#### **ORIGINAL ARTICLE**



# Coumarin Thiourea-Based Fluorescent Turn-on Hg<sup>2+</sup> Probe That Can Be Utilized in a Broad pH Range 1–11

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Received: 6 November 2019 / Accepted: 14 February 2020 © Springer Science+Business Media, LLC, part of Springer Nature 2020

#### Abstract

A novel coumarin-thiourea conjugate was synthesized facilely. It served as a fluorescent turn-on chemosensor for selective detection of  $Hg^{2+}$  ion over other common competitive metal ions including Li<sup>+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Ag<sup>+</sup>, Cu<sup>2+</sup>, Fe<sup>2+</sup>, Zn<sup>2+</sup>, Co<sup>2+</sup>, Ni<sup>2+</sup>, Mn<sup>2+</sup>, Sr<sup>2+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Al<sup>3+</sup>, Cr<sup>3+</sup> and Fe<sup>3+</sup> ions based on the  $Hg^{2+}$ -promoted desulfurization and cyclization reactions. Addition of  $Hg^{2+}$  ion to the sensor solution in 2:8 EtOH/H<sub>2</sub>O induced a hypsochromic shift of the UV–Vis absorption band from 360 nm to 340 nm accompanying distinct enhancement in the absorption intensity while addition of other metal ions failed to bring about substantial change in the absorption spectra. Addition of  $Hg^{2+}$  to the sensor solution also caused marked increase in the fluorescence emission intensity and most common competitive metal ions did not interfere with the selective sensing of  $Hg^{2+}$  ion by the sensor. The detection limit of  $Hg^{2+}$  ion by the probe was calculated to be  $1.46 \times 10^{-7}$  M and the probe could be utilized for selective detection of  $Hg^{2+}$  ion by fluorescence turn-on mode over a broad pH range of 1–11.

Keywords Coumarin · Fluorescent probe · Thiourea; Hg<sup>2+</sup>

# Introduction

It has been well addressed that mercury is one of the most toxic elements even at low concentrations and is not biodegradable. It may bring about serious health and safety problems to both human beings and environment [1]. Fast, highly selective and sensitive detection of mercuric ion in various kind of samples is of great significance in view of the diagnosis of diseases related to mercury poisoning and the monitoring of mercury pollution in environment. One of the optimal choices for convenient and selective detection of  $Hg^{2+}$  ion is

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the use of fluorescent probes. A vast number of  $Hg^{2+}$  ion fluorescent probes have been constructed in the last two decades from nanomaterials including quantum dots [2-5], boron-doped graphitic carbon nitride [6], tungsten disulfide nanosheets [7], noble metal nanoclusters (NCs) [8], and nanoparticles [9], or mostly from organic molecules by utilizing the specific reactivity of Hg<sup>2+</sup> including Hg<sup>2+</sup>-promoted deprotection reactions of dithioacetals [10-12], Hg<sup>2+</sup>-catalyzed devinylation reactions of vinyl ethers [13–15], oxymercuration reactions based on the alkynophilicity of Hg<sup>2+</sup> ion [16–18], Hg<sup>2+</sup>-induced (thiophilic) hydrolysis reactions [19-25], Hg<sup>2+</sup>-mediated desulfurization reactions of thione compounds [26-28], and complexation with various heteroatom ligands [29-43]. The majority of these fluorescent Hg<sup>2+</sup> ion probes can only be utilized in approximately neutral condition or a narrow pH range, not applicable in a broad pH range especially strongly acidic condition (pH < 2). In this respect Hg<sup>2+</sup>-promoted desulfurization and cyclization reactions of thiourea compounds have been envisaged as an effective protocol for construction of Hg<sup>2+</sup> fluorescent probes with relatively wide pH ranges, e.g. pH 6.84-9.37 [44], pH 5.81-9.04 [45], pH 6.5–9.0 [46], pH 4–11 [47], and pH 5.0–11.0 [48]. A coumarin-thiourea conjugate behaves as a fluorescent probe for Hg(II) with a broad pH range 2–12 [49]. However, the sensing of Hg<sup>2+</sup> is based on the Hg<sup>2+</sup>-promoted desulfurization of the

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probe, leading to a decrease in intramolecular charge transfer (ICT) character and resulting in fluorescence quenching which may be considerably influenced by multiple environmental factors like pH, medium polarity, temperature, and instrumental settings [50]. Following our recent endeavors to develop fluorescent chemosensors for selective and sensitive detection of metal ions [51–55], we synthesize a new coumarin thiourea derivative, which serves as a fluorescent turn-on probe for detection of Hg<sup>2+</sup> ion in aqueous solution with a broad pH range 1–11. Herein we present the study progress on the new coumarin thiourea-based fluorescent probe for Hg<sup>2+</sup> ion.

# Experimental

## **Chemicals and Reagents**

The chemicals, reagents and solvents used in this work were of analytical grade (99% purity) and were purchased from Sinopharm Chemical Reagent Co., Ltd. They were used without further purification unless otherwise addressed. Water for experiments was deionized prior to use. Stock solutions of metal ions were prepared from the salts LiCl, NaNO<sub>3</sub>, KNO<sub>3</sub>, AgNO<sub>3</sub>, Cu(NO<sub>3</sub>)<sub>2</sub>, Fe(SO<sub>4</sub>)<sub>2</sub>·7H<sub>2</sub>O, Zn(NO<sub>3</sub>)<sub>2</sub>, CoCl<sub>2</sub>·6H<sub>2</sub>O, NiCl<sub>2</sub>·6H<sub>2</sub>O, MnSO<sub>4</sub>, SrCl<sub>2</sub>·6H<sub>2</sub>O, Hg(OAc)<sub>2</sub>, CaCl<sub>2</sub>, MgCl<sub>2</sub>, Al(NO<sub>3</sub>)<sub>3</sub>·9H<sub>2</sub>O, CrCl<sub>3</sub>·6H<sub>2</sub>O and Fe(NO<sub>3</sub>)<sub>3</sub>·9H<sub>2</sub>O.

#### **Instruments and Measurements**

<sup>1</sup>H NMR and <sup>13</sup>C NMR spectra were measured on Bruker ACF-500 spectrometer by using TMS as an internal standard. IR spectra (KBr pellet) were recorded on Bruker Tensor 27 spectrophotometer. Mass spectra were measured on a MS Agilent 1100 Series LC/MSD Trap mass spectrometer (ESI-MS). UV-Vis spectra were measured on a Shimadzu UV-1800 spectrophotometer with a specification of 190-1100 nm. Fluorescence spectra were measured on a FS5 fluorescence spectrophotometer from Edinburgh Instruments Ltd. The stock solution of probe **D** (20  $\mu$ M) was prepared by dissolving probe **D** in ethanol. The stock solution of metal ions was prepared by dissolving the corresponding metal salts in deionized water. The measurements of fluorescence spectra were carried out at an excitation wavelength of 332 nm without use of the polarizer and magic angle conditions with the quartz cuvettes thickness being 1 cm. The emission spectra were recorded in a range of 350-650 nm and the slit width was 8 nm.

#### Synthesis and Characterization of Probe D

The novel coumarin thiourea-derived probe **D** was synthesized as showed in Scheme 1. Compound **2** (3-amino-7-

hydroxycoumarin) was obtained by a two-step synthetic protocol consisting of condensation and hydrolysis reaction with acetylaminoacetic acid and 2,4dihydroxybenzaldehyde as the raw materials. Further reaction between compound **2** and cyanic methacrylic thioanhydride formed from potassium thiocyanate and methacrylic chloride afforded probe **D** in 88% yield. The chemical structure of probe **D** was fully characterized by <sup>1</sup>H NMR (Fig. S1), <sup>13</sup>C NMR (Fig. S2), FT-IR spectrum (Fig. S3), and mass spectrum (Fig. S4). The data in the spectra were in good accordance with the structure.

The detailed synthetic procedure of probe **D** was as follows: 3-acetylamino-7-acetyloxycoumarin (compound 1) was prepared by the condensation reaction between 2,4dihydroxybenzaldehyde and acetylaminoacetic acid in acetic anhydride according to the procedure reported in literature [52]. Yellowish solid of compound 1 was obtained in 32% yield. Mp 230-231 °C (lit. Value: 234-236 °C [56]). To a three-neck flask were added compound 1 (2.63 g, 10 mmol), ethanol (13 mL) and concentrated hydrochloric acid (26 mL). The mixture was heated to 80 °C and stirred for 2 h. The reaction mixture was poured into ice water (200 mL) and 30% NaOH was added to adjust the solution to neutral. A large amount of brown solid precipitated and was obtained by filtration. After drying under reduced pressure, the solid was recrystallized with anhydrous ethanol to afford 1.41 g of 3-amino-7-hydroxycoumarin (compound 2) as brown powder in 80% yield. Mp 238-240 °C (lit. Value: 237-238 °C [56]). <sup>1</sup>H NMR (400 MHz, DMSO-d<sub>6</sub>): δ 5.26 (s, 2H, NH<sub>2</sub>), 6.68– 6.70 (m, 3H), 7.24 (d, J = 8.4 Hz, 1H), 9.85 (s, 1H, OH). Potassium thiocyanate (0.39 g, 4 mmol) and acetone (20 mL) were added to a flask and was then heated to 60 °C. After stirring for about 10 min methacrylic chloride (0.21 g, 2 mmol) was added and the mixture was stirred for 2 h. The color of the solution gradually changed from milky white to pale yellow. Then solution of compound 2 (0.089 g, 0.5 mmol) in acetone (10 mL) was added and the reaction was monitored by thin layer chromatography (TLC). The reaction completed in 6 h and the mixture was allowed to cool to 25 °C. After filtration the filtrate was concentrated and the residue was recrystallized with DMF/H<sub>2</sub>O (1:3, v/v) to give yellowish solids which was further purified by column chromatography with petroleum ether/ethyl acetate (5:1, v/v) as eluent. The target probe **D** was obtained as yellowish powder (0.134 g)in 88% yield. Mp 216-218 °C. <sup>1</sup>H NMR (400 MHz, DMSOd<sub>6</sub>): δ 1.95 (s, 3H, CH<sub>3</sub>), 5.74 (s, 1H, C=CH<sub>2</sub>), 6.03 (s, 1H, C=CH<sub>2</sub>), 6.90–6.66 (m, 2H), 7.58 (d, J = 8.3 Hz, 1H), 9.40 (s, 1H), 10.59 (s, 1H, OH), 11.27 (s, 1H, NH), 13.11 (s, 1H, NH). <sup>13</sup>C NMR (101 MHz, DMSO-d<sub>6</sub>): δ 18.56 (CH<sub>3</sub>), 102.63, 111.07, 114.35, 121.54, 125.33, 128.57, 130.25, 137.91, 152.52, 158.76, 161.02 (C=O), 169.84 (C=S), 177.85 (C=O). IR (KBr): v 3302.57, 1709.44, 1599.26, 1522.26, 1339.50, 1180.05, 1104.96 cm<sup>-1</sup>. MS: m/z 305 (M<sup>+</sup> + 1).

Scheme 1 Synthetic route to probe D



# **Results and Discussion**

### Sensing Behavior of Probe D

Probe **D** is not soluble in pure water and thus UV–Vis spectra of **D** in mixed solvent consisting of ethanol and water with different volume ratio (EtOH/H<sub>2</sub>O = 9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, 2:8, 1:9) were measured and showed in Fig. 1. Solution of probe **D** showed the maximum absorption band at around 360 nm. The absorption intensity did not change substantially with variation in EtOH/H2O ratio unless in 1:9 EtOH/H<sub>2</sub>O the absorption intensity decreased to a half. Fluorescence spectra of probe **D** in mixed solvent EtOH/H<sub>2</sub>O (9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, 2:8, 1:9, v/v) were showed in Fig. 2. The maximum fluorescence emission appeared at 420 nm in 9:1 EtOH/H2O and shifted to 470 nm with the increase in water ratio to  $EtOH/H_2O = 8:2$ . Further increase in water ratio led to larger shift to about 475 nm and the maximum emission intensity appeared when the medium was  $EtOH/H_2O = 2:8$ . Therefore the following sensing test experiments were carried out in EtOH/H2O (2:8) medium.

UV–Vis spectra of probe D solution (20  $\mu$ M in 2:8 EtOH/H<sub>2</sub>O) before and after addition of different metal



**Fig. 1** UV–Vis spectra of probe **D** solution (20  $\mu$ M) in different media (EtOH/H<sub>2</sub>O = 9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, 2:8, 1:9,  $\nu/\nu$ )

ions (Li<sup>+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Ag<sup>+</sup>, Cu<sup>2+</sup>, Fe<sup>2+</sup>, Zn<sup>2+</sup>, Co<sup>2+</sup>, Ni<sup>2+</sup>, Mn<sup>2+</sup>, Sr<sup>2+</sup>, Hg<sup>2+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Al<sup>3+</sup>, Cr<sup>3+</sup> and Fe<sup>3+</sup>) were measured and showed in Fig. 3. It was visible that addition of Hg<sup>2+</sup> ion induced hypsochromic shift of the absorption band from 360 nm to 340 nm accompanying distinct enhancement in the absorption intensity. Addition of other metal ions did not cause substantial change in the absorption band at 360 nm. Fluorescence emission spectra of probe **D** solution (20 µM in 2:8 EtOH/H<sub>2</sub>O) before and after addition of different metal ions (Li<sup>+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Ag<sup>+</sup>, Cu<sup>2+</sup>, Fe<sup>2+</sup>, Zn<sup>2+</sup>, Co<sup>2+</sup>, Ni<sup>2+</sup>, Mn<sup>2+</sup>, Sr<sup>2+</sup>, Hg<sup>2+</sup>, Ca<sup>2+</sup>,  $Mg^{2+}$ ,  $Al^{3+}$ ,  $Cr^{3+}$  and  $Fe^{3+}$ ) were measured at an excitation wavelength of 332 nm as showed in Fig. 4. Addition of Hg<sup>2+</sup> ion induced enhancement in the intensity of the fluorescence emission band at 475 nm by 6 fold. Addition of Ag<sup>+</sup> and Cu<sup>2+</sup> ion also caused enhancement in the intensity of the fluorescence emission band at 475 nm by 2 and 1 fold, respectively. Addition of other metal ions (Li<sup>+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Fe<sup>2+</sup>, Zn<sup>2+</sup>, Co<sup>2+</sup>, Ni<sup>2+</sup>, Mn<sup>2+</sup>, Sr<sup>2+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Al<sup>3+</sup>,  $Cr^{3+}$  and  $Fe^{3+}$ ) to probe **D** did not bring about substantial change in the fluorescence emission spectra. Thus D can be used as a fluorescence turn-on sensor for selective detection of  $Hg^{2+}$  ion.



**Fig. 2** Fluorescence emission spectra of probe **D** solution (20  $\mu$ M) in different media (EtOH/H<sub>2</sub>O = 9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, 2:8, 1:9, v/v) excited at 332 nm



Fig. 3 UV–Vis spectra of probe **D** solution (20  $\mu$ M in 2:8 EtOH/H<sub>2</sub>O) before and after addition of different metal ions (Li<sup>+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Ag<sup>+</sup>, Cu<sup>2+</sup>, Fe<sup>2+</sup>, Zn<sup>2+</sup>, Co<sup>2+</sup>, Ni<sup>2+</sup>, Mn<sup>2+</sup>, Sr<sup>2+</sup>, Hg<sup>2+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Al<sup>3+</sup>, Cr<sup>3+</sup> and Fe<sup>3+</sup>, 20  $\mu$ M) in Tris-HCl buffer (pH = 7.1)

In order to investigate the interference of competitive metal ions on selective sensing of  $\text{Hg}^{2+}$  ion by probe **D**, changes in fluorescence intensity at 475 nm of probe **D** upon addition of  $\text{Hg}^{2+}$  ion (1 equivalent) and/or other competitive metal ions (5 equivalents) were recorded and showed in Fig. 5. It was observed that the coexistence of  $\text{Ag}^+$  ion had unfavorable influence on the selective detection of  $\text{Hg}^{2+}$  ion by probe **D**. Other competitive ions did not cause obvious interference with the selective detection of  $\text{Hg}^{2+}$  ion. Probe **D** exhibited good antiinterference ability for selective sensing of  $\text{Hg}^{2+}$  ion over other common competitive metal ions.

Changes in fluorescence emission intensity at 475 nm  $(\lambda_{ex} = 332 \text{ nm})$  of probe **D** (20  $\mu$ M) upon addition of different



**Fig. 4** Fluorescence emission spectra of probe **D** solution (20  $\mu$ M in 2:8 EtOH/H<sub>2</sub>O) before and after addition of different metal ions (Li<sup>+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Ag<sup>+</sup>, Cu<sup>2+</sup>, Fe<sup>2+</sup>, Zn<sup>2+</sup>, Co<sup>2+</sup>, Ni<sup>2+</sup>, Mn<sup>2+</sup>, Sr<sup>2+</sup>, Hg<sup>2+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Al<sup>3+</sup>, Cr<sup>3+</sup> and Fe<sup>3+</sup>, 20  $\mu$ M) excited at 332 nm



**Fig. 5** Changes in fluorescence emission intensity at 475 nm ( $\lambda_{ex} = 332$  nm) of probe **D** solution (20  $\mu$ M) containing 1 equivalent of Hg<sup>2+</sup> ion (red bars) before and after addition of 5 equivalents of different competitive metal ions (Li<sup>+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Ag<sup>+</sup>, Cu<sup>2+</sup>, Fe<sup>2+</sup>, Zn<sup>2+</sup>, Co<sup>2+</sup>, Ni<sup>2+</sup>, Mn<sup>2+</sup>, Sr<sup>2+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Al<sup>3+</sup>, Cr<sup>3+</sup> and Fe<sup>3+</sup>) or probe **D** solution (20  $\mu$ M) containing 1 equivalent of different competitive metal ions (black bars)

concentrations of Hg<sup>2+</sup> (0, 2  $\mu$ M, 4  $\mu$ M, 6  $\mu$ M, 8  $\mu$ M, 10  $\mu$ M, 12  $\mu$ M, 14  $\mu$ M, 16  $\mu$ M, 18  $\mu$ M and 20  $\mu$ M) were measured and showed in Fig. 6. Gradual enhancement in the fluorescence emission intensity at 475 nm was found with increase in the concentration of added Hg<sup>2+</sup> ion from 0 to 20  $\mu$ M. Based on the results, a plot was drawn from the variation of the intensity of the fluorescence emission band at 475 nm with the concentration of Hg<sup>2+</sup> ion (0, 2  $\mu$ M, 4  $\mu$ M, 6  $\mu$ M, 8  $\mu$ M, 10  $\mu$ M, 12  $\mu$ M, 14  $\mu$ M, 16  $\mu$ M, 18  $\mu$ M and 20  $\mu$ M) added to probe **D** (20  $\mu$ M) to give a line as showed in Fig. 7. The linear fitting equation can be depicted as Y = 165,294 + 50,908X with R<sup>2</sup> = 0.9918. According to the formula L = 3S/K, where L is the detection limit, S denotes the standard deviation of fluorescence intensity of blank, and K is slope of the



**Fig. 6** Variation of fluorescence intensity at 475 nm of probe **D** (20  $\mu$ M) with increase of Hg<sup>2+</sup> concentration (0, 2  $\mu$ M, 4  $\mu$ M, 6  $\mu$ M, 8  $\mu$ M, 10  $\mu$ M, 12  $\mu$ M, 14  $\mu$ M, 16  $\mu$ M, 18  $\mu$ M and 20  $\mu$ M)

**D** (20 µM)



Fig. 7 Relationship between the intensity of the fluorescence emission band at 475 nm and the concentration of  $Hg^{2+}$  ion  $(0, 2 \mu M, 4 \mu M, 6 \mu M)$ , Fig. 2 Relationship between the intensity of the fluorescence emission band at 475 nm and the concentration of  $Hg^{2+}$  ion  $(0, 2 \mu M, 4 \mu M, 6 \mu M)$ , Fig. 2 Fluorescence emission intensity of probe **D** (20  $\mu$ M) upon addition of 1 equivalent of  $Hg^{2+}$  ion at different pH (pH = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14)

calibration curve [19], the detection limit is calculated to be  $1.46 \times 10^{-7}$  M. Therefore probe **D** can be used for selective and sensitive detection of Hg<sup>2+</sup> ion in aqueous solution by

 $8 \,\mu\text{M}$ ,  $10 \,\mu\text{M}$ ,  $12 \,\mu\text{M}$ ,  $14 \,\mu\text{M}$ ,  $16 \,\mu\text{M}$ ,  $18 \,\mu\text{M}$  and  $20 \,\mu\text{M}$ ) added to probe

fluorescence turn-on mode. To verify the applicable pH range of probe **D** for selective sensing of Hg<sup>2+</sup> ion, variation of the maximum UV-Vis absorption and fluorescence emission intensity of probe **D** upon addition of 1 equivalent of Hg<sup>2+</sup> ion at different pH (pH = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14) were measured and the results were showed in Figs. 8 and 9, respectively. In the previous section it was demonstrated that probe **D** itself showed the maximum UV-Vis absorption band at 360 nm and addition of Hg<sup>2+</sup> ion caused a hypsochromic shift of about 20 nm



**Fig. 8** Intensity of the maximum UV-Vis absorption band of probe **D** (20  $\mu$ M) upon addition of 1 equivalent of Hg<sup>2+</sup> ion at different pH (pH = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14)

(Fig. 3). This system consisting of probe **D** and  $Hg^{2+}$  ion was stable and exhibited a relatively strong absorption at 340 nm under acidic conditions (pH = 1-6), neutral condition, and weakly alkaline conditions (pH = 8-10). When the pH value increased to 11, a bathochromic shift of the maximum UV-Vis absorption band from 340 nm to around 385 nm was observed. Further increase of the pH to 12 or more led to sharp decrease in the absorption intensity. These results indicated that probe **D** was stable under from relatively strong acidic conditions to fairly strong alkaline conditions and might be utilized for selective detection of Hg<sup>2+</sup> ion in a pH range of 1-11. Fluorescence emission intensity of probe **D** (20  $\mu$ M) upon addition of 1 equivalent of Hg<sup>2+</sup> ion at different pH (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14) showed that the fluorescence intensity gradually decreased with the pH value increased from 1 to 4 and maintained constant in the pH range 5-10. When the pH value increased to 11, the fluorescence intensity increased sharply accompanying a slight shift of the emission band from around 475 nm to 485 nm. Then the fluorescence intensity decreased with further increase of the pH value until the fluorescence quenched at pH 14. The results implied that probe **D** was not stable under strongly alkaline conditions but was stable under relatively strong acidic conditions and weakly alkaline conditions. It might be applicable as a fluorescence turn-on probe for selective detection of  $Hg^{2+}$  ion in a broad pH range of 1–11.

Comparison of performance of probe **D** with other  $Hg^{2+}$  probes was summarized in Table 1. It can be discovered that probe **D** displays two advantages: first, it can detect  $Hg^{2+}$  ions by fluorescence turn-on mode over a broad pH range of 1–11; and second, it is applicable in strong acidic condition at pH 1.



## Table 1 Comparison of fluorescent probes for Hg<sup>2+</sup> ion

| Probe                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Sensing mode              | Applicable<br>pH range | Limit of detection | Ref. |
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| MeO<br>N<br>N<br>MeO<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N<br>N                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Fluorescence<br>turn-on   | 5–9                    | 36 nM              | [12] |
| S<br>S<br>S<br>S<br>S<br>S<br>S<br>S<br>S<br>S<br>S<br>S<br>S<br>S<br>S<br>S<br>S<br>S<br>S                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Fluorescence<br>turn-on   | 6–8                    | 8.1 nM             | [20] |
| SH O-<br>N-<br>I                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Fluorescence<br>turn-on   | 6–10                   | 6.5 nM             | [22] |
| $H_{Et_2N} = 0$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Fluorescence<br>turn-on   | 5.81–9.04              | 0.42 nM            | [45] |
| $\underset{Et_2N}{\overset{O}{}}_{},\overset{O}{},\overset{H}{},\overset{H}{},\overset{H}{},\overset{O}{\overset{O}},\overset{O}{\overset{O}},\overset{O}{\overset{O}},\overset{O}{\overset{O},\overset{O}{\overset{O}},\overset{O}{\overset{O},\overset{O}{\overset{O}},\overset{O}{\overset{O}},\overset{O}{\overset{O},\overset{O}{\overset{O}},\overset{O}{\overset{O},\overset{O}{\overset{O}},\overset{O},O$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Fluorescence<br>turn-on   | 6.5–9                  | 300 nM             | [46] |
| $\underset{Et_2N}{\overset{O}{\longrightarrow}} \underset{O}{\overset{H}{\longrightarrow}} \underset{NEt_2}{\overset{H}{\longrightarrow}} \underset{NEt_2}{\overset{O}{\longrightarrow}} \underset{NE}{\overset{O}{\longrightarrow}} \underset{NE}{\overset{O}{\longrightarrow}} \underset{NE}{\overset{O}{\longrightarrow}} \underset{NE}{\overset{O}{\longrightarrow}} \underset{NE}{\overset{NE}{\overset{O}{\longrightarrow}} \underset{NE}{\overset{O}{\longrightarrow}} \underset{NE}{\overset{NE}{\overset{O}{\longrightarrow}} \underset{NE}{\overset{O}{\longrightarrow}} \underset{NE}{\overset{NE}{\overset{O}{\longrightarrow}} \underset{NE}{\overset{O}{\overset{O}{\longrightarrow}} \underset{NE}{\overset{O}{\overset{NE}{\overset}} \underset{NE}{\overset{O}{\overset{O}{\overset{NE}{\overset}} \underset{NE}{\overset{O}{\overset{O}{\overset{NE}{\overset}} \underset{NE}{\overset{O}{\overset{NE}{\overset}} \underset{NE}{\overset{NE}{\overset{NE}{\overset}} \underset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset}} \underset{NE}{\overset{NE}{\overset{NE}{\overset}} \underset{NE}{\overset{NE}{\overset{NE}{\overset}} \underset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset{NE}{\overset$ | Fluorescence<br>turn-on   | 4–11                   | 3.2 nM             | [47] |
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                                                                                                                                                                                                                                                                                      | Fluorescence<br>turn-on   | 5–11                   | 9.1 nM             | [48] |
| H H H O O                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Fluorescence<br>quenching | 2–12                   | 6.5 nM             | [49] |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        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A plausible sensing mechanism of probe **D** for fluorescent detection of  $Hg^{2+}$  ion is proposed as showed in Scheme 2. The weakly fluorescent probe **D** readily binds with  $Hg^{2+}$  ion due to the strong interaction between sulfur atom and thiophilic  $Hg^{2+}$  ion. Then a desulfurization and cyclization process occurs to form a hydropyrrolidinone with strong fluorescence, similar to the sensing processes observed on other thiourea-based Hg<sup>2+</sup> fluorescent probes reported previously [44–49]. The coexistence of Ag<sup>+</sup> and Cu<sup>2+</sup> ions may interfere with the selective sensing of Hg<sup>2+</sup> ion by probe **D** because Ag<sup>+</sup> and Cu<sup>2+</sup> ions also exhibit thiophilicity like Hg<sup>2+</sup> ion [32–34].

## Table 1 (continued)

| Fluorescence 3-8 0.35 nM [57]<br>f(t) = f(t)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                      |              |             |         |        |
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-----------------------------------------------------------------------------------------|--------------------------------------|--------------|-------------|---------|--------|
| $ \begin{array}{c} \displaystyle \underset{k \in \mathcal{K}}{ \displaystyle \bigoplus_{k \in \mathcal{K}}} & \text{turn-on} \\ \\ \displaystyle \underset{k \in \mathcal{K}}{ \displaystyle \bigoplus_{k \in \mathcal{K}}} & \underset{k \in \mathcal{K}}{ \displaystyle \bigoplus_{k \in \mathcal{K}} & \underset{k \in \mathcal{K}}{ \displaystyle \bigoplus_{k \in \mathcal{K}}} & \underset{k \in \mathcal{K}}{ \displaystyle \bigoplus_{k \in \mathcal{K}}} & \underset{k \in \mathcal{K}}{ \displaystyle \bigoplus_{k \in \mathcal{K}}} & \underset{k \in \mathcal{K}}{ \displaystyle \bigoplus_{k \in \mathcal{K}} & \underset{k \in \mathcal{K}}{ \displaystyle \bigoplus_{k \in \mathcal{K}}} & \underset{k \in \mathcal{K}} & \underset{k \in \mathcal{K}}{ \displaystyle \bigoplus_{k \in \mathcal{K}} & \underset{k \in \mathcal{K}}{ \displaystyle \bigoplus_{k \in $ |                                      | Fluorescence | 3-8         | 0.35 nM | [57]   |
| $\begin{aligned} & \left( \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     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                                                                                     |                                      | Fluorescence | 4_7         | 52 nM   | [58]   |
| $ \begin{array}{c} \begin{array}{c} & & \\ & & \\ & \\ & \\ & \\ & \\ & \\ & \\ & $                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                      | tum on       | /           | 52 1111 | [30]   |
| $ \begin{array}{c} {}_{EA} \stackrel{F}{\hookrightarrow} \stackrel{F}{\hookrightarrow} \stackrel{F}{h^{C}} & Fluorescence & 6-10 & 6 nM & [59] \\ {}_{H,h^{h}} \stackrel{F}{\hookrightarrow} \stackrel{F}{h^{h}} & Fluorescence & 3-9 & 45.4 nM & [60] \\ {}_{H,h^{h}} \stackrel{O}{\hookrightarrow} \stackrel{O,H^{H}}{h^{H}} & Fluorescence & 6-8 & 2.8 nM & [61] \\ {}_{H,h^{h}} \stackrel{O}{\hookrightarrow} \stackrel{O,H^{H}}{h^{h}} \stackrel{F}{h^{H}} & Fluorescence & 3-10 & 130 nM & [62] \\ {}_{H,h^{h}} \stackrel{N}{\hookrightarrow} \stackrel{H}{h^{h}} \stackrel{H}{h^{h}} & Fluorescence & 2-10 & 140 nM & [63] \\ {}_{H,h^{h}} \stackrel{O}{\hookrightarrow} \stackrel{O,H^{H}}{H^{H}} & Fluorescence & 2-10 & 140 nM & [63] \\ {}_{H,H^{H}} \stackrel{O}{\hookrightarrow} \stackrel{O,H^{H}}{H^{H}} & Fluorescence & 4-9 & 26 nM & [64] \\ {}_{H^{O}} \stackrel{O,H^{H}}{H^{H}} \stackrel{H}{H^{H}} & Fluorescence & 1-11 & 146 nM & This work \end{array} $                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | S N= S S                             | tu111-011    |             |         |        |
| $ \begin{array}{c} {}_{B,M} \stackrel{h}{\hookrightarrow} \stackrel{h}{\hookrightarrow} \stackrel{h}{\hookrightarrow} \stackrel{h}{\hookrightarrow} \stackrel{h}{\hookrightarrow} \stackrel{h}{\to} \stackrel{h}{\to}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                      |              |             |         |        |
| Fluorescence 6–10 6 nM [59]<br>turn-on<br>Fluorescence 6–10 6 nM [59]<br>turn-on<br>Fluorescence 3–9 45.4 nM [60]<br>turn-on<br>$\zeta = \zeta = \zeta = \zeta = 0$<br>$\zeta = \zeta = 0$<br>$\zeta = \zeta = 0$<br>$\zeta = 0$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Et <sub>2</sub> N O NEt <sub>2</sub> |              |             |         |        |
| $\begin{split} & \operatorname{turn-on} & \operatorname{turn-on} \\ & \operatorname{fightarrow} & \operatorname{funcescence} & 3-9 & 45.4  \operatorname{nM}  [60] \\ & \operatorname{turn-on} & \operatorname{funcescence} & 6-8 & 2.8  \operatorname{nM}  [61] \\ & \operatorname{fightarrow} & \operatorname{funcescence} & 6-8 & 2.8  \operatorname{nM}  [61] \\ & \operatorname{turn-on} & \operatorname{funcescence} & 3-10 & 130  \operatorname{nM}  [62] \\ & \operatorname{turn-on} & \operatorname{funcescence} & 3-10 & 130  \operatorname{nM}  [62] \\ & \operatorname{turn-on} & \operatorname{funcescence} & 2-10 & 140  \operatorname{nM}  [63] \\ & \operatorname{turn-on} & \operatorname{turn-on} & \operatorname{funcescence} & 4-9 & 26  \operatorname{nM}  [64] \\ & \operatorname{turn-on} & \operatorname{funcescence} & 1-11 & 146  \operatorname{nM}  \operatorname{This} \\ & \operatorname{turn-on} & turn$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                      | Fluorescence | 6–10        | 6 nM    | [59]   |
| $ \int_{h^{\infty}} \int_{$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | H <sub>2</sub> N                     | turn-on      |             |         |        |
| Fluorescence 3-9 45.4 nM [60]<br>urn-on<br>$s = \int_{c}^{c} \int_{c}^{o} \int_{c}^{o} \int_{s}^{d} \int_{s}^{d$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | ,N <sup>†</sup> ≡C                   |              |             |         |        |
| Fluorescence 3-9 45.4 nM [60]<br>turn-on<br>$\zeta = \zeta = \zeta = 0$<br>$\zeta = \zeta = 0$<br>$\zeta =$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                      |              |             |         |        |
| $\begin{aligned} & \underset{l \to l}{\overset{l \to l}{\mapsto}} + \underset{l \to l}{\overset{l \to l \to l}{\mapsto}} + \underset{l \to l}{\overset{l \to l \to l}{\mapsto}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\mapsto}} + \underset{l \to l}{\overset{l \to l \to l}{\mapsto}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\mapsto}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\mapsto}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l \to l}{\to}} + \underset{l \to l \to l}{\overset{l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to}} + \underset{l \to l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to} + \underset{l \to l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to} + \underset{l \to l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to} + \underset{l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to} + \underset{l \to l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to} + \underset{l \to l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to l \to l \to l} + \underset{l \to l \to l \to l \to l}{\overset{l \to l \to l \to l \to l}{\to} + \underset{l \to l \to l \to l \to l}{\to l \to l \to l} + \underset{l \to l \to l \to l \to l}{\overset{l \to l \to l \to l}{\to l \to l \to l \to l} + \underset{l \to l \to l \to l \to l}{\to l \to l \to l} + \underset{l \to l \to l \to l}{\to l \to l \to l} + \underset{l \to l \to l \to l}{\to l \to l \to l \to l} + \underset{l \to l \to l \to l \to l}{\to l \to l \to l} + \underset{l \to l \to l \to l \to l \to l \to l}{\to l \to l$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | $\bigcirc$                           | Fluorescence | 3–9         | 45.4 nM | [60]   |
| $ \begin{array}{c} ( \downarrow^{+} \downarrow_{\downarrow,N} \downarrow_{O}^{CO,H} \\ = \left( \downarrow^{+} \downarrow_{\downarrow,N} \downarrow_{O}^{CO,H} \\ = \left( \downarrow^{+} \downarrow_{\downarrow,N} \downarrow_{\downarrow,O}^{+} \downarrow_{O}^{+} \downarrow_{I} \right)^{SEI} \\ = \left( \downarrow^{+} \downarrow_{\downarrow,N} \downarrow_{\downarrow,O}^{+} \downarrow_{I} \downarrow_{I} \right)^{SEI} \\ = \left( \downarrow^{+} \downarrow_{\downarrow,N} \downarrow_{\downarrow,O}^{+} \downarrow_{I} \downarrow_{I} \right)^{SEI} \\ = \left( \downarrow^{+} \downarrow_{\downarrow,N} \downarrow_{\downarrow,O}^{+} \downarrow_{I} \downarrow_{I} \right)^{SEI} \\ = \left( \downarrow^{+} \downarrow_{\downarrow,N} \downarrow_{\downarrow,O}^{+} \downarrow_{I} \downarrow_{I} \downarrow_{I} \downarrow_{I} \right)^{SEI} \\ = \left( \downarrow^{+} \downarrow_{I} \downarrow_$                                   |                                      | turn-on      |             |         |        |
| $ \begin{array}{c} \downarrow & \downarrow $                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           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| $ \begin{aligned} &                                  $                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 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| $ \begin{array}{c} \begin{array}{c} & & \\ & \\ & \\ & \\ & \\ & \\ & \\ & \\ & \\ $                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   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| $\begin{aligned} & \underset{l \to 0}{\overset{r}{\underset{h_{N}}}} & \underset{l \to 0}{\overset{r}{\underset{N}}} & \underset{l \to 0}{\overset{r}{\underset{N}} & \underset{l \to 0}{\overset{R}} & \underset{l \to 0}{\overset{r}{\underset{N}}} & \underset{l \to 0}{\overset{r}{\underset{N}}} & \underset{l \to 0}{\overset{R}} & \underset{l \to 0}{\overset{R}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                      | Fluorescence | 6–8         | 2.8 nM  | [61]   |
| $ \begin{aligned} &  ( + \zeta_{+}, \zeta_{+}, \zeta_{+}, \zeta_{+}) \\ &  ( + \zeta_{+}) \\ &  ( + \zeta_{+}, \zeta_{+}) \\ &  ( + \zeta_{+}) $                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                      | turn-on      | 0.0         | <b></b> | [~ ]   |
| $\begin{aligned} &                                   $                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 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| $ \begin{array}{c} & \qquad $                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          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    |              |             |         |        |
| Fluorescence 3–10 130 nM [62]<br>$ \underset{\substack{H_{N}N \leftarrow f_{N} \overset{N}{f_{L}} \leftarrow f_{N} & \qquad \qquad$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    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| $ \begin{array}{c} \underset{H_{n} \downarrow \downarrow$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | ~CONHEt                              |              |             |         |        |
| Fluorescence 3–10 I30 nM [62]<br>$ \underset{\substack{H_{2}N \leftarrow \begin{pmatrix} + \\ H_{2} \end{pmatrix}}{H_{0}} \leftarrow \begin{pmatrix} + \\ H_{0} \end{pmatrix}}{H_{0}} \leftarrow \begin{pmatrix} + \\ H_{0} \end{pmatrix}{H_{12}}{H_{0}} \leftarrow \begin{pmatrix} + \\ H_{0} \end{pmatrix}{H_{12}}{H_{12}}{H_{0}} \leftarrow \begin{pmatrix} + \\ H_{0} \end{pmatrix}{H_{12}}{H_{12}}{H_{12}} \leftarrow \begin{pmatrix} + \\ H_{0} \end{pmatrix}{H_{12}}{H_{12}} \leftarrow \begin{pmatrix} + \\ H_{12} \end{pmatrix}{H_{12}} \leftarrow $                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Br、                                  |              | <b>2</b> 10 | 100 37  | F ( 07 |
| $\begin{array}{c} \underset{H,N}{H} \underset{H,O}{} H,$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                      | Fluorescence | 3-10        | 130 nM  | [62]   |
| $ \begin{array}{c} & \stackrel{MH_2}{\underset{HO}{HO}} \\ & \stackrel{NG}{\underset{C}{G}} \\ & \stackrel{NG}{\underset{C}{G}} \\ & \stackrel{NG}{\underset{C}{G}} \\ & \stackrel{G}{\underset{C}{G}} \\ & \stackrel{G}{\underset{C}{G}} \\ & \stackrel{Fluorescence}{\underset{LITI-On}{Int}} \\ & \stackrel{G}{\underset{C}{G}} \\ & \stackrel{G}{\underset{C}{G}} \\ & \stackrel{G}{\underset{C}{G}} \\ & \stackrel{G}{\underset{C}{G}} \\ & \stackrel{G}{\underset{G}{G}} \\ & \stackrel{G}{\underset{G}{G}} \\ & \stackrel{G}{\underset{C}{HO}} \\ & \stackrel{G}{\underset{G}{G}} \\ & \stackrel{G}{\underset{G}{G} \\ & \stackrel{G}{\underset{G}{G}} \\ & \stackrel{G}{\underset{G}{G} \\ & \stackrel{G}{\underset{G}{G}} \\ & \stackrel{G}{\underset{G}{G}} \\ & \stackrel{G}{\underset{G}{G}} \\ & \stackrel{G}{\mathsf{$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | $H_2N \longrightarrow N$             | turn-on      |             |         |        |
| $ \begin{array}{c} \underset{HO}{HO} \\ \underset{HO}{HO} \\ \\ \underset{HO}{ } \\ \\ \underset{HO}{ } \\ \\ \underset{HO}{ } \\ \\ \underset{HO}{ } \\ \\ \\ \underset{HO}{ } \\ \\ \\ \underset{HO}{ } \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | NH <sub>2</sub>                      |              |             |         |        |
| $ \begin{array}{c} \underset{l}{\overset{NG}{\leftarrow}, \underset{S}{\leftarrow}, \underset{S}{\leftarrow}, \underset{S}{\leftarrow}, \underset{N}{\leftarrow}, \underset{S}{\leftarrow}, \underset{N}{\leftarrow}, \underset{S}{\leftarrow}, \underset{N}{\leftarrow}, \underset$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | HO                                   |              |             |         |        |
| $ \begin{array}{c} \underset{l}{\overset{N}{\underset{L}{\underset{N}{\underset{L}{\underset{N}}{\underset{N}}{\underset{N}}}}}}}}}}$ 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| $ \begin{aligned} &                                  $                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 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| Ethn' $\bigcirc$ $\circ' ~$ NHEt turn-on<br>$\downarrow \downarrow $                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | IIII                                 | Fluorescence | 4–9         | 26 nM   | [64]   |
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Scheme 2 Plausible sensing mechanism of probe **D** towards  $Hg^{2+}$  ion

## Conclusions

A new fluorescent turn-on chemosensor **D** for selective Hg<sup>2+</sup> ion detection was developed based on the Hg<sup>2+</sup>-promoted desulfurization and cyclization reactions of a coumarin-thiourea conjugate. UV-Vis spectra measurement revealed that addition of  $Hg^{2+}$  ion to the sensor **D** solution in 2:8 EtOH/H<sub>2</sub>O induced a hypsochromic shift of the absorption band from 360 nm to 340 nm accompanying distinct enhancement in the absorption intensity. Addition of other metal ions (Li<sup>+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Ag<sup>+</sup>, Cu<sup>2+</sup>, Fe<sup>2+</sup>, Zn<sup>2+</sup>, Co<sup>2+</sup>, Ni<sup>2+</sup>, Mn<sup>2+</sup>, Sr<sup>2+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Al<sup>3+</sup>, Cr<sup>3+</sup> and Fe<sup>3+</sup>) did not cause substantial change in the absorption spectra. Fluorescence spectra measurement results indicated that addition of Hg<sup>2+</sup> to the sensor solution in 2:8 EtOH/H<sub>2</sub>O brought about marked increase in the fluorescence emission intensity. Most common competitive metal ions did not interfere with the selective sensing of  $Hg^{2+}$  ion by the sensor **D**. The detection limit of  $Hg^{2+}$ ion by probe **D** is calculated to be  $1.46 \times 10^{-7}$  M. The probe **D** can be utilized for selective detection of  $Hg^{2+}$ ion by fluorescence turn-on mode over a broad pH range of 1-11. Therefore it may play an important role in various samples determination including acidic environmental waste water samples. Further exploration on this respect will be performed in the near future.

# References

- Wolfe MF, Schwarzbach S, Sulaiman RA (1998) Effects of mercury on wildlife: a comprehensive review. Environ Toxicol Chem 17:146–160
- Tang Z, Yang J, Li G, Hu Y (2019) Synthesis of sulfur-rich nitrogen dots from a single source precursor and its application in dual-mode sensing. Talanta 195:550–557
- Guo H, Li J, Li Y, Wu D, Ma H, Wei Q, Du B (2019) Exciton energy transfer-based fluorescent sensor for the detection of Hg<sup>2+</sup> through aptamer-programmed self-assembly of QDs. Anal Chim Acta 1048:161–167
- Liu Y, Tang X, Deng M, Cao Y, Li Y, Zheng H, Li F, Yan F, Lan T, Shi L, Gao L, Huang L, Zhu T, Lin H, Bai Y, Qu D, Huang X, Qiu F (2019) Nitrogen doped graphene quantum dots as a fluorescent probe for mercury(II) ions. Microchim Acta 186:140
- 5. Liang JY, Han L, Liu SG, Ju YJ, Li NB, Luo HQ (2019) Carbon dotsbased fluorescent turn off/on sensor for highly selective and sensitive detection of  $Hg^{2+}$  and biothiols. Spectrochim Acta A 222:117260
- 6. Boorboor Azimi E, Badiei A, Jafari M, Banitalebi Dehkordi A, Ghasemi JB, Mohammadi Ziarani G (2019) Boron-doped

graphitic carbon nitride as a novel fluorescent probe for mercury(II) and iron(III): a circuit logic gate mimic. New J Chem 43:12087–12093

- Li X, Liu J, Gong X, Qing T, Zhang P, Feng B (2019) Synthesis of fluorescent tungsten disulfide by nitrogen atom doping and its application for mercury(II) detection. J Mater Chem C 7:4096–4101
- Zhou Y, Wang J, Yang G, Ma S, Zhang M, Yang J (2019) Cysteinerich protein-templated silver nanoclusters as a fluorometric probe for mercury(II) detection. Anal Methods 11:733–738
- Jiang Y, Duan Q, Zheng G, Yang L, Zhang J, Wang Y, Zhang H, He J, Sun H, Ho D (2019) An ultra-sensitive and ratiometric fluorescent probe based on the DTBET process for Hg<sup>2+</sup> detection and imaging applications. Analyst 144:1353–1360
- Cheng X, Qu S, Xiao L, Li W, He P (2018) Thioacetalized coumarin-based fluorescent probe for mercury(II): ratiometric response, high selectivity and successful bioimaging application. J Photochem Photobiol A 364:503–509
- Ma J, Zhang C, Xiao Y, Zhang M, Wang Q, Zheng W, Zhang S (2019) Preparation 2-(anthracen-9-yl)-1,3-dithiolane as a novel dual-channel AIE-active fluorescent probe for mercury (II) ion with excellent performance. J Photochem Photobiol A 378:142–146
- Huang S, Gao T, Bi A, Cao X, Feng B, Liu M, Du T, Feng X, Zeng W (2020) Revealing aggregation-induced emission effect of imidazolium derivatives and application for detection of Hg<sup>2+</sup>. Dyes Pigments 172:107830
- Han Y, Yang C, Wu K, Chen Y, Zhou B, Xia M (2015) A facile naphthalene-based fluorescent chemodosimeter for mercury ions in aqueous solution. RSC Adv 5:16723–16726
- Shang X, Wang N, Cerny R, Niu W, Guo J (2017) Fluorescent protein-based turn-on probe through a general protectiondeprotection design strategy. ACS Sens 2:961–966
- Wu C, Wang J, Shen J, Bi C, Zhou H (2017) Coumarin-based Hg<sup>2+</sup> fluorescent probe: synthesis and turn-on fluorescence detection in neat aqueous solution. Sensors Actuators B Chem 243:678–683
- Lee H, Kim H (2011) Ratiometric fluorescence chemodosimeter for mercuric ions through the Hg(II)-mediated propargyl amide to oxazole transformation. Tetrahedron Lett 52:4775–4778
- Mubarok AZ, Lin S-T, Mani V, Huang C-H, Huang S-T (2016) Design of controlled multi-probe coupled assay via bioinspired signal amplification approach for mercury detection. RSC Adv 6: 58485–58492
- Duan X, Gu B, Zhou Q, Hu X, Huang L, Su W, Li H (2017) A simple fluorescent probe for detecting mercury(II) ion in aqueous solution and on agar gels. J Iran Chem Soc 14:1207–1214
- Li Q, Hu Y, Hou H-N, Yang W-N, Hu S-L (2018) A new coumarincarbonothioate-based turn-on fluorescent chemodosimeter for selective detection of Hg<sup>2+</sup>. Inorg Chim Acta 471:705–708
- Pang B, Li Q, Li C, Yang Z (2019) A highly selective and sensitive coumarin derived fluorescent probe for detecting Hg<sup>2+</sup> in 100% aqueous solutions. J Lumin 205:446–450
- Chen L, Park SJ, Wu D, Kim HM, Yoon J (2019) A two-photon fluorescent probe for colorimetric and ratiometric monitoring of mercury in live cells and tissues. Chem Commun 55:1766–1769
- Zhang C, Zhang H, Li M, Zhou Y, Zhang G, Shi L, Yao Q, Shuang S, Dong C (2019) A turn-on reactive fluorescent probe for Hg<sup>2+</sup> in 100% aqueous solution. Talanta 197:218–224

- Xu Z, Shi W, Yang C, Xu J, Liu H, Xu J, Zhu B (2019) Highly selective and sensitive fluorescent probe for the rapid detection of mercury ions. RSC Adv 9:10554–10560
- Duan Q, Lv X, Liu C, Geng Z, Zhang F, Sheng W, Wang Z, Jia P, Li Z, Zhu H, Zhu B (2019) Dichlororesorufin-based colorimetric and fluorescent probe for ultrasensitive detection of mercury ions in living cells and zebrafish. Ind Eng Chem Res 58:11–17
- 25. Wang S, Ding H, Wang Y, Fan C, Liu G, Pu S (2019) Novel multiresponsive fluorescence switch for Hg<sup>2+</sup> and UV/Vis lights based on diarylethene-rhodamine derivative. Tetrahedron 75: 1517–1524
- Choi MG, Kim YH, Namgoong JE, Chang S-K (2009) Hg<sup>2+</sup>-selective chromogenic and fluorogenic chemodosimeter based on thiocoumarins. Chem Commun 24:3560–3562
- Chen J, Liu W, Wang Y, Zhang H, Wu J, Xu H, Ju W (2013) Turnon fluorescence sensor based on the aggregation of pyrazolo[3,4b]pyridine-based coumarin chromophores induced by Hg<sup>2+</sup>. Tetrahedron Lett 54:6447–6449
- Zhou H, Tian W, Jiang M, Li P, Zeng S, Chen W, Ma A (2015) A selective, colorimetric and ratiometric chemosensor for Hg<sup>2+</sup> and its application as test papers. Anal Sci 31:12815–11289
- Wu Z-L, Shi D, Huang L, He W-Y, Sun X-Y, Liu B, Shen J-S (2019) Highly selective and sensitive turn-on fluorescent probes for sensing Hg<sup>2+</sup> ions in mixed aqueous solution. Sensors Actuators B Chem 281:311–319
- Han JH, Hirashima S, Park S, Sugiyama H (2019) Highly sensitive and selective mercury sensor based on mismatched base pairing with <sup>diox</sup>T. Chem Commun 55:10245–10248
- Song F, Yang C, Shao X, Du L, Zhu J, Kan C (2019) A reversible "turn-on" fluorescent probe for real-time visualization of mercury(II) in environmental samples and its biological applications. Dyes Pigments 165:444–450
- 32. Shi W-J, Li C-F, Huang Y, Tan H, Wei Y-F, Liu F, Feng L-X, Zheng L, Chen G-S, Yan J (2019) A remarkable colorimetric probe for fluorescent ratiometric and ON-OFF discriminative detection of Hg<sup>2+</sup> and Cu<sup>2+</sup> by double-channel imaging in living cells. Dyes Pigments 171:107782
- Huang Y, Li C-F, Shi W-J, Tan H-Y, He Z-Z, Zheng L, Liu F, Yan J-W (2019) A near-infrared BODIPY-based fluorescent probe for Hg<sup>2+</sup> and Cu<sup>2+</sup> ions in living cells. Talanta 198:390–397
- Chen Z-E, Zhang H, Iqbal Z (2019) A new thiosemicarbazone fluorescent probe based on 9,9'-bianthracene for Hg<sup>2+</sup> and Ag<sup>+</sup>. Spectrochim Acta A 215:34–40
- Wu Y, Wen X, Fan Z (2019) An AIE active pyrene based fluorescent probe for selective sensing Hg<sup>2+</sup> and imaging in live cells. Spectrochim Acta A 223:117315
- 36. Srivastava S, Thakur N, Singh A, Shukla P, Maikhura VK, Garg N, Prasad A, Pandey R (2019) Development of a fused imidazo[1,2a]pyridine based fluorescent probe for Fe<sup>3+</sup> and Hg<sup>2+</sup> in aqueous media and HeLa cells. RSC Adv 9:29856–29863
- 37. Wang Q, Jin L, Wang W, Hu T, Chen C (2019) Rhodamine derivatives as selective "naked-eye" colorimetric and fluorescence off-on sensor for Hg<sup>2+</sup> in aqueous solution and its applications in bioimaging. J Lumin 209:411–419
- Bayindir S (2019) A simple rhodanine-based fluorescent sensor for mercury and copper: the recognition of Hg<sup>2+</sup> in aqueous solution, and Hg<sup>2+</sup>/Cu<sup>2+</sup> in organic solvent. J Photochem Photobiol A 372: 235–244
- Kumar A, Sahoo PR, Arora P, Kumar S (2019) A light controlled, sensitive, selective and portable spiropyran based receptor for mercury ions in aqueous solution. J Photochem Photobiol A 384:112061
- Gao Q, Jiao Y, He C, Duan C (2019) A novel ratiometric fluorescent probe for mercury (II) ions and application in bio-imaging. Molecules 24:2268

- 41. He Y, Wang X, Wang K, Wang L (2020) A triarylamine-based fluorescent covalent organic framework for efficient detection and removal of mercury(II) ion. Dyes Pigments 173:107880
- 42. Wang X, Ma X, Wen J, Geng Z, Wang Z (2020) A novel bimacrocyclic polyamine -based fluorescent probe for sensitive detection of Hg<sup>2+</sup> and glutathione in human serum. Talanta 207:120311
- 43. Karuk Elmas SN, Dincer ZE, Erturk AS, Bostanci A, Karagoz A, Koca M, Sadi G, Yilmaz I (2020) A novel fluorescent probe based on isocoumarin for Hg<sup>2+</sup> and Fe<sup>3+</sup> ions and its application in livecell imaging. Spectrochim Acta A 224:117402
- 44. Ma W, Xu Q, Du J, Song B, Peng X, Wang Z, Li G, Wang X (2010) A Hg<sup>2+</sup>-selective chemodosimeter based on desulfurization of coumarin thiosemicarbazide in aqueous media. Spectrochim Acta A 76:248–252
- Zhou Y, Chu K, Zhen H, Fang Y, Yao C (2013) Visualizing Hg<sup>2+</sup> ions in living cells using a FRET-based fluorescent sensor. Spectrochim Acta A 106:197–202
- 46. Xu Y, Jing Z, Xiao Y, Zhang T-T, Miao J-Y, Zhao B-X (2014) A new fluorescent turn-on chemodosimeter for mercury ions in solution and its application in cells and organisms. Anal Chim Acta 807: 126–134
- 47. Wang M, Wen J, Qin Z, Wang H (2015) A new coumarinrhodamine FRET system as an efficient ratiometric fluorescent probe for Hg<sup>2+</sup> in aqueous solution and in living cells. Dyes Pigments 120:208–212
- Li Y, Qi S, Xia C, Xu Y, Duan G, Ge Y (2019) A FRET ratiometric fluorescent probe for detection of Hg<sup>2+</sup> based on an imidazo[1,2-a]pyridine-rhodamine system. Anal Chim Acta 1077:243–248
- Shiraishi Y, Sumiya S, Hirai T (2010) A coumarin-thiourea conjugate as a fluorescent probe for Hg(II) in aqueous media with a broad pH range 2–12. Org Biomol Chem 8:1310–1314
- van de Weert M, Stella L (2011) Fluorescence quenching and ligand binding: a critical discussion of a popular methodology. J Mol Struct 998:144–150
- Li H, Sun X, Zheng T, Xu Z, Song Y, Gu X (2019) Coumarinbased multifunctional chemosensor for arginine/lysine and Cu<sup>2+</sup>/Al<sup>3+</sup> ions and its Cu<sup>2+</sup> complex as colorimetric and fluorescent sensor for biothiols. Sensors Actuators B Chem 279: 400–409
- Gu L, Zheng T, Xu Z, Song Y, Li H, Xia S, Shen L (2019) A novel bifunctional fluorescent and colorimetric probe for detection of mercury and fluoride ions. Spectrochim Acta A 207:88–95
- 53. Wang Y, Xu Z, Dai X, Li H, Yu S, Meng W (2019) A new spiropyran-based sensor for colorimetric and fluorescent detection of divalent Cu<sup>2+</sup> and Hg<sup>2+</sup> ions and trivalent Ce<sup>3+</sup>, Cr<sup>3+</sup> and Al<sup>3+</sup> ions. J Fluoresc 29:569–575
- 54. Zheng T, Xu Z, Zhao Y, Li H, Jian R, Lu C (2018) Multiresponsive polysiloxane bearing photochromic spirobenzopyran for sensing pH changes and  $Fe^{3+}$  ions and sequential sensing of Ag<sup>+</sup> and Hg<sup>2+</sup> ions. Sensors Actuators B Chem 255:3305–3315
- 55. Liu M, Xu Z, Song Y, Li H, Xian C (2018) A novel coumarin-based chemosensor for colorimetric detection of Ag(I) ion and fluorogenic sensing of Ce(III) ion. J Lumin 198:337–341
- Kudale AA, Kendall J, Warford CC, Wilkins ND, Bodwell GJ (2007) Hydrolysis-free synthesis of 3-aminocoumarins. Tetrahedron Lett 48:5077–5080
- Rani BK, John SA (2018) Fluorogenic mercury ion sensor based on pyrene-amino mercapto thiadiazole unit. J Hazard Mater 343:98–106
- Yuan X, Leng T-H, Guo Z-Q, Wang C-Y, Li J-Z, Yang W-W, Zhu W-H (2019) A FRET-based dual-channel turn-on fluorescence probe for the detection of Hg<sup>2+</sup> in living cells. Dyes Pigments 161:403–410

- Nagy M, Kovacs SL, Nagy T, Racz D, Zsuga M, Keki S (2019) Isocyanonaphthalenes as extremely low molecular weight, selective, ratiometric fluorescent probes for mercury(II). Talanta 201: 165–173
- 60. Yuan Y, Chen X, Chen Q, Jiang G, Wang H, Wang J (2019) New switch on fluorescent probe with AIE characteristics for selective and reversible detection of mercury ion in aqueous solution. Anal Biochem 585:113403
- Shinohara Y, Tsukamoto K, Maeda H (2019) A fluorescent turn-on probe for Hg<sup>2+</sup> with a high contrast designed by manipulating functional groups tethered to naphthalimide. J Photochem Photobiol A 371:407–413
- Yuan Y, Guo L, Chen Z, Zhu Y, Feng L, Hu W, Tian M, Wang H, Feng F (2019) A novel quick and highly selective "turn-on"

fluorescent probe for  $\mathrm{Hg}^{2+}$  and its application. Microchem J 147:615–621

- 63. Lv H, Yuan G, Zhang G, Ren Z, He H, Sun Q, Zhang X, Wang S (2020) A novel benzopyran-based colorimetric and near-infrared fluorescent sensor for Hg<sup>2+</sup> and its imaging in living cell and zebrafish. Dyes Pigments 172:107658
- Patel SK, Das D (2020) A novel rhodamine-based optical probe for mercury(II) ion in aqueous medium: a nanomolar detection, wide pH range and real water sample application. Spectrochim Acta A 225:117504

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