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Preparation and bioapplication of high-quality, water-soluble, biocompatible, and near-infrared-emitting CdSeTe alloyed quantum dots

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Abstract

A facile method is developed for the preparation of high-quality, water-soluble, and near-infrared (NIR)-emitting CdSeTe alloyed quantum dots (AQdots) with l-cysteine as the capping agent. By changing the size and the composition of AQdots the photoluminescent quantum yield (QY) can reach as high as 53% and the emission color can be tuned between visible and NIR regions (580–814 nm). Furthermore, the prepared NIR-emitting AQdots have been successfully applied for HL-60 cell imaging and glucose and cholesterol assay, which demonstrates the great potential of the AQdots for biological applications.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Fluorescent semiconductor nanocrystals or quantum dots (Qdots) are attracting much interest from diverse research communities because of their unique and tunable optical properties [1–3]. The novel properties of Qdots, such as improved brightness, narrow and symmetric emission spectra, resistance against photobleaching, and multicolor light emission, have opened new possibilities for ultrasensitive chemical analysis and cellular imaging. Among them, Qdots with near-infrared (NIR) emission (650–900 nm) are of particular interest for biological imaging and detection because biological autofluorescence and absorbance can be reduced to their minima in this wavelength range [2, 4–6].

In the last decades, many efforts have been devoted to the preparation of high-quality NIR-emitting Qdots through organometallic or aqueous routes [5]. However, researchers have found that the far-red to NIR-emitting binary Qdots were technically challenging and the relatively poor optical properties limited their applications in biological imaging and detection [6–10]. Researchers tried to develop efficient synthetic methods to overcome these problems. However, the most routine synthesis of NIR-emitting Qdots may involve relatively complicated multistep processes [6, 11–18]. Nie et al [19, 20] reported a simple protocol to synthesize CdSeTe alloyed semiconductor quantum dots (AQdots) with a striking nonlinear relationship between the energy gap and its composition compared with other types of AQdots, such as Zn$_x$Cd$_{1-x}$S [21] and Zn$_x$Cd$_{1-x}$Se [22], thus the CdSeTe AQdots showed excellent NIR-emitting properties and broad absorption spectral coverage (even up to 900 nm). This indicated that the CdSeTe AQdots could be used as an ideal candidate for applications in NIR emission. Although some NIR-emitting AQdots were synthesized, they were mostly prepared by an organometallic method which restricted their direct applications in biosystems [6, 7, 19, 20, 23–27]. In order to improve the water solubility of the AQdots, the surface-capping molecules need to be modified or replaced by hydrophilic molecules using a ligand exchange method. However, the as-prepared AQdots often have drawbacks including decreased stability and fluorescence efficiency because of the lack of a capping layer [7, 23, 25, 27]. Therefore, it is important to develop facile methods to synthesize AQdots with outstanding NIR fluorescence directly.
in an aqueous medium. However, it is still difficult to find a simple method to prepare AQdots for application in bioassays [28]. To the best of our knowledge, only a few NIR-emitting AQdots have been directly prepared in aqueous solutions. For example, NIR-emitting CdTeS AQdots were synthesized via a hydrothermal route with 3-mercaptopropionic acid (MPA) as the stabilizer [29]. Hg-based NIR-emitting AQdots were also synthesized in an aqueous medium in the presence of MPA [30, 31]. In these methods MPA was always used as the stabilizer [29–33]. However, MPA is a volatile liquid with an awful odor and its carcinogenic properties may further inhibit its use in laboratories [34, 35]. Therefore, it is of importance to explore other alternative stabilizers. L-cysteine as a sulfur amino acid is an ideal candidate as a capping agent because of its good biocompatibility and the avoidance of Qdot-induced cytotoxicity [36, 37]. However, up to now l-cysteine and its derivatives have rarely been applied in the synthesis of ligand-protected NIR-emitting AQdots in aqueous solution [13].

Furthermore, Qdot-based chemical and biological assays have become a very exciting area [3, 38]. Great efforts have been made to develop Qdot-based optical sensors [2, 39–42], but most experiments have been carried out in the visible light region. NIR fluorescence is attractive for biosensing and biolabeling applications because of the absence of an autofluorescent background and increased penetration of excitation and emission light through tissue [2–6].

Herein, we report the preparation of high-quality NIR-emitting CdSeTe AQdots in an aqueous medium using l-cysteine as the stabilizer following a facile one-pot refluxing route. By changing the growth time and/or composition, the fluorescence emission of the AQdots could be tuned from the visible to NIR region. The as-prepared CdSeTe AQdots have excellent water solubility, stability and high quantum yield (QY), and can be successfully applied to cellular imaging. The fluorescence of the AQdots was sensitive to hydrogen peroxide (H₂O₂), which was used for the sensitive determination of glucose and cholesterol. All these results show that the prepared CdSeTe AQdots with NIR emission have great potential applications for biosensing and imaging.

2. Experimental detail

2.1. Materials

Selenium powder (Se, 99.5%, 200 mesh) and tellurium powder (Te, 99.8%, 200 mesh) were purchased from Acros Organics (New Jersey, USA). Cadmium chloride was purchased from Tixin Chemical Reagent (Shanghai, China). Sodium borohydride and Rhodamine B were purchased from Tianjin Chemical Research Institute (Tianjin, China). l-cysteine (98%), glucose, cholesterol, glucose oxidase, cholesterol oxidase from *Pseudomonas* and Tritxon-X-100 were purchased from Sigma-Aldrich. The analytical grade H₂O₂ was purchased from Shanghai Biochemical Reagent Company (Shanghai, China). The PBS (0.01 mol l⁻¹) solutions with various pH values were prepared by mixing stock solutions of NaH₂PO₄ and Na₂HPO₄, and then adjusted with 0.01 mol l⁻¹ NaOH and H₃PO₄. All other reagents were of analytical grade and used without further purification. Ultrapure water with 18.2 MΩ cm⁻¹ (Millipore Simplicity, USA) was used throughout the experiments.

2.2. Synthesis of the l-cysteine-capped CdSeTe AQdots

In the synthesis, all reactions were carried out in oxygen-free water under nitrogen. l-cysteine-capped CdSeTe AQdots were prepared through the incorporation of selenium ions into CdTe nanocrystals [33, 43]. Typically, 0.25 mmol of CdCl₂ and 0.6 mmol of l-cysteine were dissolved in 200 ml water and the pH adjusted to 11.5 with 1 M NaOH. The precursor solution was then loaded into a three-necked flask clamped in a heating mantle. The solution was heated to 95 °C under argon flow to obtain a colorless solution. At this temperature, 2.0 ml of fresh NaHTe aqueous solution prepared from KBH₄ and Te powder (0.125 mmol) was injected into the reaction system under vigorous stirring; the solution was then refluxed at 95 °C. After 0.5 h heating, a different volume of the freshly prepared sodium hydroselenide (NaHSe) solution premixed with an appropriate amount of l-cysteine was added into nanocrystalline CdTe precursor solution. The solution pH was then adjusted to 11.5 with an appropriate amount of 1 M NaOH solution. Further nucleation and growth of the AQdots proceeded upon refluxing the solution at 95 °C under open air conditions with a reflux condenser. Part of the refluxing solution was taken out at regular intervals for further characterizations. The as-prepared CdSeTe AQdots were precipitated and washed with 2-propanol. The AQdots were dried overnight at room temperature in a vacuum. The final product in powder form could be resuspended in water.

2.3. Experimental measurements

The fluorescence spectra and fluorescence lifetime study of the AQdot samples were obtained with an Edinburgh FLs920P fluorescence spectrometer (Edinburgh Instruments Ltd, UK). The optical absorption spectra were measured using a Shimadzu 3600 UV–vis spectrometer (Shimadzu, Japan). The room temperature fluorescence QYs were determined by comparing the integrated emission of the AQdot samples with the reference (rhodamine 6G in ethanol, QY = 95%). The IR spectroscopic measurements were performed on a Bruker model VECTOR22 Fourier-transform spectrometer using KBr pressed disks. The TEM images were acquired using a JEOL JEM-2100 (JEOL, Japan) transmission electron microscope operating at an acceleration voltage of 200 kV. For the XRD characterization, the CdTe and the CdSeTe AQdots were precipitated with the same volume of isopropyl alcohol and centrifuged to collect the precipitate, and then the purified AQdots were dried in a vacuum to obtain dry powder. The XRD analysis was performed with a Philips X-pert x-ray diffractometer at a scanning rate of 4° min⁻¹ in the 2θ range from 10° to 80°, with graphite monochromatized Cu Kα radiation (λ = 0.15418 nm). Purified and dried CdTe or CdSeTe AQdots were suspended in a vacuum and diluted in ultrapure water to ppb level for elemental analysis of Cd, Se
and Te. The percentage of cysteine was extrapolated from the percentages of Cd, Se and Te. The elemental analysis of AQdots was performed on a VG PQExCell ICP-MS system.

2.4. Near-infrared fluorescence assay for H$_2$O$_2$, glucose and cholesterol

The CdSeTe(1:4):750 AQdots were successfully synthesized with the procedures described in section 2. The AQdot solution was purified in a ultratitration tube (MWC = 5 kDa) and then diluted with PBS solution (pH 7.4, 0.01 mol$^{-1}$). At a fixed concentration of the CdSeTe(1:4):750 AQdot solution, various concentrations of H$_2$O$_2$ were added. After 40 min incubation at room temperature, the fluorescence intensity of the solution was recorded at 750 nm with an excitation wavelength of 300 nm. The slit widths of both excitation and emission were 2 nm. For the biocatalytic growth of H$_2$O$_2$, different concentrations of glucose together with 50 μg ml$^{-1}$ glucose oxidase were incubated at 37°C for 3 h. The cholesterol was dissolved in ethanol first and diluted with PBS (containing 0.8% Triton X-100 to improve cholesterol dispersion), and different concentrations of cholesterol together with 0.2 μmol l$^{-1}$ of cholesterol oxidase were reacted for 3 h at 37°C. Then 1 ml of 5 μg ml$^{-1}$ CdSeTe(1:4):750 AQdots was added into the biocatalytic growth solution and incubated for 40 min at room temperature, and then the fluorescence spectra were recorded.

2.5. Cell imaging

The synthesized CdSeTe(1:4) AQdots for emission at 655 nm (CdSeTe(1:4):655) were ultratitration in a Millipore filtration tube (CMW = 5000). Then the purified AQdots were redispersed with PBS (10 mmol l$^{-1}$, pH 7.4). The human promyelocytic leukemia (HL-60) cells were cultured in Dulbecco’s modified Eagle’s medium (DMEM, 10% fetal bovine serum) to obtain a suitable density. The AQdots were then added and incubated with HL-60 cells (30–50% confluent cultured in a 15–100 mm tissue culture dish) overnight in 5% CO$_2$ at 37°C. After the incubation was completed, the stained HL-60 cells were centrifuged and washed with PBS (10 mmol l$^{-1}$, pH 7.4) three times. The transfected cells were then spread on a cover glass and the confocal fluorescence microscopy images were obtained with a LSM710 confocal laser-scanning microscope (Carl Zeiss) with 405 nm diode laser excitation.

3. Results and discussions

3.1. Preparation and characterization of CdSeTe AQdots

L-cysteine was selected as a capping agent for the synthesis of CdSeTe AQdots. The detailed experimental procedures were described in section 2. Besides the effect of thiol ligands, the pH value of the precursor solution has also a strong effect on the fluorescence efficiency and emission wavelength. The fluorescence intensity at a given reflux time increased with the increase in pH value, and no emission spectra were observed at pH values below 8.0 or above 12.5. This may be because deprotonation of the thiol group in the l-cysteine molecule occurs at high pH values. The deprotonation may strengthen the covalent bond between Cd and the l-cysteine molecule, leading to the increase in fluorescence intensity with increasing pH. Thus a pH of 11.5 was selected as the optimal condition. The synthesis of CdSeTe AQdots was carried out based on the incorporation of Se$^{2-}$ into the CdTe nanocrystals. The solution of CdTe was heated at 95°C for 0, 30, 60 and 90 min before the addition of NaHSe. The fluorescence emission of the CdTe Qdots shifted from 511 to 620 nm within 180 min, with the increase of QY from 2% to 19%. High-quality CdSeTe AQdots were obtained after the solution with CdTe was heated for 30 min via NaHSe injection. In the presence of excess l-cysteine and cadmium, the injection of NaHSe resulted in the formation of alloyed nanocrystals. And the solution color changed from colorless to shallow orange because the Se$^{2-}$ deposited on/into the CdTe nanocrystals as a result of the high association constant of CdSe. In a typical synthesis of CdSeTe AQdots, the molar ratio of Se to Te was 1:4, and the AQdots was denoted as CdSeTe(1:4). The emission spectra of the CdSeTe AQdots with different reflux times are shown in figure 1. With further growth of nanocrystals during continuous refluxing [44], the fluorescence continued to shift to long wavelengths, and the fluorescence intensity gradually increased with the removal of surface defects from the alloyed nanocrystals. Size-based tuning of the fluorescence emission was confirmed by TEM and fluorescence spectroscopy. Apart from growth time, the composition was also a key factor for tuning the optical properties of the CdSeTe AQdots [19]. To investigate the effect of Se$^{2-}$ on the AQdots, different molar ratios of Se precursor were introduced into the CdTe nanocrystals. Figure 2 shows the fluorescence spectra, QY and their corresponding emission wavelengths, respectively. The fluorescence emission of the l-cysteine-capped CdSeTe AQdots continued to red-shift with the increase of Se molar ratios at the same growth time and shifted quickly. The fluorescence emission of CdSeTe AQdots more easily reached the NIR region at a given refluxing time compared to CdTe Qdots. In a typical process, it only took 8.5 h for the synthesis of l-cysteine-capped CdSeTe AQdots with emission at 750 nm (QY = 26%), while it took 21 h to obtain CdTe Qdots with the same emission (QY = 7%). The fluorescence spectra of CdTe, CdSeTe(1:19), CdSeTe(1:10), CdSeTe(1:4), CdSeTe(1:3) and CdSeTe(1:1) AQdots with different Se molar ratios in same growth time of 3 h are shown in figure 2(a). The fluorescence peaks are located at 655, 672, 686, 715 and 720 nm, respectively, with full width at half-maximum fluorescence intensity (FWHM) of 58, 59, 62, 72 and 75 nm. The QY were 51%, 34%, 41%, 22% and 10%, respectively. The QY of CdSeTe AQdots was generally higher than that of the CdTe Qdots. The reason for this may be the removal of surface defects from the AQdots by the incorporated Se ions due to the high association constant of CdSe compared to CdTe and the highly crystalline structure. The emission profile of the AQdots remained unchanged after 4 months of storage in ambient conditions, suggesting good stability. This can be attributed to the generation of the sulfide shell of l-cysteine and the inhibition of hole trapping processes [45, 46]. On the
basis of these studies, it can be concluded that the fluorescence emission of the CdSeTe AQdots can be continuously tuned by changing the growth time and the composition.

As for the prepared CdSeTe AQdots, the Se molar fraction was determined by inductively coupled plasma mass spectrometry (ICP-MS) elemental analysis. The results are listed in table 1. In previous studies of L-cysteine-capped CdTe Qdots, thermal decomposition of L-cysteine was confirmed to release sulfur ions [45–48]. For CdSeTe(1:4)686 (686 denotes the fluorescence wavelength, QY = 41%), the molar ratio of Cd to (Se and Te) was 1:0.3 (table 1). The balance between the cations and anions could be explained by the sulfur ions that were incorporated into the AQdot nanocrystals (table 1) [28, 43].

The FTIR spectrum (figure 3) was used to identify the functional groups on the surface of the CdSeTe(1:4)686 AQdots. The standard spectra of L-cysteine show two peaks at 2655 and 2548 cm$^{-1}$ that can be attributed to the stretch vibration of the S–H bond. The characteristic peak at 1641 cm$^{-1}$ corresponds to the C=O vibration, which represents the carboxyl group. The diminution of the broad absorption around 2550 cm$^{-1}$ resulting from the S–H bond in the L-cysteine molecule indicates that the thiol group of L-cysteine combines on the surface of the CdSeTe AQdots.

Table 1. ICP-MS elemental analysis of CdTe and CdSeTe AQdots.

<table>
<thead>
<tr>
<th>AQdots</th>
<th>[Cd]$^a$</th>
<th>[Se]$^a$</th>
<th>[Te]$^a$</th>
<th>Cd:Se:Te molar ratio</th>
<th>Composition$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CdTe619</td>
<td>14.39</td>
<td>0</td>
<td>5.94</td>
<td>1:0.00:0.36</td>
<td>CdTe$<em>{0.36}$Sn$</em>{0.54}$</td>
</tr>
<tr>
<td>CdSeTe(1:19)655</td>
<td>61.80</td>
<td>1.53</td>
<td>9.97</td>
<td>1:0.04:0.14</td>
<td>CdSe$<em>{0.04}$Te$</em>{0.14}$Sn$_{0.82}$</td>
</tr>
<tr>
<td>CdSeTe(1:10)672</td>
<td>53.76</td>
<td>2.85</td>
<td>9.33</td>
<td>1:0.08:0.15</td>
<td>CdSe$<em>{0.08}$Te$</em>{0.15}$Sn$_{0.77}$</td>
</tr>
<tr>
<td>CdSeTe(1:4)686</td>
<td>55.31</td>
<td>5.85</td>
<td>9.58</td>
<td>1:0.15:0.15</td>
<td>CdSe$<em>{0.15}$Te$</em>{0.15}$Sn$_{0.70}$</td>
</tr>
<tr>
<td>CdSeTe(1:3)715</td>
<td>58.48</td>
<td>14.06</td>
<td>9.58</td>
<td>1:0.34:0.14</td>
<td>CdSe$<em>{0.34}$Te$</em>{0.14}$Sn$_{0.52}$</td>
</tr>
<tr>
<td>CdSeTe(1:1)720</td>
<td>65.50</td>
<td>26.20</td>
<td>9.05</td>
<td>1:0.57:0.12</td>
<td>CdSe$<em>{0.57}$Te$</em>{0.12}$Sn$_{0.31}$</td>
</tr>
</tbody>
</table>

$^a$ The unit is $\mu$g ml$^{-1}$.

$^b$ The normalized composition of CdTe and CdSe$_x$Te$_y$S$_z$ AQdots. There is an uncertainty of ±10% associated with the dilution and ICP-MS analyses.
Figure 2. (A) Normalized fluorescence spectra of CdTe and CdSeTe AQdots with 3 h reflux time. (B) Quantum yield (QY) and emission wavelength of CdSeTe AQdots (with 3 h growth time) as a function of Se:Te molar fraction. (C) The relationship between QY and reflux time of the different CdSeTe AQdots. (D) The relationship between QY and emission wavelength of the different CdSeTe AQdots.

Figure 3. FTIR spectra of L-cysteine and L-cysteine-capped CdSeTe AQdots.

through the Cd–S bond. The IR spectra of the AQdots in the range of 1000–1300 cm\(^{-1}\), which includes the C–OH stretching and O–H bending vibrations, implies the existence of large numbers of residual hydroxy groups. Therefore, the carboxyl groups confer the hydrophilicity and stability of the Qdots in aqueous systems, and greatly broaden their potential applications in biochemistry diagnostics.

Physical characterizations of the L-cysteine-capped CdSeTe AQdots were also performed. In high resolution transmission electron microscopy (HRTEM) images, the L-cysteine-capped CdSeTe(1:4)686 AQdots showed an average size of about 4 nm, which was slightly larger than that of CdTe nanocrystals as shown in figure 4. The nanoparticles were reasonably monodisperse, with a standard deviation of 10%, and the shape could be estimated to be spherical. Further effective evidence of their hydrodynamic diameters was obtained by ultrafiltration. The synthesized CdSeTe AQdots could pass through a membrane filter with a 100 kDa (1 Da ~ 1.66 × 10\(^{-27}\) kg) molecular-weight cutoff, corresponding to a pore size of 6 nm.

The XRD patterns were further used to confirm the structure and composition of the L-cysteine-capped CdSeTe AQdots as shown in figure 4(C). The XRD patterns of the CdTe powder show a peak at 26° (111) and a broad band at about 42° due to the overlap of (220) and (311) diffractions, confirming that the CdTe Qdots have a zinc-blende crystal structure similar to that of thiol-capped or glutathione-capped CdTe Qdots [47–49]. The diffraction peaks in the XRD patterns of the CdSeTe AQdots were close to CdTe Qdots,
revealing that the CdSeTe AQdots had a zinc-blende crystal structure. The diffraction peaks gradually shifted to larger angles with the increase of Se molar fraction, which also indicated that there was no phase separation or separated nucleation of CdTe or CdSe in the CdSeTe AQdots as in previous reports [28].

Fluorescence lifetime measurements probe the degree of wavelength overlap of the carriers, or the oscillator strength of the transition [50, 51]. It was reported that with the type-II nature increasing, the wavefunction overlap between the electron and hole decreased because of larger charge separation giving longer lifetime values [16, 19, 52]. The fluorescence time-resolved spectra of CdTe Qdots and four types of CdSeTe AQdots (CdSeTe(1:19)655, CdSeTe(1:10)672, CdSeTe(1:4)686, CdSeTe(1:3)715) are shown in figure 5 and the lifetime value is 30, 31, 33, 35 and 38 ns, respectively. Obviously, the lifetime of CdSeTe AQdots is longer than that of CdTe Qdots, and increases with increasing Se fraction. For the Qdots with the same structures, the larger size can lead to the longer lifetime, which means that the decay lifetime increases gradually with the size change of AQdots.

3.2. NIR fluorescence detection of hydrogen peroxide, glucose and cholesterol

The Qdots with NIR fluorescence are attractive for biosensing because of low interference from biomolecules. In this work, the fluorescence of the CdSeTe AQdots was sensitive to hydrogen peroxide (H₂O₂). NIR-emitting CdSeTe(1:4)750 AQdots were used to fabricate a fluorescence sensing system for H₂O₂ assay. For numerous H₂O₂-generating oxidases, the prepared NIR-emitting AQdots can be a versatile fluorescent reporter monitoring the activities of oxidase and detecting their substrates. The quenching effect of H₂O₂ on the fluorescence of CdSeTe(1:4)750 AQdots was investigated. The fluorescence of the CdSeTe(1:4)750 AQdots decreased by about 50% in the
presence of 0.01 mmol l\(^{-1}\) H\(_2\)O\(_2\) after 40 min incubation. And the quenching effect was strongly dependent on the incubation time within 40 min. However, after 40 min, no obvious change was observed with further increase of incubation time. Thus, the following fluorescence determination was carried out after 40 min incubation.

The effect of L-cysteine on the fluorescence quenching of CdSeTe(1:4)750 AQdots was studied. The quenching effect decreased with increase of L-cysteine. The quenching may be the effect of AQdot surface traps, caused by oxidation of L-cysteine or S\(^2\)\textsuperscript{-} surface states and acting as electron acceptors to quench the excitation of the Qdots [39, 42, 53].

The fluorescence spectra of the CdSeTe(1:4)750 AQdots with different concentrations of H\(_2\)O\(_2\) were investigated. An efficient quenching effect was obtained in the presence of 1 mmol l\(^{-1}\) of H\(_2\)O\(_2\). And a significant blue-shift was observed in the maximum emission with the increase of H\(_2\)O\(_2\) concentration. A linear relationship between fluorescence intensity and the logarithm of H\(_2\)O\(_2\) concentration was obtained within a linear range of three orders of magnitude, from 5 \(\times\) 10\(^{-6}\) to 3 \(\times\) 10\(^{-3}\) mol l\(^{-1}\). A linear concentration range was from 1 \(\times\) 10\(^{-5}\) to 2 \(\times\) 10\(^{-3}\) mol l\(^{-1}\). From the calibration curve of fluorescence intensity to concentration of H\(_2\)O\(_2\), the estimated concentration range of the generated H\(_2\)O\(_2\) in the glucose and cholesterol system was 4 \(\times\) 10\(^{-6}\)–1.8 \(\times\) 10\(^{-3}\) mol l\(^{-1}\) and 7 \(\times\) 10\(^{-6}\)–1.4 \(\times\) 10\(^{-3}\) mol l\(^{-1}\), respectively.

3.3. Cell imaging

To investigate the availability of stable NIR fluorescence and small dimensions of the AQdots, the L-cysteine-capped CdSeTe(1:4)655 AQdots were used for HL-60 cell imaging as shown in figure 7. At physiological pH, the negatively charged CdSeTe(1:4)655 AQdots can combine with the positively charged basic proteins, such as histone, which are abundant in cell nuclei [47]. These CdSeTe(1:4)655 AQdots, with a diameter of about 4 nm could gain access to the cellular matrix, and the fluorescence still remained bright over 24 h. A long incubation time and a transfection reagent were essential to cell staining. It was found that the cell labeled with CdSeTe(1:4)655 AQdots showed a higher contrast compared with fluorescein due to lower interference in NIR region. This suggested that the AQdots with NIR emission had great possibility for targeted cell imaging under appropriate functionalization conditions.

4. Conclusions

In summary, L-cysteine-capped CdSeTe AQdots were synthesized by a facile aqueous route. The results showed that the emission wavelength could be tuned by controlling the growth time and composition. The prepared CdSeTe AQdots possess higher QY and the emissions were more prone to reach the NIR region compared to CdTe Qdots. Use of the NIR-emitting Qdots in biological applications gives low interference with...
biomolecules in this region. The prepared NIR-emitting CdSeTe AQdots have been successfully applied to cellular imaging and glucose or cholesterol assay, which presents great potential for novel biological applications of NIR-emitting Qdots.

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Figure 7. Cell imaging of the t-cysteine-capped CdSeTe(1:4)655 AQdots in micelles on HL-60 cells: (A) DIC image of cells, (B) confocal microscopy image, (C) merged image.