Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy xxx (xxxx) xxx

Contents lists available at ScienceDirect

Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy

journal homepage: www.elsevier.com/locate/saa

Surface functionalized quantum dots as biosensor for highly selective and sensitive detection of ppb level of propafenone

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ARTICLE INFO

Article history:
Received 27 June 2019
Received in revised form
22 October 2019
Accepted 24 October 2019
Available online xxx

Keywords:
CdTe quantum dots
Propafenone
Ion-association complex
Resonance Rayleigh scattering

ABSTRACT

Monodispersed CdTe quantum dots (QDs) were prepared by using thioglycolic acid as surfactants in aqueous solution. The thioglycolic acid was chemically adsorbed on the surface of CdTe QDs that enables the QDs positively charged. In week acidic media, propafenone is positively charged, which can combine with the CdTe QDs to form larger ion-association complex via electrostatic attraction and hydrogen bond. Moreover, the formed ion-association complex could increase the intensity of resonance Rayleigh scattering (RRS), second-order scattering (SOS) and frequency doubling-scattering (FDS) of CdTe QDs, and quench the CdTe QDs fluorescence. Importantly, under optimal experimental conditions, the increased RRS, SOS and FDS intensity, and quenched fluorescence intensity of CdTe QDs were in direct proportion to the propafenone concentration in a certain range, respectively. Among them, the RRS method exhibited the highest sensitivity. In a wide concentration range of propafenone from 0.003 to 7.0 μg mL^{-1}, the detection limit could reach 0.96 ng mL^{-1}, which was much lower than previously reported methods. To simulate practical applications, the possible foreign interfering substances were also investigated, such as common ions, amino acid, and glucide. The proposed method here is rapid, sensitive and shows promising application for detection of ppb level of propafenone in human serum.

1. Introduction

Quantum dots (QDs) have been widely used in applications of optical devices, medical diagnosis, and lasers, *etc.*, especially served as fluorescent probes in the bioanalysis field [1–4]. Quantum dots are characterized by size effect, adjustable particle size, single absorption, multiple emissions and wide range of emission wavelength. Therefore, a series of QDs based fluorescent probes with different emission wavelengths and colors can be obtained by single excitation [5]. Importantly, the fluorescence quantum efficiency of QDs is very high, which is generally 1000 times higher than that of traditional organic dyes [6]. Thus, the target molecules can be easily detected by using QDs as fluorescent probes, even very low concentrations of target molecules. As a result, the detection limit is significantly reduced, and the detection sensitivity is significantly improved. In addition, QDs possess high photochemical stability, strong anti-photobleaching ability, and fluorescence resistance to quenching, *etc.*, which are also widely used for protein and DNA detection, cell labeling imaging, tracking of living cell life dynamic process, and targeted tracking of tumor cells in living animals [7].

Up to now, the most studied QDs are mainly CdS, CdSe, CdTe, *etc.*, because of their wide band gap, which enable them excellent fluorescence characteristics. With the continuous improvement of the preparation and surface modification methods of QDs, the research on the detection of small drug molecules using QDs serving as molecular probes has also been developed rapidly [8,9]. QDs as fluorescent probes have exhibited high sensitivity and great advantages in the detection of trace drugs. For examples, Liang et al. used CdSe QDs to determine the content of spironolactone in tablets [10]. The change of fluorescence intensity of CdSe QDs was

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https://doi.org/10.1016/j.saa.2019.117709
1386-1425/

linear with the concentration of spironolactone in the range of 6.0–1680 μM, and the detection limit was 0.48 μM. Spironolactone contains a hydrophilic thiol group, and when a hydrophilic thiol replaces the organic amine ligand on the surface of the CdSe QDs, it causes fluorescence quenching of the QDs. Ding et al. used the red fluorescent QDs coupled with goat anti-mouse secondary antibody to detect the content of enrofloxacin in chicken muscle tissue, in which the surface-modified QDs interacted with enrofloxacin to indirectly emit competitive fluorescence. The detection range is 1–100 ng mL^{-1}, and the detection limit is 2.5 ng mL^{-1}. This method is more sensitive and rapid than HPLC and LC-MS [11]. The application prospect of QDs in the field of drug content determination is worth expecting.

Propafenone is widely used in treating illnesses about the rapid heart beating such as atrial and ventricular arrhythmias [12,13]. Various methods for determination of propafenone have been reported, such as spectrophotometry [14,15], HPLC [16], exchange column chromatography [17] and liquid chromatography-mass spectrometry [18]. In which, spectrophotometry, typically ultraviolet–visible (UV–Vis) spectrophotometry [19,20], has been widely used because of its advantages of simple operation, rapid operation and cheap instrument. However, the present detection methods are complex, time-consuming, low sensitivity or poor specificity, making it difficult to quickly detect. Therefore, a simple and rapid detect sensor is urgently needed for the detection of propafenone with high sensitivity and specificity.

Herein, *for the first time*, we attempt to construct a more simple and sensitive method for detecting a trace amount of propafenone by using hydrophilic CdTe QDs as molecular probes. In the weak acid, propafenone could combine with the thioglycolic acid-modified CdTe QDs via electrostatic attraction and hydrogen bond. The interaction of CdTe QDs with propafenone was systematically studied by a series of spectral characterization, including fluorescence, UV–Vis absorption, RRS, spectra, etc. With the RRS method, ppb (ng mL^{-1}) levels of propafenone in serum samples can be detected in less than 30 min. The detection limit of propafenone here is 0.96 ng mL^{-1} for buffer solution. The reaction mechanism was also studied. From the Stern-Volmer plots, we believe the fluorescence quenching type of CdTe QDs-propafenone system is a static quench.

2. Experimental procedure

2.1. Chemicals

$CdCl_2 \cdot 2.5H_2O$ (Shanghai Chemicals Reagent Co., Shanghai), tellurium powder (Te, Sinopharm Chemical Reagent Co., Shanghai), thioglycolic acid (Sinopharm Chemical Reagent Co., Shanghai), $NaBH_4$ (Tianjin Huanwei Fine Chemical Co., Tianjin) were used as received without further purification. Britton-Robinson (BR) buffer solutions with different pH were prepared and adjusted pH values by a pH meter.

2.2. Synthesis of CdTe QDs

The CdTe QDs were synthesized according to previously reported methods with slight modification [21,22]. Typically, under N_2 atmosphere, 0.0383 g Te powder was added to a 50 mL three-neck flask containing 5 mL deionized water at room temperature. Then, excessive sodium borohydride was added under magnetic stirring, and the colorless NaHTe solution was obtained. Meanwhile, 0.0694 g $CdCl_2 \cdot 2.5H_2O$ and 0.05 mL thioglycolic acid was added into a three-necked flask containing 150 mL deionized water under stirring, and the pH was adjusted to 9.0 by dropwise addition of 1 mol L^{-1} NaOH solution. The solution was degassed by N_2 bubbling for about 30 min to remove oxygen. After that, a 0.5 mol L^{-1} H_2SO_4 solution was introduced into the as-prepared NaHTe solution to produce H_2Te gas, which was passed through the cadmium precursor with a slow N_2 flow for 30 min. The resulting mixture was then heated to 368 K at reflux with a condenser under open-air conditions for 2 h. Finally, the green-emitting CdTe QDs were obtained. The molar ratio of Cd^{2+}/TGA/HTe^- was fixed at 10.5:2.5:.

1.0 mL above as-prepared CdTe QDs solution, buffer solution and an appropriate amount of propafenone were added into a 10 mL volumetric flask, diluted with deionized water to the mark and mixed thoroughly with a gentle shake. After incubation for 30 min, the optical spectra of the solution were examined. The RRS spectra were recorded with synchronous scanning at $\lambda_{ex} = \lambda_{em}$. The SOS and FDS spectra were recorded by scanning at $\lambda_{ex} = 1/2\lambda_{em}$ and $\lambda_{ex} = 2\lambda_{em}$, respectively.

2.3. Characterizations

The fluorescence, RRS, FDS, and SOS spectra were carried out on a Hitachi F-2500 spectrofluorophotometer (Hitachi Company, Japan). The UV–Vis spectra were recorded on a UV-8500 spectrophotometer (Tianmei Corporation, Shanghai). TEM characterization was performed with H-7500 transmission electron microscope (Hitachi Company, Japan) operated at 200 kV. The pH was adjusted by a PHS-3C pH meter (Leici, Shanghai).

3. Results and discussion

3.1. TEM images of CdTe QDs and propafenone coupled CdTe QDs

To expand the application of QDs in the analysis field, the water-solubility of QDs is particularly important. In our experiments, we applied a solution-phase method to prepare the CdTe QDs, this method possesses various advantages, such as convenient raw material sources, mild experimental conditions, simple method, green and cheap. The TEM image (Fig. 1a) displays that the synthesized CdTe QDs possess good dispersity in water solution, and size is about 3.5 nm (Fig. 1b). During the synthesis process, thioglycolic acid was used as stabilizing reagents, which can chemically be adsorbed on the surface of CdTe QDs. Due to the surface-adsorbed ligands of thioglycolic acid-containing functional groups of carboxylic acid, so the prepared CdTe QDs have very good water-solubility and can be directly linked to molecules by electrostatic adsorption or covalent coupling. After added propafenone solution, the size of CdTe QDs became larger (Fig. 1c and d, 11.5 ± 0.1 nm), indicating that the propafenone can react with surface coated thioglycolic acid of CdTe QDs. The successful coupled between propafenone and thioglycolic acid provides potential detection of propafenone by using optical properties of CdTe QDs.

3.2. Fluorescence spectra of CdTe QDs-propafenone system

Fig. 2a displays the fluorescence spectra of the CdTe QDs-propafenone system. As shown in Fig. 2a, the synthesized thioglycolic acid-modified CdTe QDs have narrow and symmetrical peaks, and the maximum emission wavelength was located at 560 nm under the excitation of 350 nm. The fluorescence of CdTe QDs was obviously quenched with the increase of propafenone concentration. Moreover, the fluorescence quenched intensity possesses a good linear relationship with the propafenone concentration (Fig. 2b). The linear equation was $\Delta F = 413.57c - 264.3$ (c, μg·mL^{-1}), linear range was 0.026–7.00 μg mL^{-1}, correlation coefficient was 0.9975, detection limit was 7.92 ng·mL^{-1}. Furthermore, by careful examination of the fluorescence spectra, it is found that the fluorescence peaks of CdTe QDs presented a little red shift, indicating the particle size of the CdTe QDs become larger by

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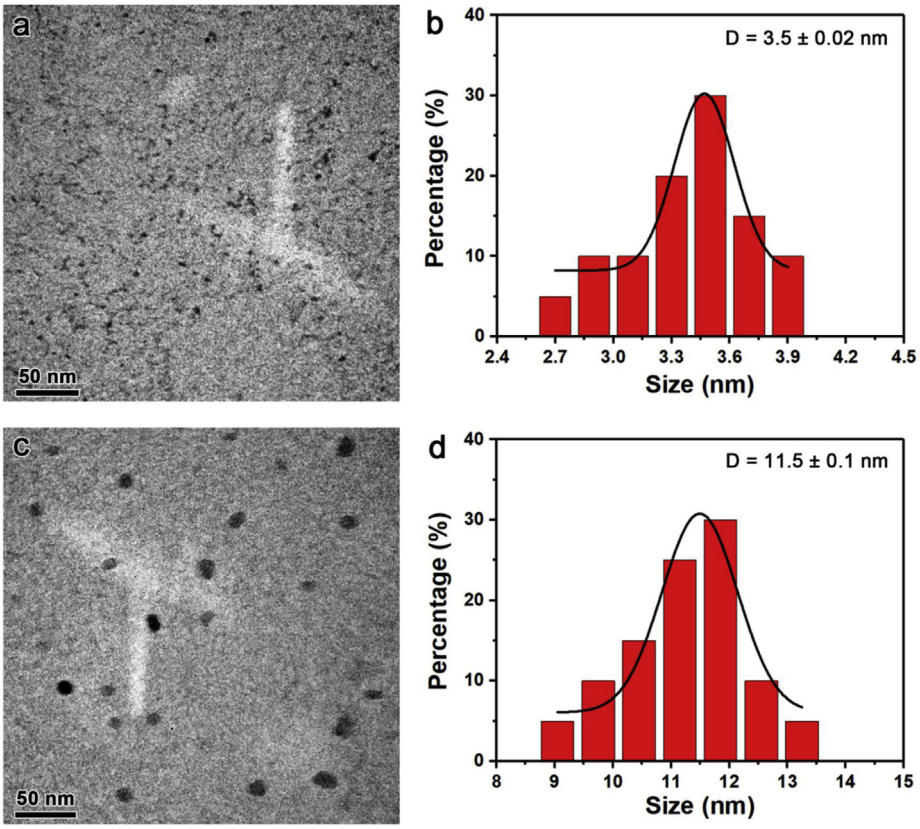

Fig. 1. TEM images of (a) CdTe QDs and (c) presence of propafenone. (b,d) Statistical analysis of the size of CdTe QDs measured by TEM images in (a,c), respectively. In (b,d) 3.5 nm and 11.5 nm are the mean size, 0.02 nm and 0.1 nm are the standard deviation, respectively.

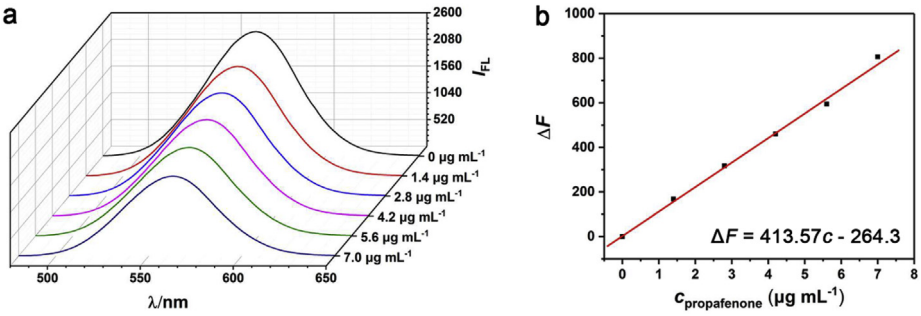

Fig. 2. (a) Fluorescence spectra of CdTe QDs-propafenone system ($\lambda_{ex}/\lambda_{em}$ = 350/560 nm). Propafenone concentration (μg·mL^{-1}): 0, 1.4, 2.8, 4.2, 5.6 and 7.0, respectively. CdTe QDs concentration: 2×10^{-4} mol L^{-1}. (b) Linear relationship between the variation of fluorescence intensity and propafenone concentration in CdTe QDs-propafenone system at a wavelength of 560 nm.

adding propafenone [23], which was consistent with the TEM images (Fig. 1a,c). It also demonstrated that the propafenone was successfully connected to the surface of thioglycolic acid-modified CdTe QDs.

3.3. RRS spectra of CdTe QDs-propafenone system

RRS is a special kind of elastic scattering when the wavelength of Rayleigh scattering is in or near its molecular absorption band. Due to the high sensitivity, simplicity, and rapidity, the RRS method has gained increasing interest in the fundamental studies. The RRS spectra of CdTe QDs, propafenone and CdTe QDs-propafenone system are shown in Fig. 3a. Both the CdTe QDs and propafenone exhibited weak RRS intensity. However, when they reacted with each other to form the ion-association complex, a new maximum scattering RRS peak appeared at ~341 nm. As propafenone concentration increases, the RRS intensity of the CdTe QDs-propafenone system was gradually enhanced and the enhanced degree exhibited a good linear relationship with propafenone concentration (Fig. 3b). The linear equation was $\Delta I_{RRS} = 227.06c + 10.23$ (c, μg·mL^{-1}), the linear range was 0.003–7.00 μg·mL^{-1}, the correlation coefficient was 0.9987, and the detection limit was 0.96 ng·mL^{-1}.

3.4. FDS and SOS spectra of CdTe QDs-propafenone system

The FDS spectra of CdTe QDs-propafenone system are shown in Fig. 4a. The FDS intensity of CdTe QDs is very weak, and the maximum peak of CdTe QDs is located at 398 nm by using 790 nm as the maximum excitation peak. When propafenone reacted with

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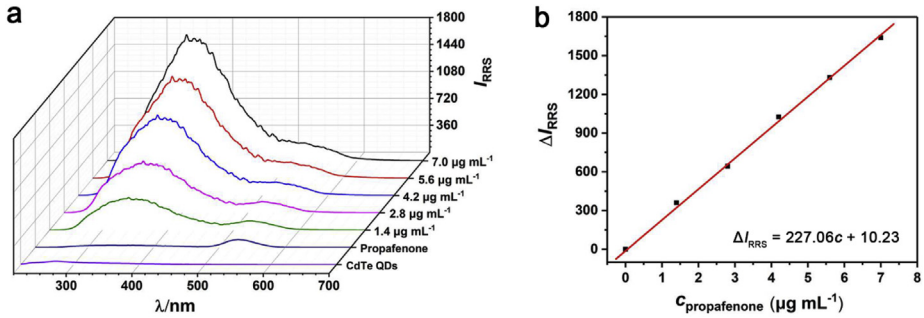

Fig. 3. (a) RRS spectra of CdTe QDs-propafenone system. Propafenone concentration (μg·mL^{-1}): 1.4, 2.8, 4.2, 5.6 and 7.0, respectively. CdTe QDs concentration: 2×10^{-4} mol L^{-1}. (b) Linear relationship between the variation of RRS intensity and propafenone concentration in CdTe QDs-propafenone system at a wavelength of 341 nm.

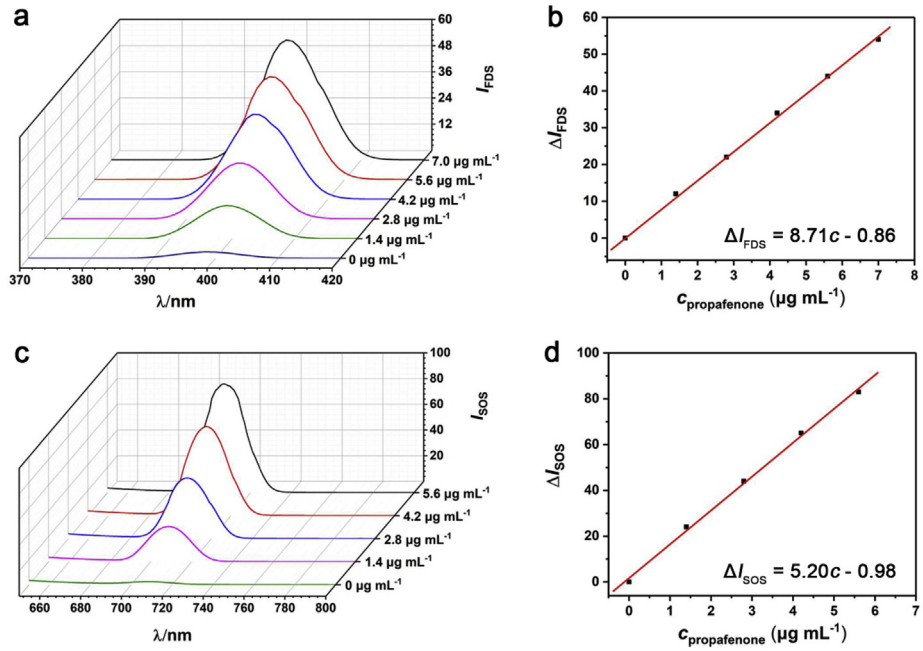

Fig. 4. (a) FDS spectra of CdTe QDs-propafenone system ($\lambda_{ex}/\lambda_{em}$ = 790/398 nm). Propafenone concentration (μg·mL^{-1}): 0, 1.4, 2.8, 4.2, 5.6 and 7.0, respectively. (b) Linear relationship between the variation of FDS intensity and propafenone concentration in CdTe QDs-propafenone system at a wavelength of 398 nm. (c) SOS spectra of CdTe QDs-propafenone system ($\lambda_{ex}/\lambda_{em}$ = 350/707 nm). Propafenone concentration (μg·mL^{-1}): 0, 1.4, 2.8, 4.2 and 5.6, respectively. (d) Linear relationship between the variation of SOS intensity and propafenone concentration in CdTe QDs-propafenone system at a wavelength of 707 nm. CdTe QDs concentration: 2×10^{-4} mol L^{-1}.

CdTe QDs, the FDS intensity was significantly enhanced and the FDS enhancement was in direct proportion to the propafenone concentration from 0.081 μg·mL^{-1} to 7.00 μg·mL^{-1} (Fig. 4b). The linear equation was $\Delta I_{FDS} = 8.71c$-0.86 (c, μg·mL^{-1}), the correlation coefficient was 0.9980, and the detection limit was 24.30 ng·mL^{-1}. Fig. 4c displays the SOS spectra of the CdTe QDs-propafenone system. When the propafenone was added to the CdTe QDs solution, the SOS intensity of the solution was also enhanced and SOS enhancement was linearly related to the propafenone concentration in the range of 0.089–5.60 μg·mL^{-1} (Fig. 4d). The linear equation was $\Delta I_{SOS} = 5.20c$-0.98 (c, μg·mL^{-1}), the correlation coefficient was 0.9952, and the detection limit was 26.10 ng·mL^{-1}.

3.5. Comparison of methods

Under the optimal experimental conditions, the FL, RRS, FDS and SOS spectra of the CdTe QDs-propafenone system were measured to study the interaction between the CdTe QDs and propafenone. Meanwhile, the linear relationship between the variation of optical intensity and propafenone concentration was calculated. The standard curves of FL, RRS, FDS and SOS methods for detection of propafenone are summarized and listed in Table 1, including linear equations, correlation coefficients, linear ranges, and detection limits. In this, some new analytical methods were established for the determination of propafenone. By comparison, we found that the RRS method possessed a wider linear range and higher sensitivity than FL, FDS and SOS methods for detection of ppb level of propafenone.

4. Optimum reaction conditions

4.1. Effect of the acidity

The effect of acidity on the RRS intensity of the CdTe QDs-propafenone system was studied. In our experiments, BR buffer was used to control the pH value of the analytical system. Experimental results verified that the appropriate pH range of the CdTe QDs-propafenone system was 5.6–7.0. Below or above this pH range, the RRS intensity was significantly reduced. In this experiment, the pH 6.4 BR buffer solutions were used as the reaction

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Table 1
The standard curves of the CdTe QDs-propafenone system.

Method	Linear equation ($\mu g \cdot mL^{-1}$)	Correlation coefficient (r)	Detect limits ($ng \cdot mL^{-1}$)	Linear range ($\mu g \cdot mL^{-1}$)
FL	$\Delta F = 413.57c$-264.3	0.9975	7.92	0.026–7.00
RRS	$\Delta I = 227.06c$+10.23	0.9987	0.96	0.003–7.00
FDS	$\Delta I = 8.71c$-0.86	0.9980	24.30	0.081–7.00
SOS	$\Delta I = 5.20c$-0.98	0.9952	26.10	0.089–5.60

medium and the optimal dosage of the BR buffer solution was 0.5 mL.

4.2. Effect of CdTe QDs concentration

The effects of different concentrations of CdTe QDs on the RRS intensity of CdTe QDs-propafenone system were investigated. The experimental results confirmed that the suitable dose of the CdTe QDs-propafenone system was 1.0 mL. The insufficient or excessive amount of CdTe QDs will affect the RRS intensity. The optimized concentration of thioglycolic acid-modified CdTe QDs in this experiment was 2.0×10^{-4} mol L^{-1}.

4.3. Effect of ionic strength

The influence of ionic strength on the RRS intensity of the CdTe QDs-propafenone system was studied by adding 0.1 mol L^{-1} NaCl solution. As shown in Fig. 5, for the CdTe QDs-propafenone system, the intensity of RRS spectra showed a decreasing trend by the addition of NaCl solution, which results from the desorption of propafenone from the surface of thioglycolic acid-modified CdTe QDs. Therefore, it can be inferred that propafenone reacted with CdTe QDs by electrostatic attraction [24]. This also suggests that the quenching mode of propafenone to CdTe QDs is mainly static quenching.

4.4. Effect of incubation time

The interaction of CdTe QDs with propafenone was monitored at room temperature (~25 °C) at different time scales. After 30 min of the reaction, the interaction process reached equilibrium and remained stable for more than 1.5 h. Thus, in our study, the RRS spectra were tested after 30 min to ensure the complete interaction of CdTe QDs with propafenone.

5. Reaction mechanism of CdTe QDs-propafenone system

5.1. Fluorescence quenching mechanism

It is well known that fluorescence quenching can be generally divided into two different mechanisms, static quenching and dynamic quenching, which can be distinguished by the temperature-dependent difference in the lifetime of the excited states [25,26]. For dynamic quenching, the fluorescence substance collided with the quenching agent, resulting in decreased quantum yield and fluorescence intensity. The static quenching is caused by the formation of a non-fluorescent complex between fluorescent substance and quenching agent.

Both static and dynamic processes can be described by the Stern-Volmer of Eq. (1) [27–29]:

$$F_0 / F = 1 + K_q \tau_0 [Q] = 1 + K_{SV} [Q] \quad (1)$$

where F_0 and F are the fluorescence intensity of fluorescence substance in the absence and presence of quencher, respectively, K_q is the quenching rate constant, τ_0 is the lifetime. [Q] is the quencher concentration, and K_{sv} is the Stern-Volmer quenching constant. Within a certain concentration, the curve of F_0/F versus [Q] (Stern-Volmer curve) would be linear. In this study, K_{sv} can be calculated through the linear part of the Stern-Volmer curve. Fig. 6 displays the linear plots of the CdTe QDs-propafenone system at two different temperatures. The quenching constants K_{SV} of the reaction obtained from Fig. 6 are 2.32×10^4 (278 K) and 0.96×10^4 (291 K), respectively, which decreases as temperature increases. According to the quenching constant K_{SV} and the formula $K_{SV} = K_q \tau_0$, the bimolecular quenching constant K_q is between 0.96×10^{12} and 2.32×10^{12} L mol^{-1} s^{-1}, in which the average lifetime of molecular (τ_0) is 10^{-8} s. The obtained quenching constant K_q is much larger than the general diffusion quenching constant of 10^{10} L mol^{-1} s^{-1} [30]. Therefore, the quenching type of CdTe QDs-propafenone system is a static quench.

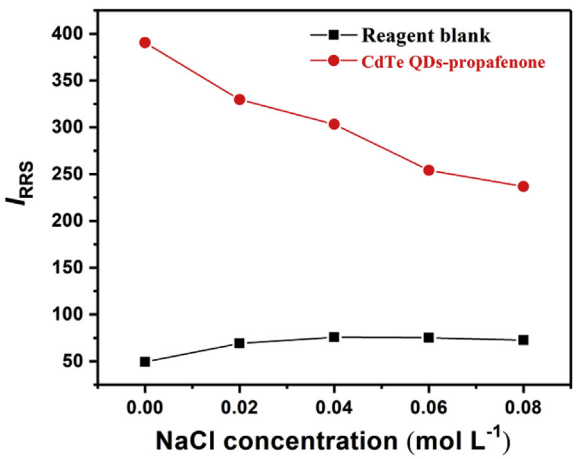

Fig. 5. Effect of ionic strength on CdTe QDs-propafenone system. Propafenone concentration: 2.8 μg mL^{-1}. CdTe QDs concentration: 2×10^{-4} mol L^{-1}.

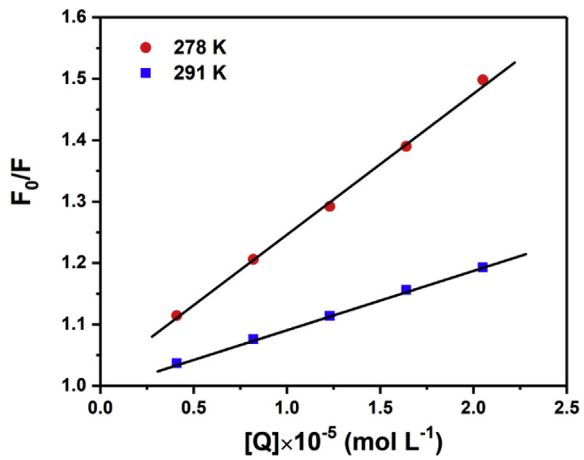

Fig. 6. Stern-Volmer plots of fluorescence quenching of CdTe QDs-propafenone system at two different temperatures. CdTe QDs concentration: 2×10^{-4} mol L^{-1}.

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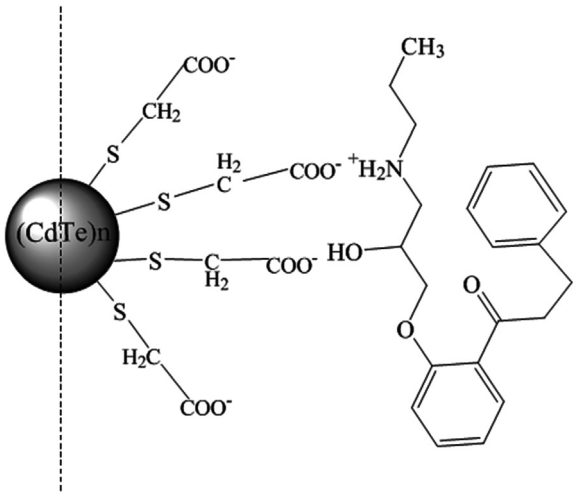

Fig. 7. Schematic diagram of the proposed connection mode between thioglycolic acid modified CdTe QDs and propafenone.

In acidic media, propafenone can combine with CdTe QDs through electrostatic attraction and hydrogen bond to form larger ionic association complexes, in which induced the fluorescence quenching of CdTe QDs and the RRS intensity increment of system. The possible connection model of CdTe QDs with propafenone was shown in Fig. 7. In which the electron transformation may occur on the surface of CdTe QDs via the interaction of CH_2COO^- (thioglycolic acid) with propafenone [31]. As known, for semiconductor nanocrystals, fluorescence occurs when electrons transfer from the excited state to the ground state. However, the existence of propafenone may hinder the electrons transition, leading to the fluorescence quenching of CdTe QDs.

5.2. Mechanism of RRS intensity enhancement

The possible reasons for the enhancement of RRS are discussed as bellows.

5.3. Resonance-enhanced Rayleigh scattering effect

When discussing the resonance-enhanced Rayleigh scattering effect, it is necessary to investigate the relationship between the resonance scattering spectrum and the absorption spectrum [32]. From Fig. 8, we can see that the RRS spectrum is in its absorption band. Thus, the intensity of resonance scattering can be significantly enhanced during the absorption of light and a re-scattering process.

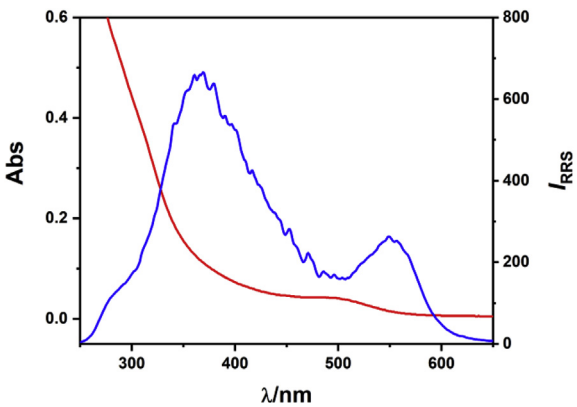

Fig. 8. UV–Vis absorption spectrum and RRS spectrum of CdTe QDs-propafenone system. CdTe QDs concentration: 2×10^{-4} mol L^{-1}, propafenone concentration: 2.8 μg mL^{-1}.

(2) Increase of particle size of CdTe QDs

For a molecule or material, other parameters are fixed, the larger size, the higher the RRS intensity. In weak acidic media, propafenone can combine with the CdTe QDs to form larger ion-association complexes, which has been proved by TEM images in Fig. 1a,c. This also can induce the RRS enhancement of the CdTe QDs-propafenone system.

5.4. Enhancement of hydrophobicity

For molecular propafenone, both benzene and ketone in its molecular structure are hydrophobic groups, which are not easily soluble in aqueous solution. Therefore, when propafenone is adsorbed on the surface of the CdTe QDs to form ion-association complexes, a hydrophobic interface will be formed between the complexes and the water. The formed hydrophobic interfaces also will increase RRS intensity.

6. Selectivity of RRS method and its analytical application

6.1. Effect of foreign substances

Under optimal experimental conditions, we studied the selectivity of the RRS method in the presence of a series of foreign substances, including amino acid, metal ions, albumin, etc. As the results in Table 2, the Zn^{2+}, Pb^{2+}, VB_{12}, pepsin, BSA, and HSA display much smaller tolerance, most of the common metal ions, glucose, and amino acids do not interfere with the detection of propafenone. Thus, the RRS method possesses good selectivity and can be used to detect the content of propafenone.

6.2. Analytical application

2.0 mL fresh serum sample (healthy) was thoroughly mixed with 20% trichloroacetic acid and centrifuged at 4500 rpm for

Table 2
Effect of coexistent substances for CdTe QDs-propafenone system ($c_{propafenone} = 4$ μg mL^{-1}).

Foreign substances	Concentration (μg·mL^{-1})	Change in I_{RRS} (%)	Foreign substances	Concentration (μg·mL^{-1})	Change in I_{RRS} (%)
glycin	2800	1.6	NH_4^+	400	1.5
tyrosine	840	8.0	K^+	480	4.0
histidine	2200	3.9	Na^+	400	2.8
VB_{12}	80	4.6	Zn^{2+}	60	1.7
pepsin	80	−2.2	Pb^{2+}	140	4.6
BSA	108	1.7	Cl^-	400	2.8
HSA	120	1.8	I^-	480	4.02
maltose	2800	−3.1	CH_3COO^-	280	4.6
glucose	1440	−7.1	NO_3^-	1460	5.4
lactose	1440	−5.7	SO_4^{2-}	200	1.7

Table 3
Results for the determination of serum samples.

Sample	Found/μg·mL^{-1}	Added/μg·mL^{-1}	Found (n = 5)/μg·mL^{-1}	Recovery/%	R.S.D./%
Serum1	ND	1.4	1.43	102.4	4.22
Serum2	ND	2.8	2.67	95.3	2.85
Serum3	ND	5.6	5.71	101.8	4.31

ND: not detected.

Please cite this article as: X. Wang et al., Surface functionalized quantum dots as biosensor for highly selective and sensitive detection of ppb level of propafenone, Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, https://doi.org/10.1016/j.saa.2019.117709

10 min. Then diluted 1.0 mL aliquot of the supernatant to 20.0 mL, and used to detect the content of propafenone. The relative standard deviation (R.S.D.) and recovery were measured by the standard addition method. As shown in Table 3, the values of propafenone found in the three serum samples were consistent with the expected values. Furthermore, the relative standard deviation (R.S.D.) was lower than 5%, indicating the precision of this method. And the recoveries over the range of 95.3−102.4% are acceptable. Thus, the RRS method can be used to detect propafenone in serum.

7. Conclusions

Thioglycolic acid-modified CdTe QDs with good dispersibility and uniform size were prepared in the aqueous solution. The interaction of CdTe QDs with propafenone was studied by UV−Vis absorption spectroscopy, fluorescence spectroscopy, RRS spectroscopy, FDS spectroscopy, and SOS spectroscopy. The reaction mechanism is discussed combined with fluorescence spectroscopy and RRS spectroscopy. In week acidic media, thioglycolic acid-modified CdTe QDs interact with propafenone mainly through electrostatic attraction and hydrogen bonding, resulting in sharp quenching of fluorescence and significant enhancement of RRS intensity. In a certain range, the propafenone concentration has a good linear relationship with the RRS intensity enhancement. Based on this, a new method for determining the ppb level of propafenone is proposed and then was applied to the determination of propafenone in serum samples. The experiment proved that this method is accurate, rapid and sensitive enough for determining propafenone at low ppb levels, and showed promising analysis application.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We gratefully acknowledge the financial support from the National Natural Science Foundation of China (NSFC, No. 21605125), Chongqing Municipal Key Laboratory on Luminescence and Real-Time Analysis, Southwest University (CSTC, 2006CA8006), the Project on Promotion of Innovation Ability of Colleges and Universities in Gansu Province (No. 2019A-260), and Key Laboratory of Shaanxi Province for Craniofacial Precision Medicine Research, College of Stomatology, Xi'an Jiaotong University (No.2018LHM-KFKT004).

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