

## Temperature-dependent photoluminescence of highly luminescent water-soluble CdTe quantum dots

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Received 18 November 2008

### Abstract

Highly luminescent water-soluble CdTe quantum dots (QDs) have been synthesized with an electrogenerated precursor. The obtained CdTe QDs can possess good crystallizability, high quantum yield (QY) and favorable stability. Furthermore, a detection system is designed firstly for the investigation of the temperature-dependent PL of the QDs.

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**Keywords:** Quantum dots; Temperature-dependent photoluminescence; Fluorescent detection

CdTe quantum dots (QDs) have gained increasing attention in technological applications and fundamental studies because of their unique properties such as small size, size-tunable absorption and emission wavelengths, and superior photostability. Although many extensive studies have been reported for the synthesis of CdTe QDs [1–7], one of the major challenges is to obtain water-soluble QDs with high QY. In recent years, the temperature-dependence of the QDs has been studied [8–10], and a variety of QDs has been employed as optical temperature probes which is widely required for more efficient applications in biology [8,11]. In this letter, we report a facile synthesis of highly luminescent water-soluble CdTe QDs and firstly design a detection system to investigate the PL of the obtained CdTe QDs, which is found to be temperature-dependent.

Highly luminescent CdTe QDs were synthesized in an aqueous system with a novel Te source to conveniently produce a CdTe precursor using a cathodic stripping Te electrode [12]. Briefly, the generation of CdTe precursor was carried out using an applied potential of  $-1.2$  V in the electrolyte containing  $2.0$  mmol/L CdCl<sub>2</sub> and  $16.6$   $\mu$ L 3-mercaptopropionic acid (MPA) at pH 10 adjusted with  $0.1$  mol/L NaOH. The CdTe precursor could be easily formed due to the favorable thermodynamics [13] in the presence of MPA, accompanied by a color change of electrolyte from colorless to dark brown. After that, the solution of CdTe precursor was heated in a water bath with moderate stirring at  $80$  °C. The CdTe QDs were gradually crystallized, the size of which could be controlled by changing the heating time. The resulting CdTe QDs were deposited by acetone, and after centrifugation the precipitate was washed by acetone at least three times and redissolved in water.

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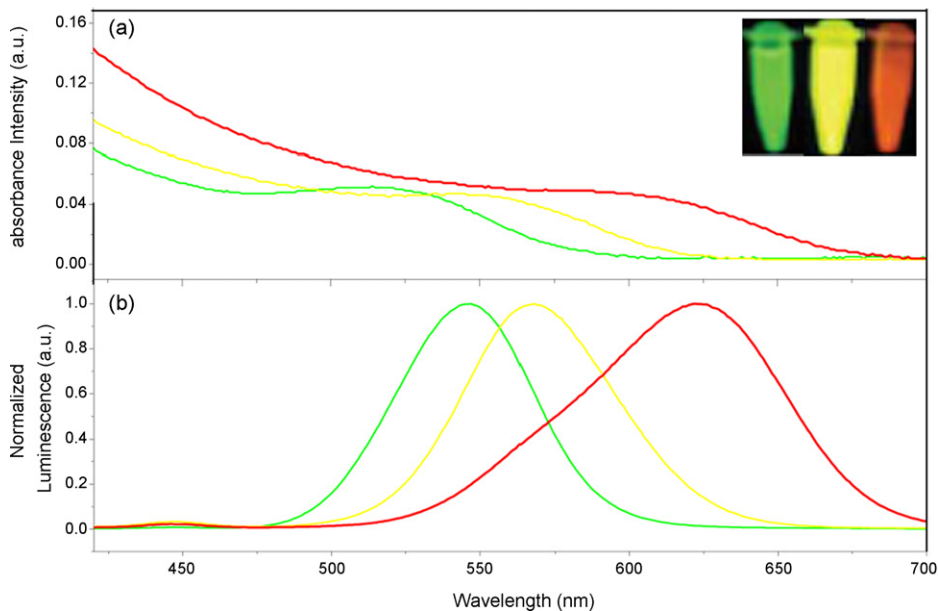


Fig. 1. UV-vis absorption (a) and PL spectra (b) of MPA-capped CdTe QDs obtained at different heating times. The inset shows fluorescent photograph of as-synthesized CdTe QDs under UV irradiation.

Fig. 1 shows the UV-vis absorption and PL spectra of MPA-capped CdTe QDs obtained at different heating times. The absorption peaks occur at 514, 534 and 578 nm, and the PL emission peaks are at 547, 568 and 622 nm ( $\lambda_{\text{ex}} = 388$  nm) for the heating times of 2, 8 and 20 h, respectively. The fluorescent color under UV irradiation changed from green to yellow and finally red with increasing heating time (inset in Fig. 1). The sizes of the CdTe QDs could be estimated from the UV-vis adsorption spectrum by Peng's empirical equations [14] to be from 2.0 to 3.5 nm. This indicated that the size of the QDs could be tuned easily by varying the heating time in water bath.

The size and morphology of the CdTe QDs were characterized with high-resolution transmission electron microscopy (HR-TEM). Fig. 2 shows a TEM image of the as-synthesized CdTe QDs with a typical size of  $3.0 \pm 0.3$  nm obtained at heating time of 8 h. The average size was consistent with the result obtained from the UV-vis absorption. Moreover, the inset in Fig. 2a shows the lattice fringes of an individual particle, indicating a highly crystalline structure of the CdTe QDs. Quantum yield value was measured relative to Rhodamine 590 in water and were calculated using the following equation [15]:

$$\varphi_f = \varphi'_f \left( \frac{I}{I'} \right) \left( \frac{A'}{A} \right) \quad (1)$$

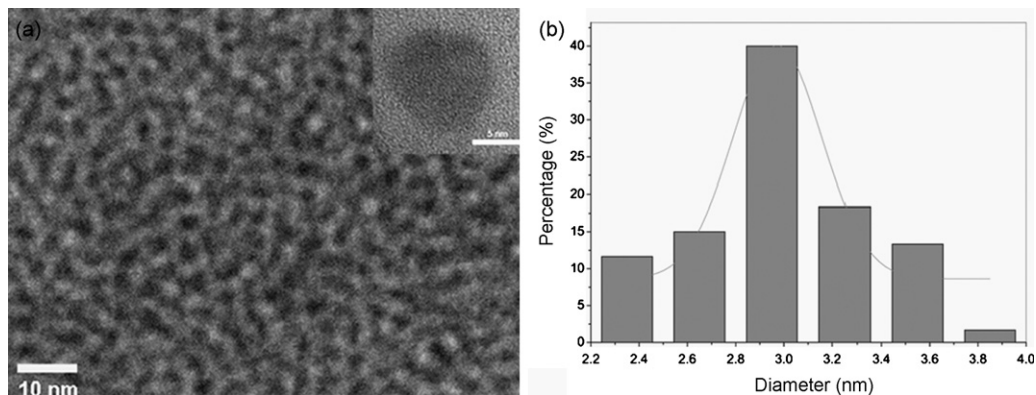


Fig. 2. A typical TEM image of MPA-capped CdTe QDs obtained at heating time of 8 h and its corresponding size distribution. The inset shows a HR-TEM image of an individual particle.

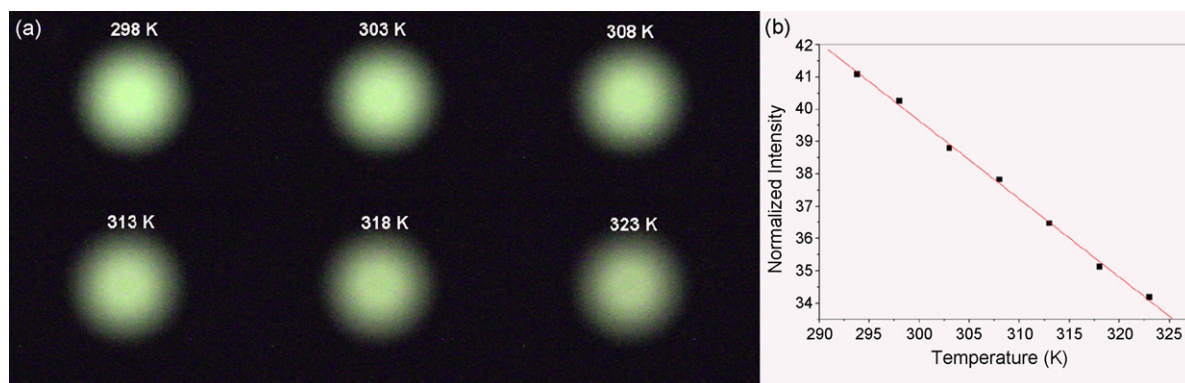


Fig. 3. (a) Fluorescent image of the sample showing affects of increasing temperature on PL intensity of the as-synthesized CdTe QDs, (b) the linear correlation between PL intensity and temperature.

where  $I$  (sample) and  $I'$  (standard) are the integrated emission peak areas,  $A$  (sample) and  $A'$  (standard) are the absorbances at the excitation wavelength. The QY of the obtained CdTe QDs obtained at heating times of 2 and 8 h were 28.6% and 59.3%, respectively, and then reached a maximum value of 79.5% at 20 h. Such a remarkable QY is much higher than those of CdTe QDs synthesized in aqueous solution [1–3]. Furthermore, the as-synthesized CdTe QDs showed favorable stability for several months when kept at 4 °C.

A detection system containing the Navitar Zoom6000 system (USA), SENTech STC-N63 CCD camera and LakeShore 321 autotuning temperature controller was used to investigate the temperature-dependent PL of the as-synthesized CdTe QDs. The detection process was as follows: positioning and illuminating the sample, adjusting microscope to focus on the sample for observation. On increasing the temperature of the sample from 298 K to 323 K (5 K min<sup>-1</sup>), the PL intensity photographs were recorded by the CCD camera. Subsequently, the scanned intensity was carried out by software ImageJ. It is clearly seen in Fig. 3a that the PL intensity declined with increasing temperature over the range from 298 to 323 K. Moreover, Fig. 3b shows the PL intensity decreases linearly,  $\sim 0.1 \text{ K}^{-1}$ , with increasing temperature. It is worth mentioning that the PL intensity increased when the temperature decreased from 323 to 298 K. However, after the temperature decreased from 323 to 298 K, the PL intensity was approximately 50% of that at 298 K before heating (data not shown). It is believed that some reactions such as oxidation would occur, which disturbed the repopulation of mobile electrons and holes leading to the irreversible PL quenching [8].

In summary, we report a facile synthesis of highly luminescent water-soluble CdTe QDs with an electrogenerated precursor. The obtained CdTe QDs have good crystallizability, high QY and good stability. Moreover, a detection system is designed firstly for the determination of the temperature-dependent PL of the QDs. Such results indicate that the CdTe QDs may have potential application as bioprobe in sensitive biosensing and imaging.

## Acknowledgments

This work was supported by National Natural Science Foundation of China (Nos. 60571031, 60501009 and 90406023), National Basic Research Program of China (Nos. 2006CB933206 and 2006CB705602).

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