wu, X. Zhou, H. Zhang and X. Zhong, *Nano Res.* **2010**, *3*, 379.

Synthesis of MnO nanocubes

24.5 mg (0.1 mmol) of Mn(OAc)2 and 2 mL of oleylamine were mixed with 5 mL ODE in a 50 mL flask. Under nitrogen flow, the mixture was quickly heated to 130 °C under magnetic stirring. The formed solution was kept at this temperature for 10 min and cooled down to room temperature. Then 30 mL of anhydrous ethanol was added into the solution, and the suspension was centrifuged at 4000 rpm for 5 min. The supernatant was discarded and the MnO NPs were redispersed in hexane to give a brown dispersion.

References:

(1) X. Zhong, R. Xie, L. Sun, I. Lieberwirth and W. Knoll, *J. Phys. Chem. B* **2006**, *110*, 2.

(2) M. Yin and S. O'Brien, *J. Am. Chem. Soc.* **2003**, *125*, 10180.

Synthesis of Au nanodots

34.0 mg (0.1 mmol) of $HAuCl_4 \cdot 3H_2O$ and 1.0 mL of oleylamine were mixed with 15 mL toluene in a 50 mL flask. Under nitrogen flow, the mixture was slowly heated to 65 °C under magnetic stirring. The formed solution was kept at this temperature for 6 h and cooled down to room temperature. Then 30 mL of anhydrous ethanol was added into the solution, and the suspension was centrifuged at 4000 rpm for 5 min. The supernatant was discarded and the the Au NPs were redispersed in hexane to give a red dispersion.

References:

C. Shen, C. Hui, T. Yang, C. Xiao, J. Tian, L. Bao, S. Chen, H. Ding and H. Gao, *Chem. Mater*. **2008**, *20*, 6939.

Ligand Exchange. Exchange of the native hydrophobic ligands on QDs surface by AMP (or other nucleotide or nucleoside ligands including adenosine, adenine, GMP, guanosine, CMP, and cytidine) was performed as follows. Typically, 1.0 g (2.74 mmol) of AMP was dissolved in 3.0 mL of ethanol and the pH of the resulting solution was adjusted to 10 with the use of concentrated NaOH or TMAH solution. Then 0.3 mL of the obtained AMP solution (containing 0.27 mmol AMP) in ethanol was added dropwise into a purified QDs solution in hexane (or $CHCl_3$) (containing 1×10^{-6} M QDs, 20.0 mL), and vigorously stirred for 30 min. Subsequently, deionized water was added into the solution. The QDs were found to be successfully transferred from the hexane phase on the top to the aqueous phase in the bottom. The colorless organic phase was discarded and the aqueous phase containing the QDs was collected. The excess amount of free ligand was removed by centrifugation purification with use of acetone. The supernatant was discarded and the pellet was then re-dissolved in water and repeated this centrifugation-decantation process three times to get the purified QDs aqueous solutions.

Cell Labeling. Human ovarian cancer HO-8910 cell line was cultured overnight (37 ^{o}C, 5% CO_2) on glass chamber slides in Dulbecco's Modified Eagle's medium (DMEM) supplemented with 4 mM L-glutamine, 1 mM sodium pyruvate, 1% (v/v) penicillin/streptomycin/actinomycin D-antibiotic/antimycotic, and 10% (v/v) heat- inactivated fetal bovine serum (FBS). QDs were adding into the culture medium (final concentration was 100 nM) and incubated for a certain time. Then removing from culture medium, cells were fixed with 2% paraformaldehyde, washed with PBS, followed by 4′,6-diamidino-2-phenylindole dihydrochloride (DAPI) staining (18.7 uM) of the nuclear for 5 min, washed with PBS for three times, and finally immersed in 30% (v/v) glycerol/PBS. Fluorescence images were recorded with 450-550/405 nm and 550-650/488 nm emission/excitation for the visualization of DAPI and QDs respectively.

Characterization. UV–vis and PL spectra were obtained on a Shimadzu UV-2450 spectrophotometer and a Cary Eclipse (Varian) fluorescence spectrophotometer, respectively. Transmission electron microscopy (TEM) images were taken on a JEOL JEM-1400 at an acceleration voltage of 100 kV. Dynamic light scattering (DLS) was conducted with a Zeta Sizer nano series laser light scattering system (Malvern Instrument Corporation). Confocal fluorescence imaging was performed with an OLYMPUS ZX81 laser scanning microscopy and a 60x oil-immersion objective lens.

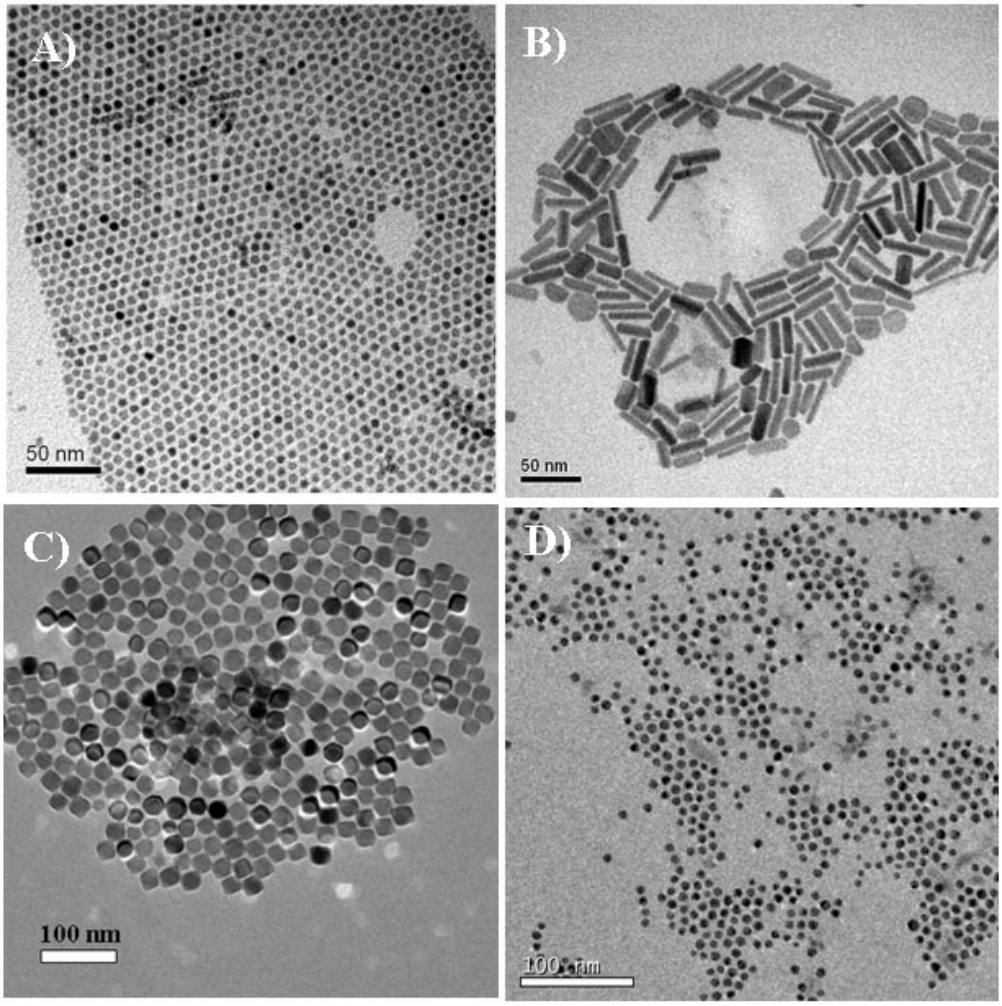

Fig. S1 TEM images of initial oil-soluble NCs before phase transfer: (A) CdSe/CdS/ZnS QDs, (B) Bi_2S_3 nanorods, (C) MnO nano-cubes, and (D) Au nanodots.

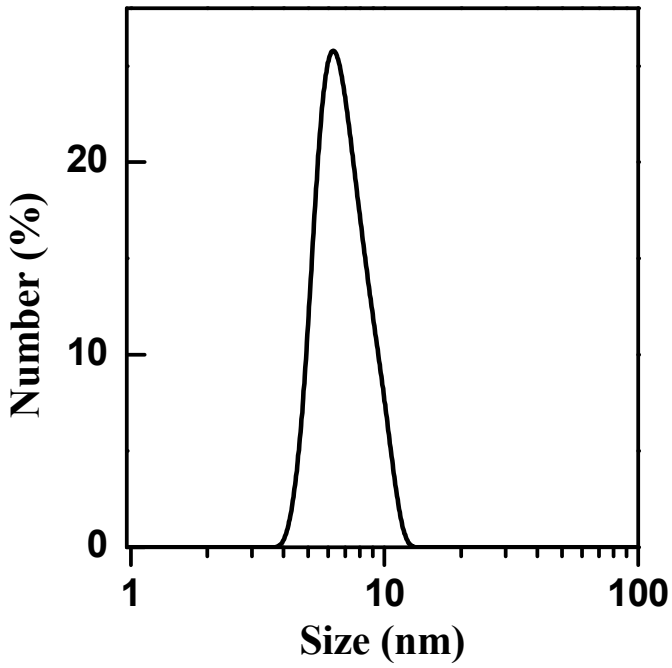

Fig. S2 Dynamic light-scattering histograms of AMP-capped water-soluble CdSe/CdS/ZnS QDs with average hydrodynamic diameter of 7.1 nm.

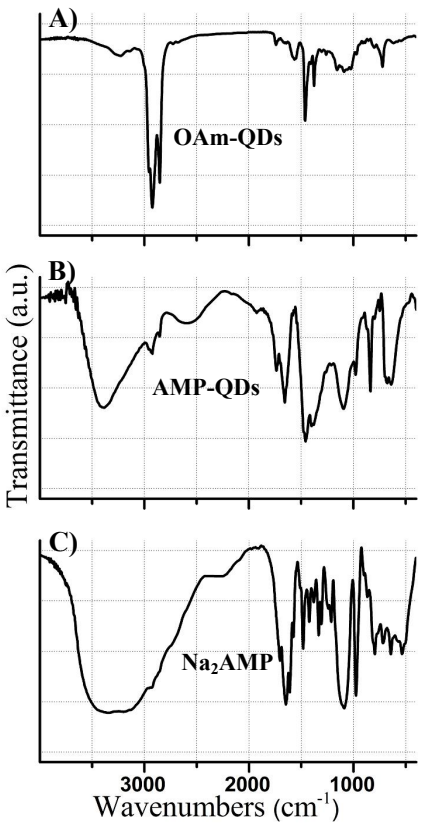

Figure S3. FTIR spectra of initial oil-soluble OAm-QDs (A), AMP-QDs after phase transfer (B), and free sodium Na_2-AMP (C).

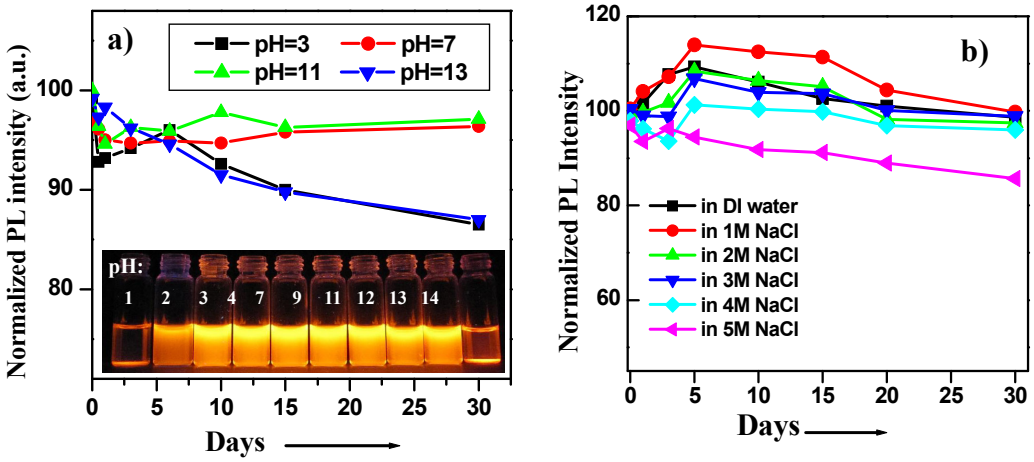

Fig. S4 Temporal evolution of relative PL intensities of AMP-QDs samples under different pH values (a), and different NaCl concentration solutions (b). Inset: Luminescence images of AMP-QDs samples with different pH values under UV light irradiation after stored for 30 days.

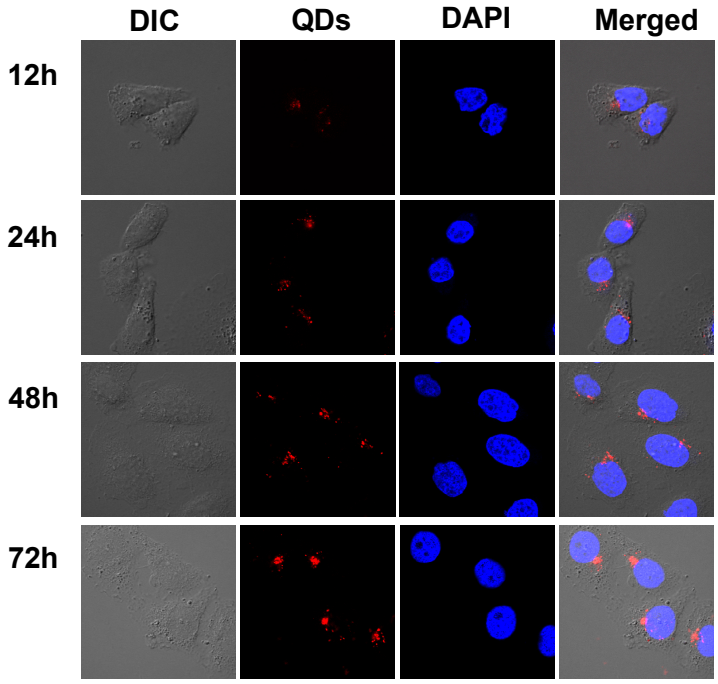

Fig. S5 Representative images of HO-8910 cells incubated with adenosine-QDs under different incubation times. Each row of the panel shows representative DIC, 604-nm emitting QDs (red), 4′,6-diamidino-2-phenylindole dihydrochloride (DAPI, blue), and the merged fluorescent composite images (right).