

Microwave-Assisted Synthesis of Water-Dispersed CdTe Nanocrystals with High Luminescent Efficiency and Narrow Size Distribution

Yao He,[†] Li-Man Sai,[†] Hao-Ting Lu,[†] Mei Hu,[†] Wen-Yong Lai,[†] Qu-Li Fan,[‡]
Lian-Hui Wang,^{*,†} and Wei Huang^{*,†,‡,§}

Institute of Advanced Materials (IAM), Fudan University, Shanghai 200433, People's Republic of China, Institute of Advanced Materials (IAM), Nanjing University of Posts and Telecommunication, Nanjing 210003, People's Republic of China, and Faculty of Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576, Republic of Singapore

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Water-dispersed nanocrystals with high photoluminescence quantum yield (PLQY) and narrow size distribution are desirable for a variety of bioapplications. In this report, we present a facile method assisted by microwave irradiation for rapidly synthesizing high-quality CdTe nanocrystals in aqueous phase. The PLQY of CdTe nanocrystals prepared in very short time (15 min) reaches as high as 82%, and the fwhm value is merely 27 nm meanwhile. Moreover, the PLQY is increased to a remarkable 98% after further amelioration through the illumination method. The key synthesis parameters (molar ratio of reagents, pH values, reaction temperature, and time) are fully discussed, and the optimum conditions are illuminated in this paper. In addition, the mechanism about microwave irradiation improving the quality of nanocrystals is discussed as well.

1. Introduction

High-quality semiconductor nanocrystals (NCs), which are considered to possess high photoluminescence quantum yield (PLQY) and narrow full-width of half-maximum (fwhm), have been becoming increasingly attractive due to their various potential applications such as in optoelectronic devices,¹ photovoltaic devices,² and biological fluorescence labeling.³ It is well-known that there are two rudimentary approaches to prepare NCs: one is the organometallic route, the other is the aqueous method. NCs with excellent spectral properties have been achieved through the former strategy in elegant work.^{4–8} For instance, CdSe NCs, whose PLQY

value reached 85% and the fwhm was as narrow as 23 nm, were successfully prepared through the organometallic route up until 2002.⁹ However, these NCs cannot be directly use in bioapplications due to their hydrophobic character. A general strategy is to transfer the hydrophobic nanocrystals from the organic phase to aqueous solution by wrapping an amphiphilic polymer around the particles.¹⁰ Although this method is efficient, it is relatively complicated and requires additional steps. Another effective strategy is to substitute the hydrophilic molecules, which have strong polar groups such as carboxylic acid or reactive groups such as Si–O–R,¹¹ for surface-binding TOPO. However, the PLQY often decreases when the nanocrystals are transferred into water because the polarity of water is too strong to break various equilibriums related to the nanocrystals.^{12,13} Besides, the manipulations are complicated as well. Aqueous synthesis is an alternative strategy to directly prepare water-dispersed NCs. In addition, it is relatively simpler, cheaper, less toxic,

* Corresponding authors. Telephone: +86-21-55664188/+86-25-83492204. Fax: +86-21-65655123/+86-25-83492349. E-mail: wlhui@fudan.edu.cn (L.H.W.), wei-huang@fudan.edu.cn, wei-huang@njupt.edu.cn, chehw@nus.edu.sg (W.H.).

[†] Fudan University.

[‡] Nanjing University of Posts and Telecommunication.

[§] National University of Singapore.

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and more environmentally friendly. However, poor-quality NCs whose PLQY was about 10% (increased to 25–30% after further posttreatment) were generally obtained.¹⁴ On the basis of systematic investigations, large amount of surface defects, which are often generated due to the long reaction time in aqueous phase, results in low PLQY.¹⁵ Tremendous effort has been devoted to improve the spectral properties of NCs directly prepared in the aqueous phase. For example, the PLQY of NCs prepared through the hydrothermal method at 200 °C was enhanced to 50% (fwhm ~ 44 nm), since the growth rate was greatly accelerated at high temperature which effectively reduced the concentration of surface defects.¹⁶

On the other hand, microwave dielectric heating is fast emerging as a widely accepted new processing technology. With comparison to conventional thermal techniques, microwave dielectric heating has three dominating merits: (a) temperature can be rapidly raised due to the high utilization factor of microwave energy, and the kinetics of the reaction rate are increased by 1–2 orders of magnitude, (b) thermal gradient effects can be effectively reduced due to the volumetric heating of microwaves, which is favorable for realizing homogeneous heating and producing a more uniform product formation, and (c) reaction selectivity is enhanced since different kinds of substances have a varied dipole constant.¹⁷ Therefore, microwave methodology has been widely used in various fields including plasma and analytical chemistry, chemical catalysis, and organic reactions.¹⁸ Besides these, it is a rapidly developing area of research, which has attracted much attention as a new method for preparing nanoscale inorganic compounds.¹⁹ It was also demonstrated that high-quality quantum dots could be successfully prepared assisted by microwave dielectric heating.²⁰ In addition, CdTe NCs, whose PLQY was increased to 60% under optimum conditions, were obtained by microwave irradiation in the aqueous phase.²¹ Recently, our group developed a new method named program process of microwave irradiation (PPMI) for rapidly synthesizing water-dispersed CdTe NCs with higher PLQY (~68%).²² Moreover, CdTe/CdS core-shell structure NCs, whose PLQY was further enhanced to 75% under optimum conditions, were

successfully obtained assisted by microwave irradiation.²³ However, the PLQY was still lower than that of the NCs synthesized through organometallic route. What's more important, with comparison to narrow size distribution of NCs prepared in the organic phase (fwhm ~ 23–40 nm), the as-prepared NCs generally possessed relatively broad size distribution (fwhm ~ 35–60 nm), which was extremely adverse for further applications, especially in biological fluorescence labeling.

With an aim to further improve the PLQY and effectively ameliorate the size distribution, we herein present a facile method assisted by microwave irradiation for synthesizing water-dispersed CdTe NCs with both high PLQY and narrow fwhm. Specifically, microwave dielectric heating is employed to realize the rapid and homogeneous growth of NCs, which is extraordinarily beneficial for preparing high-quality NCs. This synthesis is extremely simple and highly reproducible. Most importantly, in comparison to those prepared through the hydrothermal method (PLQY ~ 50%, fwhm ~ 44 nm),¹⁶ the PLQY of the as-prepared CdTe NCs reaches as high as 82%, and the fwhm value is merely 27 nm under optimum conditions. Furthermore, the PLQY is greatly enhanced to a remarkable 98% after further amelioration through the illumination method. Moreover, the mechanism by which microwave irradiation improves the quality of CdTe NCs is discussed as well.

2. Experimental Section

Chemicals. Tellurium powder (99%), CdCl₂ (99%), and thioglycolic acid (TGA) (99%) were purchased from Aldrich. 3-Mercaptopropionic acid (MPA) (98%), Rhodamine B (Especially for fluorescence test), and Rhodamine 6G (Especially for fluorescence test) were obtained from Fluka. NaBH₄ (99%) were purchased from Shanghai Chemical Reagents Company. All chemicals were used without additional purification. All solutions were prepared using Milli-Q water (Millipore) as the solvent.

Preparation of Sodium Hydrogen Telluride. Similar manipulation was described elsewhere.²⁷ Briefly, 70.95 mg of sodium borohydride and 95.7 mg of tellurium powder were added to a small

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flask; then 3 mL of ultrapure water was added. The reacting system was cooled by ice in the dark. During the reaction, a small outlet connected to the flask was kept open to discharge the pressure from the resulting hydrogen. After approximately 10 h, the black tellurium powder disappeared and sodium tetraborate white precipitation appeared on the bottom of the flask instead. The resulting NaHTe in clear supernatant was separated and used in the preparation of CdTe NCs.

Fabrication of CdTe NCs. In a typical procedure, the CdTe precursor solution was obtained by adding freshly prepared NaHTe solution to N₂-saturated CdCl₂ solution at pH 11.4 in the presence of TGA. The molar ratio of Cd²⁺/TGA/HTe⁻ was set as 1:1:0.5. CdTe (4 mL) precursor solution was injected into the exclusive vitreous vessel with a volume of 10 mL. Series of high-quality CdTe NCs were prepared at 90 °C under microwave irradiation. After finishing microwave irradiation, the CdTe NCs sample was taken when the temperature cooled to lower than 50 °C naturally. Various sizes of TGA-CdTe nanocrystals with high PLQY were prepared by controlling microwave irradiation time. When MPA was substituted for TGA, the pH value of precursors was adjusted to 8.4, and the molar ratio of Cd²⁺/MPA/HTe⁻ was set as 1:2.4:0.5 accordingly. In addition, the reaction temperature was raised to 100 °C. Other manipulations were identical with those of preparing TGA-NCs.

Illumination of CdTe NCs. The as-prepared TGA-NCs synthesized at different [TGA]/[Cd²⁺] ratio were exposed to ambient light without any other special light source at room temperature. With an aim to elaborately study the transformation of spectral properties, the samples were periodically measured by UV-PL spectroscopy every 5 days.

Apparatus and Characterization of Samples. The microwave system (Discover Application Software Version 3.5.7) used for synthesizing CdTe NCs was made by CEM of America. The system operates at 2450 MHz frequency and works at 0–300 W power. Exclusive vitreous vessels with a volume of 10 mL or 100 mL are equipped for the system to provide security during reaction demanding high temperature and pressure. All optical measurements were performed at room temperature under ambient conditions. According to the different maximum emission wavelengths of CdTe NCs, the PLQY of samples was estimated using Rhodamine 6G (QY = 95%) or Rhodamine B (QY = 99%) in ethanol which were freshly prepared with aim to reduce the measurement error, respectively.^{9,21–23,33} In detail, the PL spectra of a given sample of the CdTe nanocrystals in aqueous solution and an organic dye, whose PL spectrum overlaps significantly with that of the nanocrystal sample, were measured under the same setting as that of the Shimadzu RF-6301PC spectrofluorimeter. The optical densities (OD) at the excitation wavelength of the dye and the nanocrystal sample were set to identical values. The OD at either the first exciton absorption peak of the nanocrystals or the main absorption peak of the dye was below 0.1 in order to avoid any significant reabsorption. The integrated PL intensities (via areas) of the nanocrystals and dye were calculated from the fully corrected fluorescence spectrum. With an aim to reduce the measurement error as much as possible, six different solution concentrations of nanocrystals and the corresponding dye were used in the measurement. The integrated PL intensities vs corresponding absorbance were plotted. The plots yielded two straight lines. The gradients of the straight lines were then used to determine the PLQY according to the following equation:

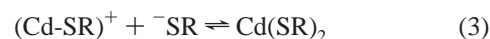
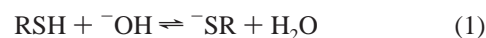
$$Q_x = Q_r M_r N_x^2 / (M_x N_r^2)$$

where N is the average refractive index of the solvent, M is the gradient of straight line, Q is quantum yield, and subscripts x and r refer to the test samples and reference solutions, respectively. In addition, the wavelength of excitonic absorption peak of the as-prepared CdTe nanocrystals was set as the excitation wavelength for measurement.

Samples were precipitated by 2-propanol and dried in vacuum-oven for X-ray powder diffraction (XRD) characterization. Transmission electron microscopy (TEM) and high-resolution TEM (HRTEM) samples were prepared by dropping the aqueous CdTe NCs solution onto carbon-coated copper grids with the excess solvent evaporated. UV-vis absorption spectra were obtained using a Shimadzu UV-3150 UV-vis-near-infrared spectrophotometer. Fluorescence experiments were performed using Shimadzu RF-6301PC spectrofluorimeter. The XRD patterns were obtained from a Rigaku D/max- γ B diffractometer. TEM and HRTEM overview images were recorded on JEOL JEM 2011 electron microscope operated at 200 kV.

3. Results and Discussion

Influence of Molar Ratio, pH Value, Reaction Temperature and Time. Figure 1a shows that the PL properties are strongly influenced by the amount of thioglycolic acid (TGA), as the stabilizer for synthesizing CdTe NCs. As previously demonstrated, the occupation of surface sites by stabilizer molecules instead of Te atoms has a tremendous contribution in removing the dangling bonds and preventing the oxidation of Te atoms, which is greatly favorable for the formation of high-quality NCs.^{22,24} Therefore, when the [TGA]/[Cd²⁺] < 0.6, the PLQY of the resulting CdTe NCs were relatively low due to the absence of adequate TGA molecules. The population of TGA molecules on the surface of NCs was increased, accompanied by accretion of the [TGA]/[Cd²⁺] ratio; thus, the PLQY was gradually enhanced and up to 82% while the [TGA]/[Cd²⁺] ratio reached the optimum value of 1.0. However, an excessive number of stabilizer molecules might distort the surface; consequently, the rough surface gave rise to new nonradiative defects.²⁴ As a result, the PLQY was distinctly diminished when [TGA]/[Cd²⁺] > 1.0. On the other hand, as described by following equations, ⁻SR ions, which originate from TGA molecules, are believed to react with Cd²⁺ ions to form the thiol-binding cadmium complexes in the following consecutive equations:²⁵



which means the Cd²⁺ ions could be ceaselessly supplied owing to decomposition of the complexes. When the [TGA]/[Cd²⁺] ratio was between 1.2 and 1.8, a multitude of complexes was produced, leading to a lower free Cd²⁺ ion concentration and a large amount of Te²⁻ ions existing in solution, which resulted in a decreased amount of CdTe nuclei being formed in the initial stage. Afterward, further NC growth occurred through dissolution of small NCs with

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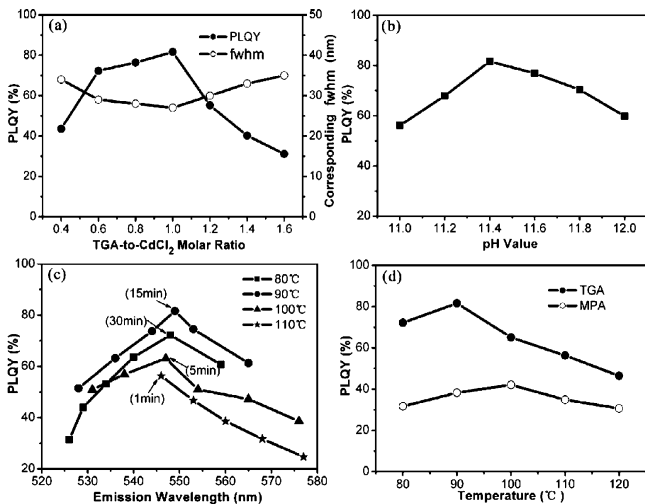


Figure 1. (a) PLQY and corresponding fwhm values of CdTe NCs versus different molar ratios between TGA and CdCl₂ in precursor solution with a pH value of 11.4. The final concentration of NaHTe and CdCl₂ in the precursor was fixed at 0.5 mM and 1.25 mM, respectively. $T = 90\text{ }^{\circ}\text{C}$. (b) PLQY of as-prepared CdTe NCs versus different pH values of initial precursor solutions. For all samples, [TGA]/[Cd²⁺] = 1.0, [Cd²⁺] = 1.25 mM, and $T = 90\text{ }^{\circ}\text{C}$. (c) Temporal PLQY of as-prepared CdTe NCs during their growth at different temperatures. For all samples, [TGA]/[Cd²⁺] = 1.0, [Cd²⁺] = 1.25 mM, and pH = 11.4. (d) Comparison of PLQY values between CdTe NCs stabilized with TGA and MPA at diverse reaction temperatures.

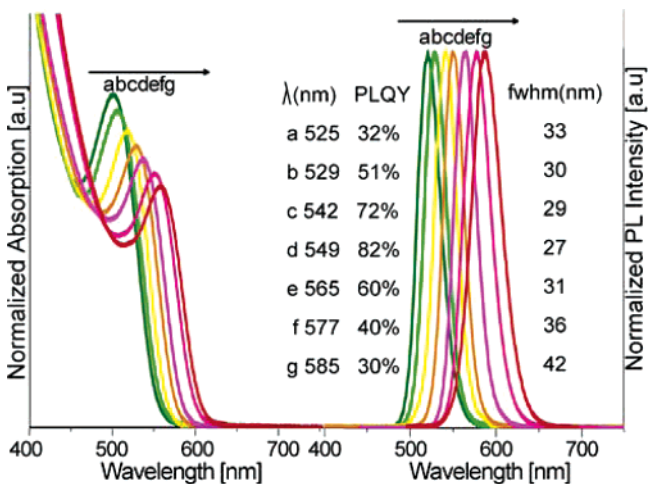


Figure 2. PL spectra of CdTe/CdS NCs with serial maximum emission wavelength and related PLQY and fwhm values are presented. For all samples, [TGA]/[Cd²⁺] = 1.0, [Cd²⁺] = 1.25 mM, and pH = 11.4. a, b, c, d, e, f, and g stand for spectra of CdTe nanocrystals obtained under the detailed conditions (temperature/time): 80 °C/1 min, 90 °C/1 min, 90 °C/10 min, 90 °C/15 min, 90 °C/30 min, 100 °C/20 min, and 100 °C/30 min, respectively.

less stability in the Ostwald ripening stage.²⁴ In the meantime, new NCs were degenerated because of the decomposition of Cd–SR complexes and residual Te²⁻ ions in solution. Consequently, the final CdTe NCs possessed broad size distribution and poor PL properties. In contrast, with the TGA-to-cadmium ratio decreasing to 1.0, more nuclei were formed due to plentiful free Cd²⁺ ions existing in the nucleation stage. An equilibrium growth/dissolution between NCs and Cd–SR complexes was preserved in the Ostwald ripening stage.^{16,22,26} As a result, NCs with high PLQY and good monodispersity were obtained in a favorable growth status.

Table 1. Evolution of PLQY of As-Prepared CdTe NCs Illuminated by Ambient Light

time (days)	0	5	10	15	20	30
PLQY, %	82	92	98	94	90	83

In this current microwave synthesis, the favorable pH value of precursor solutions generally ranged between 11.4 and 11.6, which was similar to the conventional aqueous method.¹⁴ Figure 1b presents that the TGA-stabilized CdTe NCs show pH-dependent photoluminescence, which is consistent with previous reports.^{14,26} In detail, the PLQY was gradually enhanced with increasing pH of precursor solutions from 11.0 to 11.4, but further increment of the pH led to an obvious decrease in the luminescence of CdTe NCs. The reason is that the formation of the cadmium thiol complexes, which is displayed in eqs 1–3, strongly depends on the pH of the solution.^{16,27}

The reaction temperature plays an important role in the PL properties of as-prepared CdTe NCs as well. It is well-known that NCs directly prepared in the aqueous phase generally possessed poor spectral properties (low photoluminescence quantum yield (PLQY ~ 3–10%, increased to 25–30% after further posttreatment), and broad full-width at half-maximum (fwhm) > 35 nm) due to the high concentration of defects at the surface, resulting from slow growth of NCs at low temperatures.^{14,22,23} On the other hand, it has been demonstrated that temperature has a significant influence on the attaching/detaching rate of ligands from the NC surface.^{23,28} Moreover, the increasing temperature markedly accelerates the dissolution/growth rate of complexes and leads to more free complexes.^{22,27} Thus, excessive temperatures cause detachment of the excessive ligands from the NC surface and an increase in the formation rate of complexes, which results in a large amount of surface defects and an obvious decline of PLQY. Therefore, an optimum temperature was necessary to realize the equilibrium of the attaching/detaching rate of the monomer (here, monomer refers to the complex with a ligand) from the NC surface, which is namely zero growth rate and is paramount for perfecting the surface structure of NCs and obtaining high-quality NCs.²⁹ The optimum temperature in our investigations is 90 °C (Figure 1c), which is completely different from the hydrothermal method (180 °C). We deduced that the growth rate of NCs was adequately high to reach the zero growth rate since microwave dielectric heating greatly enhances the growth rate even at relatively low temperature (90 °C) due to the microwave-specific effect mentioned above.^{20–23} The equilibrium is destroyed as the temperature was raised, which led to a decline of PLQY. In contrast, a higher temperature was demanded for increasing the growth rate to achieve the equilibrium in hydrothermal synthesis owing to the thermal gradient effects.²⁰

As shown in Figure 1d, we also made a further comparison between TGA and MPA as stabilizers of CdTe NCs in microwave synthesis. As previously reported,^{22,23} MPA-CdTe NCs reached the maximum PLQY at 100 °C, which was different from that of TGA-CdTe NCs. This result implies that a relatively higher temperature was required to realize the equilibrium for MPA as the stabilizer. The reason is probably that the stability of the Cd–SR complex is diverse

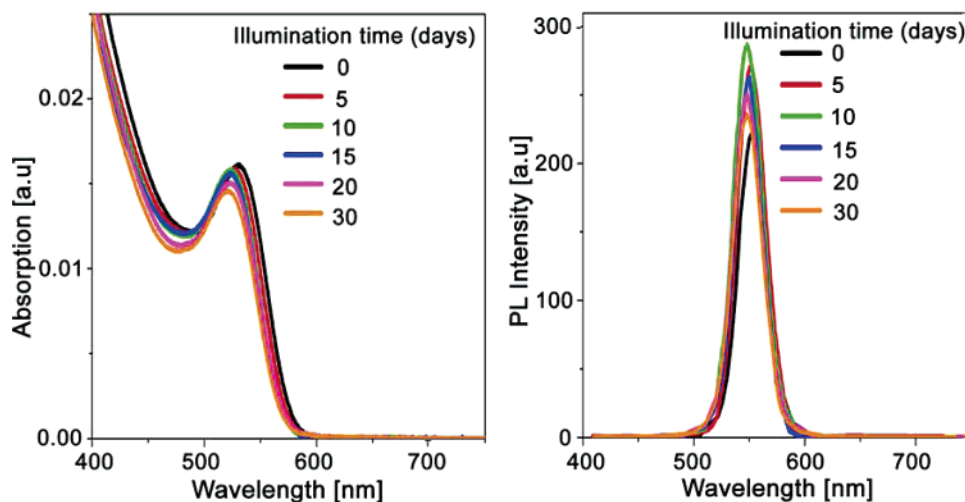


Figure 3. Evolution of absorption (left) and PL (right) spectra of TGA-CdTe NCs solution illuminated by ambient light.

according to varied kinds of thiols.²⁶ Thus, in an aim to achieve the equilibrium similar to that of a TGA-stabilized system, a relatively higher temperature is required to accelerate the decomposition of thiol–Cd complexes in the MPA-stabilized system. In addition, the PLQY of TGA-CdTe NCs was much higher than that of MPA-CdTe NCs (PLQY~42%). This result demonstrates that the complex-forming reaction has a crucial impact on the properties of NCs through regulating the amount of Cd²⁺ ions in the reaction system. Similar results were observed in conventional aqueous synthesis.¹⁴

The normalized UV-PL spectra of the as-prepared CdTe NCs with different maximum emission wavelengths in aqueous solution were displayed as well. Figure 2 reveals that a clearly resolved absorption of the first electronic transition appeared at ~500 nm and green band-edge emission appeared in only 1 min. Merely 30 min were demanded to obtain large-size CdTe NCs with a size of ~3.5 nm (luminescence maximum at 585 nm), which was sufficiently time economizing compared with conventional aqueous synthesis (several hours required). Furthermore, the PL bands were sufficiently narrow (fwhm, as low as 27 nm being increased up to 42 nm owing to size fractions of large CdTe NCs). Moreover, the PLQY exceeded 30% during the size range of NCs (~2.3–3.5 nm).

Illumination Method for Further Amelioration. It is proverbial that the illumination method is very helpful for enhancing the luminescent property of nanocrystals.¹³ Especially, the fluorescence QY of TGA-CdTe NCs was tremendously increased from 10% to 85% after 25 days of illumination.^{13a} In addition, the PLQY enhancement of TGA-ZnSe NCs was up to 3000% through illumination (PLQY increased from 1% to 30%).³⁰ In contrast, the PLQY of as-prepared NCs was more than 80% in our experiment. Thus, we deduced that the PLQY of as-prepared NCs would be up to a noteworthy value after further amelioration through the illumination method.

On the basis of this hypothesis, we elaborately investigated the PLQY transformation of as-prepared CdTe NCs during 30 days of illumination. As shown in Table 1 and Figure 3, the fluorescence quantum yield was greatly enhanced to 91.5% through 5 days of illumination. The PLQY was

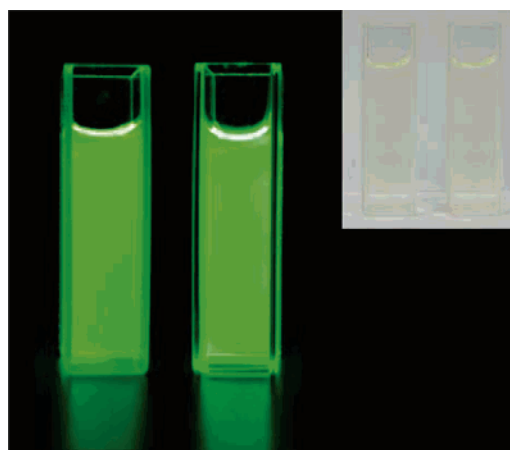


Figure 4. Photograph of the as-prepared CdTe NCs with PLQY of 82% (left) and 98% (right) in diluted aqueous solution under irradiation with 365 nm ultraviolet light from UV lamp. Insert is the image of corresponding transparent samples observed under ambient light.

remarkably reached as high as 98.3% after 10 days, which means that the luminescent efficiency of as-prepared NCs is comparable with the best quality NCs synthesized in the organometallic route.⁹ To the best of our knowledge, at present it is probably the highest PLQY value of NCs synthesized in the aqueous phase. Afterward, the PL intensity gradually declined. In spite of this, the final PLQY of the sample held at 82.7% after 30 days of illumination. On the other hand, the PL peak position was slightly blue-shifted for 1–2 nm with comparison to initial CdTe solution, which was commendably consistent with previous reports.¹⁴

Figure 4 shows the photograph of as-prepared NC aqueous solutions under the irradiation of a UV lamp and ambient light (Insert). Due to the extraordinarily high PLQY of NCs, the samples still display bright olivine color despite their extremely low optical density (absorption values at the first exciton absorption peak are smaller than 0.02, as shown in Figure 3) and high transparency in ambient light.

We found that the [TGA]/[Cd²⁺] ratio plays a critical role in the illumination process. As displayed in Figure 5, the PLQY of CdTe NCs generally reached the largest value after 10 days in spite of the diverse [TGA]/[Cd²⁺] ratio. The PLQY of CdTe NCs, which were prepared on the condition

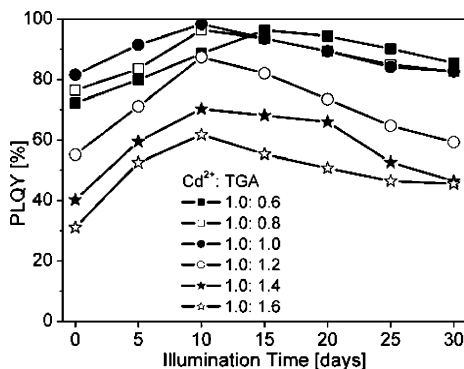


Figure 5. PLQY evolution of CdTe NCs prepared at different [TGA]/[Cd²⁺] ratios after amelioration through the illumination method.

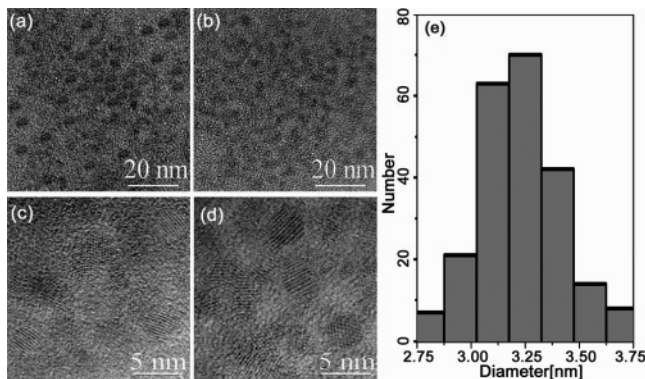


Figure 6. TEM/HRTEM images (left) of as-prepared CdTe NCs with PLQY of 82% (a, c) and corresponding NCs illuminated for 10 days with PLQY of 98% (b, d), as well as the size distribution of as-prepared CdTe NCs with PLQY of 82% (e).

of $0.6 \leq [\text{TGA}]/[\text{Cd}^{2+}] \leq 1.0$, was generally up to 95% through several days of illumination, which can be well interpreted by photochemical etching theory.¹⁴ Briefly, the improvement of PLQY is due to the etching of tellurium trap states and an improvement of the CdS shell. However, the increment of PL intensity became relatively small when the [TGA]/[Cd²⁺] ratio was higher than 1.0. The reason was probably that less free Cd²⁺ ions were residual due to a high concentration of TGA according to eqs 1–3.¹⁶ As a result, the formation of CdS shell was not adequate in photochemical etching process, which resulted in the small increment of PLQY.¹⁴ Besides, another feeble PL peak appeared at round 500 nm and became increasingly obvious along a prolonged illumination time. This result indicates that a new kind of crystalloid substance is prone to be formed since excessive S²⁻ ions are generated due to the high concentration of TGA in solution during the illumination process.

TEM/HRTEM and XRD Characterization. Figure 6 provides TEM images and HRTEM images of as-prepared CdTe NCs and corresponding NCs illuminated for 10 days. Figure 6a,b shows that both kinds of NCs appear as spherical particles with excellent monodispersity. Moreover, the existence of well-resolved lattice planes in the HRTEM images further confirms the excellent crystalline structures of the as-prepared NCs. Figure 6e shows the size distributions of as-prepared CdTe NCs with a PLQY of 82%. The size distribution of as-prepared CdTe NCs was determined by measuring more than 200 particles, which also

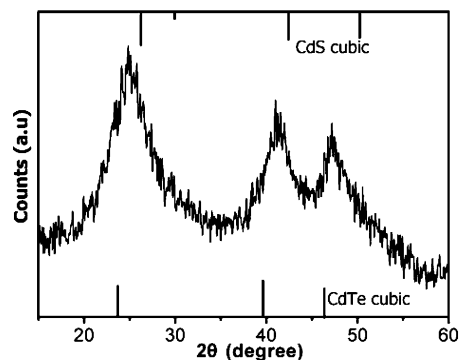


Figure 7. XRD patterns of TGA-CdTe NCs prepared at 90 °C by microwave synthesis. The standard diffraction lines of cubic CdTe and cubic CdS are also shown for comparison.

reveals the good monodispersity of the sample. The average size and standard deviation is 3.25 ± 0.15 nm, and the standard deviation of the size distribution is 4.6%, which further demonstrates the narrow size distribution of as-prepared NCs.

Furthermore, the TGA-CdTe NCs were characterized by XRD, as displayed in Figure 7. The resulting CdTe NCs belonged to the cubic (zinc) structure, which was also the dominant crystal phase of bulk CdTe. However, the positions of the XRD reflections were intermediate between the values of cubic CdTe and CdS phases. The reason was fully discussed in ref 14. In brief, sulfur was produced due to the partial hydrolysis of TGA molecules and incorporated into the growing NCs, leading to a gradient sulfur distribution from inside to the surface of NCs. Thus, mixed CdTe(S) NCs were formed during the reaction process. In addition, energy dispersive X-ray analysis (EDAX) measurements clearly showed the presence of cadmium, tellurium, and sulfur in thoroughly washed, highly luminescent nanocrystals, which further demonstrated the formation of mixed CdTe-(S) NCs.

4. Conclusion

In summary, a series of water-dispersed CdTe NCs with extremely high PLQY and narrow PL spectra were successfully synthesized assisted by microwave dielectric heating. In the microwave, the growth rate of the NCs is greatly enhanced, which is the important prerequisite for reducing the amount of surface defects in NCs. Furthermore, a thermal gradient effect is effectively reduced and homogeneous heating is well performed with comparison to conventional thermal techniques.²⁰ As a result, compared with TGA-CdTe NCs prepared through the hydrothermal method (PLQY and fwhm reached 50% and 44 nm in optimum condition, respectively),¹⁶ the spectral properties of NCs can be extraordinarily improved in microwave synthesis. Consequently, the PLQY of CdTe NCs reaches as high as 82% and is up to a remarkable 98% after further amelioration through the illumination method. Meanwhile, the small fwhm values (27–35 nm) indicate that the as-prepared NCs possess narrow size distribution. Moreover, microwave synthesis is extremely simple and convenient and free of complicated vacuum manipulation or expensive chemical reagents. Be-

sides, it is also more environmentally friendly since the whole synthesis is carried out in water. Furthermore, these nanocrystals can be potentially used for in vivo molecular imaging and biolabeling.³¹

Since the bare CdTe nanocrystals are cytotoxic and possess relatively poor photostability (especially under UV irradiation),³² we are currently ameliorating the biocompatibility and stability of the as-prepared CdTe nanocrystals for further

bioapplications. These investigations will be presented in future papers.

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