

Red Emissive MSA Capped CdTe Quantum Dots for Cell Imaging

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Abstract

The changes in the optical and electronic properties of the materials due to the quantum confinement effect in semiconductor nanoparticles have attracted huge interest in the scientific community. Within the semiconductor nanoparticles, the quantum dots (QDs) deserve a special position due to their high quantum confinement effect and unique optoelectronic properties. Among the semiconductor quantum dots, CdTe attracts more attention due to its easy manufacturing, large Bohr exciton radius, and wide range of absorption and emission tunability. These unique properties make them useful in a wide range of areas, like solar cells, sensing, bioimaging, lasing, nonlinear optical applications, etc. In the present work, MSA-capped water-soluble CdTe QDs are prepared using a simple colloidal method for cell imaging. The XRD spectrum, UV-vis absorption spectrum, PL spectrum, DLS analysis, and HR-TEM analysis are applied for the characterization of synthesized CdTe QDs. Here, we synthesized red emissive spherical CdTe QDs of average size 6nm which was confirmed using TEM and DLS analysis. The obtained particle size is found to lie in the strong confinement regime. The X-ray diffraction result reveals the successful formation of crystalline CdTe QDs. These QDs exhibit a Zinc blende cubic structure with well-defined crystallinity. The bioimaging efficiency of MSA-capped CdTe QDs is examined on N2A Cells. These results show that CdTe QDs are a promising material for cell imaging.

Keywords: Quantum dot, CdTe, MSA, water soluble, bioimaging

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INTRODUCTION

In biomedical applications, accurate and sensitive detection of biomolecules and cellular components is required. Fluorescence imaging techniques have been widely employed in biomedical fields including in vivo and in vitro imaging, molecular imaging, and cellular targeting due to their high versatility and precision. Conventionally, fluorescent organic dyes are broadly used in fluorescent imaging techniques. However, these have several key obstacles, including short fluorescence lifetime, cellular autofluorescence interference, and rapid photobleaching, which hinder prolonged imaging and tracking. On the other hand, inorganic quantum dots can overcome the above-mentioned problems of organic dyes [1–5].

The size and shape of semiconductor quantum dots (QDs) determine their unique absorption and

emission properties, excellent photothermal and chemical stability, and biocompatibility, which make them versatile materials in chemical and biological research instead of organic dyes. Compared to organic dyes, QDs have broad absorption spectra, narrow PL spectra with large Stokes shift, minimal autofluorescence, and multiple wavelength emission with a single excitation wavelength. Surface modifications are possible using different biomolecules. Considering these merits, QDs are especially desirable for bio-imaging and labeling applications [6–9].

Among the various classes of QDs II-VI semiconductor QDs include CdTe, CdSe, CdS, ZnO, ZnS, and ZnSe are most studied and applied in a wide range. Cadmium Telluride (CdTe) is an II-VI group, narrow direct band gap p-type semiconductor material with a large exciton Bohr radius [10]. So, CdTe nanocrystals show strong quantum confinement effects compared to other cadmium-based quantum dots of comparable size and also possess widely tunable absorption and emission. In most of the cases, CdTe QDs absorption peak and emission spectrum lie in the visible region. The PL spectrum is usually very sharp and possesses a very high quantum yield. By changing the preparation method and particle size of CdTe QDs, one can obtain the desired optical properties. Various chemical synthesis techniques are reported for the preparation of CdTe QDs such as UV-irradiation, chemical precipitation, reflux method, microwave irradiation, etc. Toxicity is the critical factor in the case of CdTe QDs in biomedical applications. Most of the synthesis involves the organic phase, which questions the biocompatibility and direct biological applications. So, first, we make QDs water soluble by employing various capping agents and organic ligands, which reduce toxicity. Compared to other cadmium-based chalcogenide nanocrystals CdTe nanocrystals are more stable in the aqueous phase [8,11-15]. In pure form, CdTe is insoluble in water, but it can be made water soluble by capping with ligands such as MSA, MPA, cysteine, etc. The use of a reducing agent during the synthesis process is important since it aids in boosting QD stability by lowering oxidation, which is significant considering the high oxidation tendency of tellurium [8].

Based on the above discussion, in this paper, we present the successful synthesis of MSA-capped water-soluble CdTe QDs study their optical and morphological properties, and finally study the potential applications of red emissive CdTe QDs in bioimaging of N2A cells. Red emissive QDs have very unique properties in the field of biomedical applications including low toxicity, deep tissue penetration without causing damage, resistance to photobleaching, high biocompatibility, and enabling high-quality imaging. These specialties make the red emissive QDs a valuable tool in bioimaging.

EXPERIMENTAL

The highly emissive water-soluble CdTe QDs are prepared according to our previously reported synthesis approach [16]. The schematic illustration of the synthesis procedure is shown in Figure 1. Aqueous solution of CdCl₂ (0.05M), Na₂TeO₃ (0.125M), NaBH₄(0.5g), and MSA (0.15M) are mixed under stirring after that buffer solutions citric acid (0.75mM) and borax(0.75mM) are also added and stirred well. The pH of the solutions was adjusted using NaOH, then heated at 150°C for 20 minutes. The synthesized sample was analyzed using UV-VIS absorption spectrum (JASCO-V-570), JEOL JEM-2100 HR-TEM analysis, XRD (Bruker AXS D8 Advance) analysis, Horiba SZ-100 particle size analyzer, and emission spectra were taken using Varian Cary Eclipse Fluorimeter.

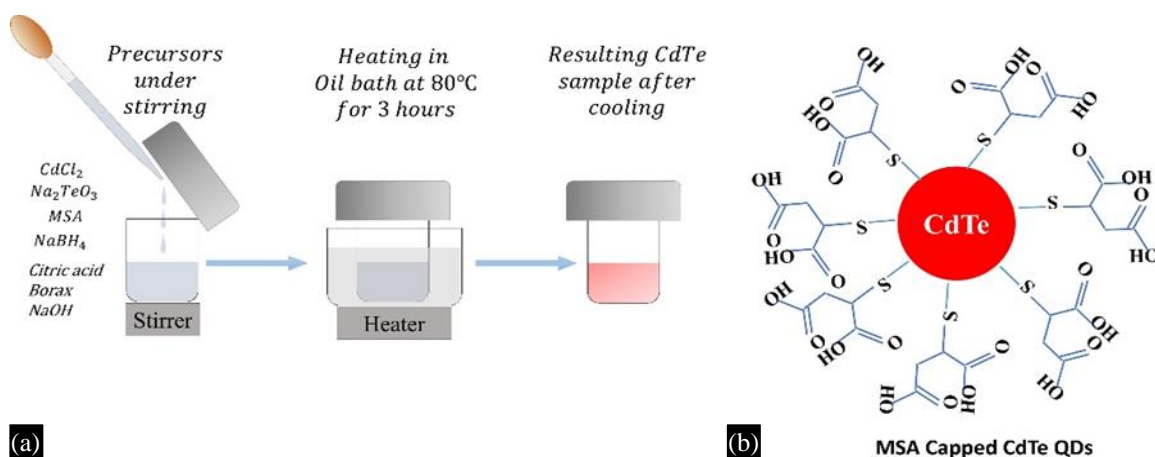


Figure 1. Schematic illustration of the (a) CdTe QDs synthesis procedure and (b) MSA capped CdTe QDs.

N2A cells are obtained from the Department of Biotechnology, CUSAT, Kerala, India. The cells were treated with MSA-capped CdTe QDs for 24 hours. The morphology and cell uptake were visualized using an inverted phase contrast fluorescence microscope (Nikon Eclipse Ti2 series, India).

RESULTS AND DISCUSSION

To understand the CdTe QDs formation process, different characterization technique is carried out. First, we carried out absorption spectroscopy, which deals with the measurement of absorption of incident radiation on a sample as a function of wavelength. In most situations, the CdTe absorption peak of the spectrum lies in the visible region [3,4]. The absorption spectra Figure 2 (a) display the prominent first excitonic peak at wavelength 640nm and the inset image is the photograph of laser-excited CdTe QDs. Transmission electron microscopy is the microscopic technique used to analyze the morphology and structure of a specimen at a nanoscale. TEM images, Figure 2 (b) and 2(c) confirmed the formation of well-dispersed QDs of the spherical shape with an average size of 6nm.

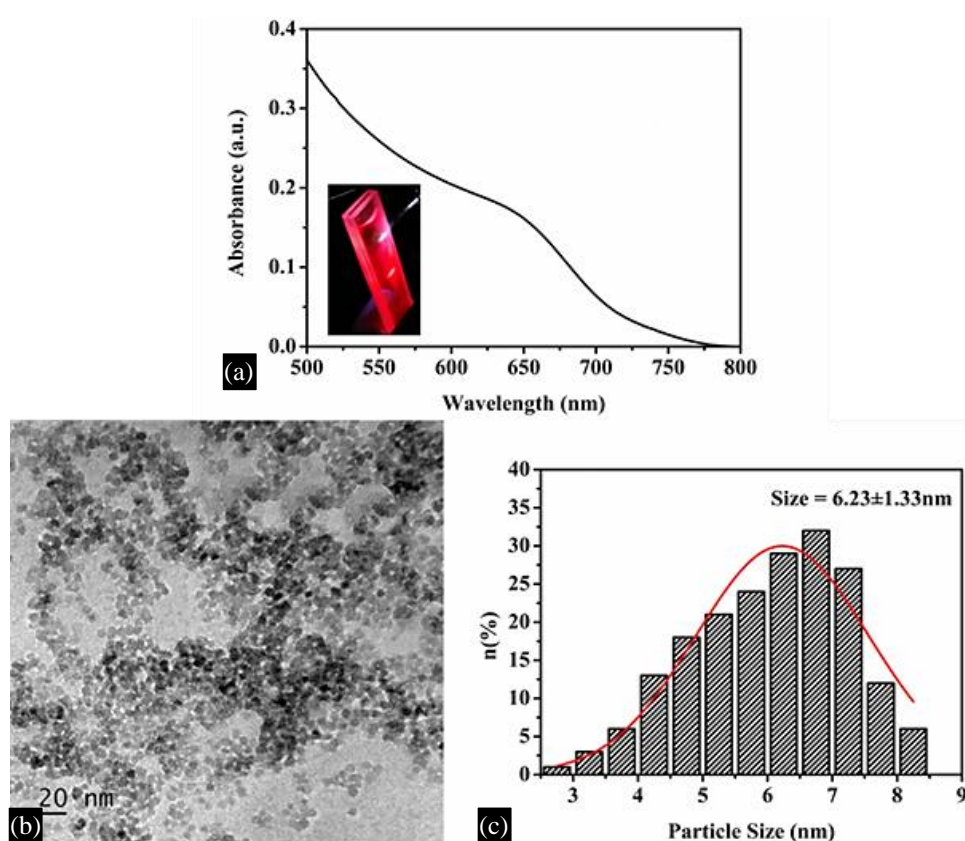


Figure 2. (a) Absorption spectra (b) TEM image and (c) particle size distribution.

Figure 3(a) shows the SAED (Selected Area Electron Diffraction) pattern of the sample. This diffraction pattern provides the Zinc blend crystalline orientation of CdTe QDs, which was again verified by the XRD spectrum shown in Fig.3(b). Both figures (3(a) and 3(b)) show the crystalline formation of CdTe QDs. The presence of the planes (111), (220), and (311) is evidence for the formation of the zinc blend crystal structure [3]. When discussing the nanoparticles, size determination is very important because it defines the confinement effect and coulombic interaction. For bulk, CdTe has a smaller direct band gap of 1.475 eV and a large exciton radius of 7.3nm compared with other II-VI group semiconductors [3]. Here we again measure the particle size using the DLS technique. Dynamic Light Scattering is a well-established technique for the size of nanoparticles in colloidal suspension. The basic principle behind DLS measurement involves the measurement of the Brownian motion of the particle in the medium and its relation to the particle size. The bombardment of the particles by the surrounding solvent molecules results in the random motion of the particles is known as Brownian motion. The velocity of Brownian motion (Brownian velocity) decreases with the increase in the size of the particles. By knowing the viscosity of the medium, the Brownian velocity can easily be found, from which the approximate size of the particles can be estimated. The particle size analyzed using the DLS technique is shown in Figure 3(c) and is consistent with the result obtained from TEM analysis. Using both TEM and DLS analysis estimated particle size is nearly around 6nm, so the synthesized CdTe QDs lie in the intermediate confinement region ($R \sim a_B$).

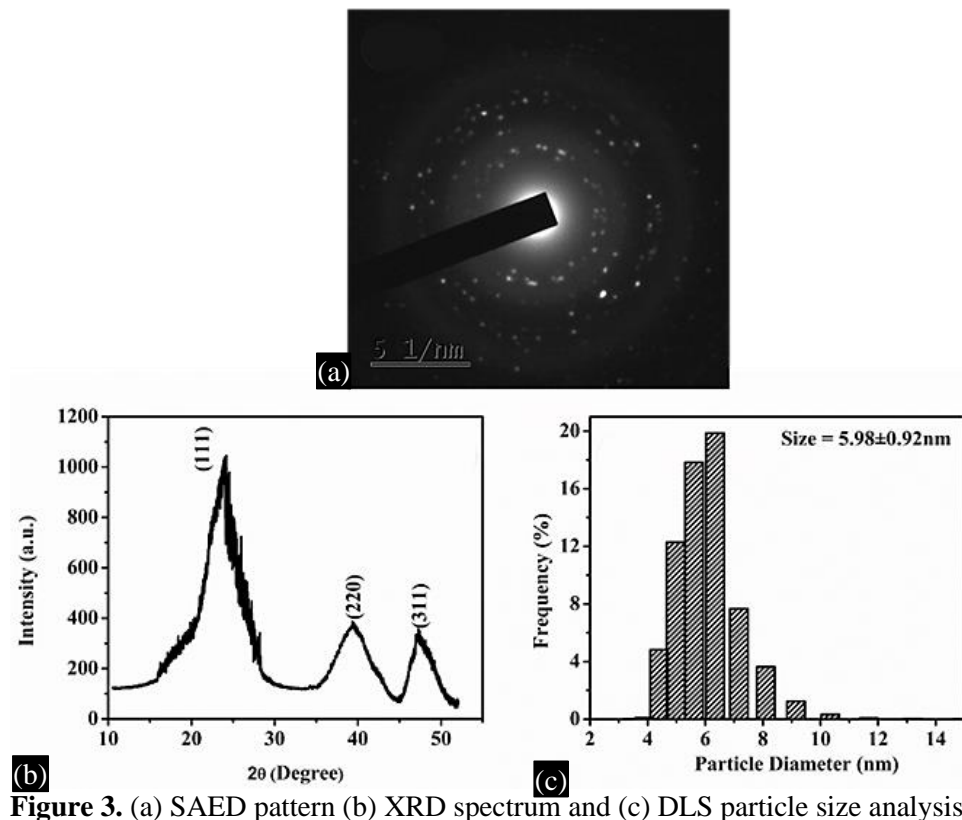


Figure 3. (a) SAED pattern (b) XRD spectrum and (c) DLS particle size analysis.

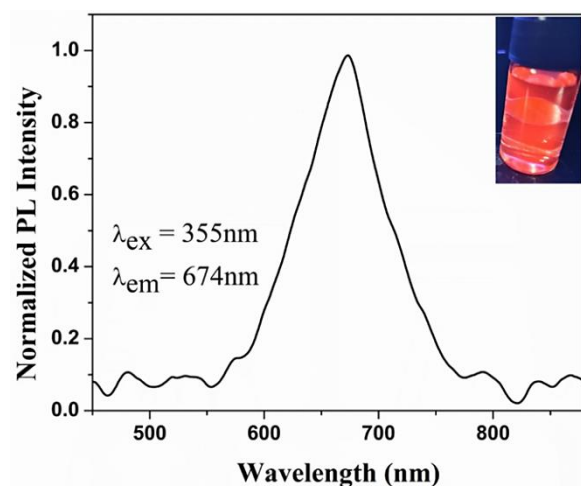


Figure 4. PL spectra and photographs of CdTe QD under UV illumination.

Photoluminescence spectra of the synthesized sample were also measured. When light incident on the material electrons are excited to higher energy levels and these excited electrons are deexcited to lower energy states and photons are emitted as a result. This process is called the photoluminescence. Figure 4 shows the normalized PL with a Gaussian emission peak centered at 672nm represented by the red color of emission with a quantum yield of 69% and the inset figure shows the photograph of the sample fluorescence taken under a UV lamp illumination. This obtained quantum yield is more sufficient for bioimaging applications. In the present work, the bioimaging ability of CdTe QDs was studied in N2A cells. These red emissive MSA-capped CdTe QDs are used for direct N2A cell imaging. Figure 5 shows the fluorescence image of N2A cells stained with MSA-capped CdTe QDs. Also, all N2A cells are stained red, which indicates the penetration of CdTe QDs. There is no sign of cell damage upon the treatment of MSA-capped CdTe QDs. Based on these results engineered red emissive CdTe

QDs are anticipated to be better and economical fluorescent probes for bioimaging.

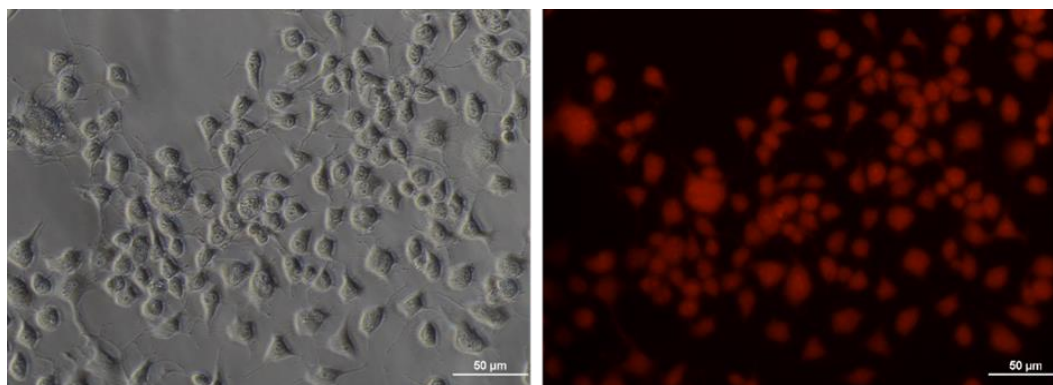


Figure 5. Fluorescence image of N2A cells stained with MSA-capped CdTe QDs.

CONCLUSIONS

In summary, aqueous phase MSA-capped red emissive water-soluble CdTe QDs are synthesized using the colloidal method. The UV-visible absorption spectra of aqueous CdTe QDs show prominent absorption at 640nm. TEM and XRD results show the formation of well-dispersed crystalline spherical-shaped CdTe QDs of zinc blend cubical structure with an average crystalline size of 6nm. The particle size of the QDs is again estimated using DLS analysis, which was in good agreement with the TEM result. The emission spectra show the peak maximum at 672nm and strong red emission with a quantum yield of 69%. These red emissive CdTe QDs are used for direct imaging of N2A cells. The fluorescence image showed clear visibility without any cell damage. From this, we concluded that water-soluble MSA-capped CdTe QDs are the most promising and economical fluorescent probes for bioimaging and sensing.

REFERENCES

1. Ken-Tye Yong, Wing-Cheung Law, Indrajit Roy, Zhu Jing, Huijie Huang, Mark T Swihart, and Paras N Prasad. Aqueous phase synthesis of CdTe quantum dots for biophotonics. *Journal of Biophotonics*.2011;4:9–20.
2. Stephen J. Byrne, Serena A.Corr, Tatsiana Y. Rakovich, Yurii K. Gunko, Yury P. Rakovich, John F. Donegan, Siobhan Mitchell and Yuri Volkov. Optimisation of the synthesis and modification of CdTe quantum dots for enhanced live cell imaging. *Journal of Materials Chemistry*. 2006;16: 2896–2902.
3. Vijayaraj Venkatachalam, Sasikakla Ganapathy, Thirunavukkarasu Subramani, Ilaiyaraja Perumal. Aqueous CdTe colloidal quantum dots for bio-imaging of Artemia sp. *Inorganic Chemistry Communications*. 2021; 128: 108510.
4. Anne S. Schulze, Isabella Tavernaro, Friederike Machka, Olga Dakischew, Katrin S. Lip, Mathias S. Wickleder. Tuning optical properties of water soluble CdTe quantum dots for biological applications. *J Nanopart Res*. 2017; 19:70.
5. S.Pandey, D.Mukherjee, P.Kshirsagar, C.Patra, D.Bodas. Multiplexed bio-imaging using cadmium telluride quantum dots synthesized by mathematically derived process parameters in a continuous flow active microreactor. *Materials Today Bio*. 2021; 11: 100123.
6. Pandey S, Mukherjee D, Kshirsagar P, Patra C, Bodas D. Multiplexed bio-imaging using cadmium telluride quantum dots synthesized by mathematically derived process parameters in a continuous flow active microreactor. *MaterialsToday Bio*.2021; 11 :100123.
7. Jin S, Hu Y, Gu Z, Liu L, Wu H . Application of Quantum Dots in Biological Imaging. *Journal of Nanomaterials*.2011; 1:834139.
8. Chen X, Guo Z , Miao P. One-pot synthesis of GSH- Capped CdTe quantum dots with excellent biocompatibility for direct cell imaging. *Heliyon*. 2018; 4(3): e00576.

9. Venkatachalam V, Ganapathy S, Subramani T. Aqueous CdTe colloidal quantum dots for bio-imaging of Artemia. *Inorganic Chemical Communication*.2021;128: 108510.
10. Ritu. Structural and optical characterization of Sm³⁺ ions and CdTe crystallites doped in silica matrices using sol-gel method. *RP Currents Trends In Engineering and Technology*. 2022; 1:54–56.
11. Nideep T K, Ramya M, Sony U, Kailasnath M. MSA capped CdTe quantum dots for pH sensing application. *Material Research Express*.2019; 6 :1–9p.
12. Ding Zhou, Min Lin, Zhaolai Chen, Haizhu Sun, Hao Zhang , Hangchen Sun & Bai Yang. Simple synthesis of highly luminescent water-soluble CdTe quantum dots with controllable surface functionality.*Chemistry of Materials*.2011;23: 21,4857–4862p.
13. Sander F Wuister, Ingmar Swart, Floris Van Driel, Stephan G Huckey, Celso de Mello Donega. Highly luminescent water-soluble CdTe quantum dots. *Nano Letters*. 2003; 3:4,503–507p.
14. P F GM da costa, L G Merizio, N Wolff, H Terrascke, Ass de Camargo. Real time monitoring of CdTe quantum dots growth in aqueous solution. *Scientific reports*.2024; 14:7884.
15. Yu, W. W., Chang, E., Drezek, R., & Colvin, V. L. Water-soluble quantum dots for biomedical applications. *Biochemical and Biophysical Research Communications*.2006; 348(3): 781–786p.
16. Nideep T K, Ramya M, Kailasnath M. Amplified spontaneous emission from MSA capped CdTe QD synthesized using colloidal method. *AIP Conference Proceedings*.2020; 2244:1–5p.