

Synthesis of size-tunable photoluminescent aqueous CdSe/ZnS microspheres via a phase transfer method with amphiphilic oligomer and their application for detection of HCG antigen

Changhua Zhou,^{a,□} Hang Yuan,^{b,□} Huaibin Shen,^a Yi Guo,^c Xiaomin Li,^a Dan Liu,^a Li Xu,^{c,*} Lan

Ma,^{b,*} Lin Song Li^{a,*}

^aKey Laboratory for Special Functional Materials of the Ministry of Education, Henan University,

Kaifeng, 475004, PR China

^bLife Science Division, Graduate School at Shenzhen, Tsinghua University, Shenzhen, 518055, PR

China

^cKey Lab for Molecular Enzymology and Engineering, Ministry of education, Jilin University,

Changchun, 130012, PR China

□These authors contributed equally to this paper.

E-mail: lsli@henu.edu.cn, malan@sz.tsinghua.edu.cn, xuli@jlu.edu.cn

Materials

All reagents were used as received without further purification. Cadmium oxide (CdO, 99.99%), sulfur (S, 99.98%, powder), 1-octadecene (ODE, 90%), oleic acid (OA, 90%), selenium (Se, 99.99%, powder), and zinc oxide (ZnO, 99.99%, powder) were purchased from Aldrich. Maleic anhydride, *n*-hexadecanol, triethylamine, hexanes, chloroform, toluene, acetone, and methanol were obtained from Beijing

Chemical Reagent Ltd., China. All reagents were used as received without further purification.

Stock solution for Cd precursor and Se precursor

Cd precursor: a mixture (4 g in total) of CdO (0.0154 g, 0.12 mmol), OA (0.36 mmol), and ODE was loaded into a 25 mL three-neck flask. Then it was heated to 240 °C under nitrogen to obtain a colorless clear solution. *Se precursor* : it was made by degassing Se (0.188 g, 2.4 mmol), OA (1.94 g, 7.2 mmol), and 18 mL of ODE in a 50 mL three-neck flask. The mixture was then heated to 100 °C for 20 min and subsequently heating the mixture at 220 °C for 3 h. During this period, the color of the mixture changed from transparent to orange and red, and finally it turned into yellow.

Stock solution for shell growth

Zinc precursor (0.1 M): it was prepared by dissolving ZnO (0.1628 g, 2 mmol) in the mixture of OA (5.64 g, 16 mmol) and ODE (13.70 mL) at 310 °C. *Cadmium precursor (0.1 M)*: the Cd precursor was prepared by dissolving CdO (0.256 g, 2 mmol) in the mixture of OA (5.64 g, 16 mmol) and ODE (13.7 mL) at 240 °C. *Sulfur precursor (0.1 M)*: it was prepared by dissolving sulfur (0.064 g, 2 mmol) in ODE (20 mL) at 150 °C. All precursor were made under a nitrogen flow.

Synthesis of CdSe QDs

Solution for Cd precursor in 25 mL flask was heated to 280 °C under nitrogen gas flow. Next, 2 mL (0.24 mmol) Se stock solution was injected into the above flask. The color of solution turned into light orange right after injection, then changed to orange,

light red, red, and dark red as the increase of reaction time. Aliquots were taken at different time intervals, ultraviolet-visible absorption and photoluminescence (PL) spectra were recorded for each aliquot. PL spanning most of the visible spectra from 470 nm to 650 nm was obtained. The temperature of the Se precursor for the injection is important for synthesizing high quality CdSe QDs. The temperature ranging from 20 to 280 °C of Se precursor could be used to synthesize CdSe QDs. But if the temperature is higher, the quality of CdSe QDs is better, and preferably about 280 °C. The resulting CdSe QDs could be dissolved in chloroform, hexanes, and toluene, respectively.

Synthesis of CdSe/ZnS core-shell QDs

Nearly monodisperse CdSe QDs ranging from 1.8 nm to 5.5 nm in diameter were synthesized and purified, respectively. By choosing different sizes of CdSe as core, CdSe/ZnS core-shell QDs with emitting color covering from green to red have been synthesized. A typical synthesis was performed as follows: 3 mL of ODE and 1 g of OA were loaded into a 25 mL reaction vessel. The CdSe QDs in hexanes (2.8 nm in diameter, 2.7×10^{-7} mol) were added, and the system was kept at 100 °C under N₂ flow for 30 min to remove hexanes and other undesired materials of low vapor pressure. Subsequently, the solution was heated up to 160 °C under N₂ flow where the shell growth was performed. The amounts of the injection solutions injected for each step were as follows: 0.52 mL of the Cd and S solutions for the first layer and the temperature was slowly raised to ~180°C in ~5 min. 0.77 mL of each injection solution for the second layer and the temperature was slowly raised to ~200 °C in ~5

min, 1.1 mL of each injection solution for the third layer and the temperature was slowly raised to ~ 220 °C in ~ 5 min, 1.45 mL of each injection solution for the fourth layer the temperature was slowly raised to ~ 240 °C in ~ 5 min, and 2.0 mL of each injection solution for the fifth layer and keep the temperature at 240 °C for 30 min. This slow temperature jump not only enhances the reaction yield, but also improves the crystallinity. We found that a period of 10 min between each addition was sufficient for the reaction to be completed, because the UV-vis and PL spectra showed no further changes after this time period.

The procedure for synthesizing polymaleic anhydride (PMA)

80 g (0.82 mol) maleic anhydride and 95 mL methylbenzene were loaded to a three necked flask and heated to 70 °C. 8 g (0.03 mol) benzoyl peroxide (BPO) and 50 mL methylbenzene were mixed at room temperature and added to the refluxing solution of maleic anhydride. Reflux is continued for 5 hours after the addition is complete. After the reaction mixture was cooled to the room temperature, the methylbenzene was poured out and 6 mL *n*-butanone was added to the flask. The mixture was heated to reflux at 86-90 °C for 1/2 hour and cooled to 60 °C. PMA was then precipitated by adding 200 mL methylbenzene. The obtained product was finally dried at 50-60 °C for 24 h to remove the residual methylbenzene.

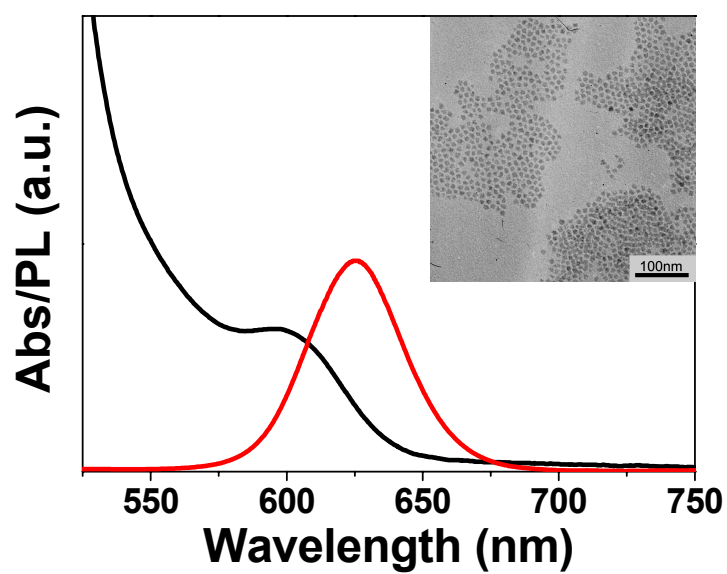


Figure S1. Absorption (dark line) and PL (red line) spectra of hydrophobic CdSe/ZnS QDs dissolved in chloroform. Inset: A TEM image of CdSe/ZnS QDs in chloroform.

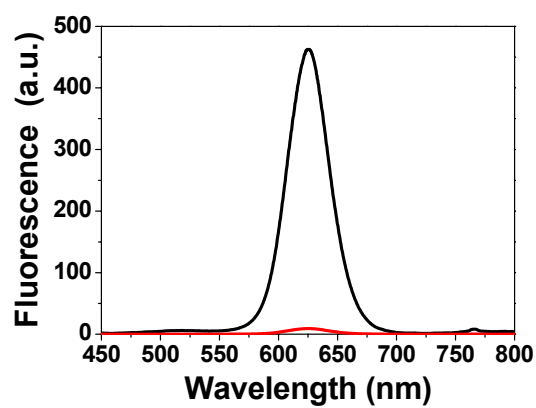


Figure S2 PL (excited at 365nm) spectra of CdSe/ZnS microspheres (dark line) and single QDs left in the supernatant (red line).

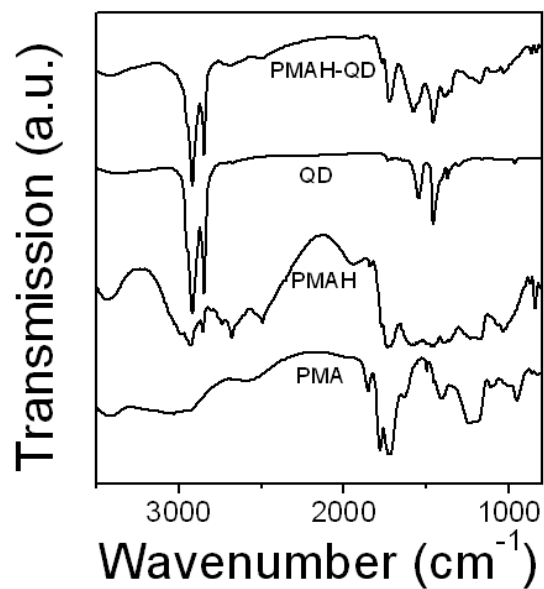


Figure S3 FTIR characterizations of PMAH and PMAH modified PL microspheres consisting of CdSe/ZnS QDs.

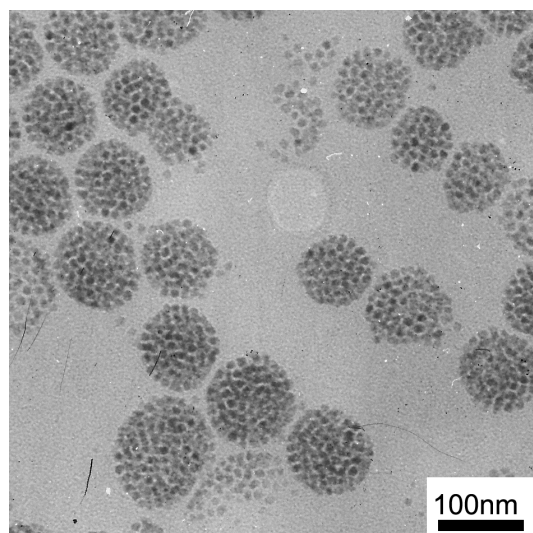


Figure S4 A TEM image of PL microspheres (94 nm) after thermal stability test (at 100°C).