Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 126 (2014) 329–332

Contents lists available at ScienceDirect

Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy

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

Short Communication

Convenient and selective "off–on" detection nitric oxide in solution and thin film with quinoline based fluorescence sensor

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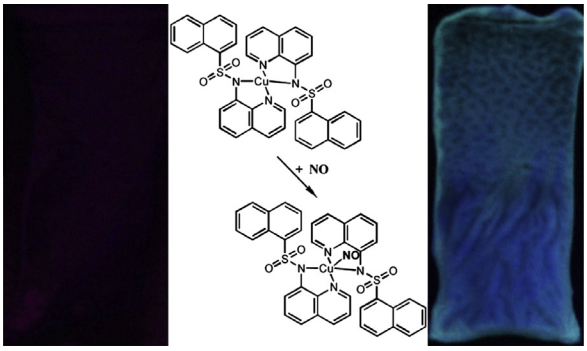
HIGHLIGHTS

- A naphthalene-sulfonamino-quinoline based copper(II) complex has been synthesized to effective probe nitric oxide (NO) in solution and thin film.
- The complex has potential application to meet the detection requirements of a NO assay.

GRAPHICAL ABSTRACT

A naphthalene-sulfonamino-quinoline based copper(II) complex has been synthesized to effective probe nitric oxide (NO) in solution and thin film. The complex has potential application to meet the detection requirements of a NO assay.



ARTICLE INFO

Article history:
Received 25 December 2013
Received in revised form 19 February 2014
Accepted 24 February 2014
Available online 12 March 2014

Keywords:
Nitric oxide
Fluorescence probe
Quinoline
Copper complex

ABSTRACT

Quinoline based fluorescence sensor (**1**) was synthesized and characterized with mass spectra (MS), ^{1}H nuclear magnetic resonance (^{1}H NMR) spectrometer, elemental analyses, and infrared (IR) spectra. Following fluorescence experiments demonstrate **1** can coordinate with copper ions, and lead to fluorescence completely quenched. The **1**-copper complex was used as a "turn-on" fluorescence biosensor to convenient and highly effective detect nitric oxide (NO) over other radicals in solution and PCL-based thin film. The finding would enable the quinoline based fluorescence probe to be an "off–on" convenient NO fluorescence probe.

Introduction

Nitric oxide (NO), a reactive free radical, is produced by inducible and constitutive nitric oxide synthases. NO can act as an important biological mediator of some biological processes in plants and animals [1–6], and modulate the activities of proteins [7], or exert cytotoxic effects on a variety of pathogens, a requirement for understanding fully the details of its biological roles [8]. Due to its significance to human health and disease, development of a convenient and effective detecting method for NO is a challenge for scientists [9]. Possessing high sensitivity and simple manipulation, fluorescence sensing method has been widely regarded as the best tool for tracking NO [10–15].

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http://dx.doi.org/10.1016/j.saa.2014.02.177
1386-1425/

Herein, a quinoline derivative (**1**) was synthesized. Its spectral property has been investigated. The experimental results indicated that it can coordinate with copper ions, and lead to fluorescence completely quenched. Significantly, the copper complex (**2**) exhibited the specific fluorescence "turn-on" sensing ability for NO in either solution or the polycaprolactone (PCL)-based thin film. The results enable the quinoline derivative as a convenient and highly efficient fluorescence "off–on" sensor for NO detection.

Experimental

Materials and methods

All chemicals used in this report were reagent grade unless noted. Polycaprolactone (PCL, M_n 4.5×10^4) was purchased from Sigma–Aldrich Co., Ltd. and used as a polymer matrices. DMF (chromatographically pure), 4-aminobenzenesulfonic acid (SULF), N-(1-naphthyl) ethylenediamine dihydrochloride (NNED), and sodium nitrite were purchased from Aladdin reagent Co., Ltd. Pyridine was dried over CaH_2 for 2–3 days and then distilled prior to use.

Naphthalene-sulfonaminoquinoline (NSQ, 1) was synthesized according to the method of literature. [16] The copper complex ($Cu{\cdot}(NSQ)_2$) was synthesized by a one-step reaction and characterized (Scheme 1).

*Synthesis of naphthalene-sulfonaminoquinoline (NSQ, **1**)*

2-Naphene sulfonate chloride (4.7 g, 0.021 mol) has been added to the 25 mL pyridine solution of 8-amino quinoline (3 g, 0.021 mol) under ice bath. This solution has been stirred under 0 °C for 2 h, and then 60 °C for 5 h. After that, the mixture poured into 200 mL ice water. The precipitate has been collected, and recrystallized with chloroform as slight yellow solid as product (6.2 g, yield 88.4%). MS (ESI): *m/z* 333.1 ($[M–H]^-$), (334.1 calcd for $C_{19}H_{14}N_2O_2S$); ^{1}H NMR ($CDCl_3$, 300 MHz, TMS, ppm): δ 7.364 (m, 3H), 7.504 (m, 2H), 7.679 (m, 2H), 7.968 (d, *J* = 6.3, 1H), 8.026 (m, 2H), 8.373(d, *J* = 5.7, 1H), 8.701(d, *J* = 3, 1H), 8.837(d, *J* = 6.3, 1H), 9.554(s, 1H). Anal. Calcd for $C_{19}H_{14}N_2O_2S$: C, 68.24; H, 4.22; N, 8.38; S, 9.59%. Found: C, 68.16; H, 4.33; N, 8.52; S, 9.31%.

*Synthesis of $Cu{\cdot}(NSQ)_2$ (**2**)*

1 (33.4 mg, 0.1 mmol) and sodium hydroxyl (4 mg, 0.1 mmol) were dissolved in the mixture of dichloromethane (4.5 mL) and methanol (4.5 mL) to obtain a light brown solution. After $CuSO_4{\cdot}5H_2O$ (25 mg, 0.1 mmol) has been added, the solution become dark brown. After stirred overnight under RT, the obtained precipitate was filter out as final product. MS (ESI): *m/z* 752.2 ($[M + Na]^+$), (729.1 calcd for $C_{38}H_{26}CuN_4O_4S_2$); 1482.6 ($[2\,M + Na]^+$), (1482.1 calcd for $NaC_{76}H_{52}Cu_2N_8O_8S_4$); ^{1}H NMR ($CDCl_3$, 300 MHz, TMS, ppm): δ 7.29–7.55 (m, 5H), 7.72–7.88 (m, 3H), 7.92–8.12 (m, 3H), 8.80–8.94 (m, 2H); IR (KBr pellet): ν (cm^{-1}): 3455, 1632, 1580, 1505, 1467, 1383, 1321, 1300, 1267, 1132, 1115, 953, 879, 829, 794, 767, 677, 638, 596, 581. UV–vis (DMF): λ_{mas} (ε) 371 nm ($20\,M^{-1}\,cm^{-1}$), 318 nm ($2.6 \times 10^2\,M^{-1}\,cm^{-1}$), 294 nm ($3.9 \times 10^2$ - $M^{-1}\,cm^{-1}$). Anal. Calcd for $C_{38}H_{26}CuN_4O_4S_2{\cdot}2H_2O$: C, 59.56; H, 3.95; N, 7.31. Found: C, 60.12; H, 4.11; N, 6.97.

Analysis

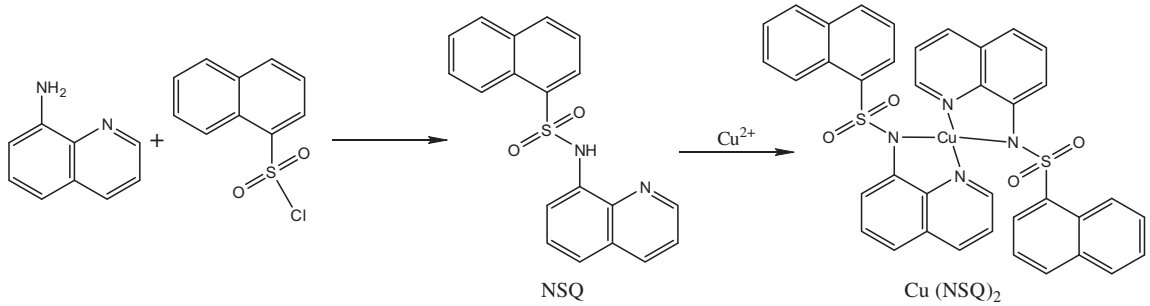
Elemental analyses were performed on a Perkin–Elmer-2400C instrument. Mass spectra were performed on an IonSpec QFT-ESI MS. FT-IR spectra were obtained in KBr pellets with a Bruker Tensor 27 FT-IR instrument. Thermogravimetric (TG) and differential thermal analysis (DTA) were recorded with a Rigaku Standard TG-DTA type. Samples were heated at 10 °C min^{-1} from room temperature to 800 °C in a dynamic nitrogen atmosphere (flow rate = 70 mL min^{-1}). Ultraviolet/visible (UV/vis) spectra were recorded in a conventional quartz cell (light path 10 mm) on a Varian Cary 100 UV–visible spectrophotometer equipped with temperature controller to keep the temperature at 25 °C. Fluorescence spectra were recorded in a conventional quartz cell ($10 \times 10 \times 45$ mm) at 25 °C on a Shimadzu RF-5301PC spectrofluorophotometer (xenon lamp photosource) equipped with a single cell Peltier temperature controller accessory to keep the temperature at 25 °C. Fluorescence images were performed on a ZF-7B three-used ultraviolet analysis instrument (Shanghai Kanghua Biochemistry instrument Co., Ltd.) and a Kodak Z885 zoom digital camera (Eastman Kodak Company) for photo collection. Tri-distill water and N, N-dimethyl formamide (DMF, chromatographically pure) was used as solvent in all spectral measurements without special mentioned.

Results and discussion

The absorption and emission spectral property of **1** has been investigated. The typical UV–vis curves of **1** with the gradual addition of Cu^{2+} has shown in Fig. 1. In Fig. 1a, intensity of absorbance peak at 370 nm gradually increased in the UV–vis spectrum of **1** with the stepwise addition of Cu^{2+}. This absorbance was expected to correspond to the formation of a five-membered chelate ring between two nitrogen atoms in **1** and Cu^{2+}, which extended the conjugated system and thus resulted in the increase of the absorbance at 370 nm. The phenomenon illustrated that the Cu^{2+} was coordinated to **1**.

The IR spectrum displayed the bands of N–H stretching vibration at 3299 cm^{-1} **1** in Fig. 2a have dissappeared in Fig. 2b, which indicated the coordinate complex formed between **1** and Cu^{2+} with N–Cu bond formation.

Therefore, the quinoline based copper complex **2** have been synthesized and characterized with MS (Fig. S3), ^{1}H NMR



Scheme 1. The synthesis process of $Cu(NSQ)_2$ (**2**).

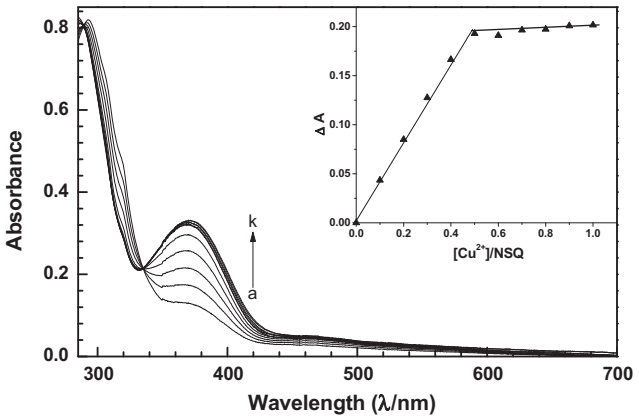


Fig. 1. (a) UV–vis spectra of **1** upon the addition of Cu^{2+} (the counter ion was acetate) in DMF solution at 25 °C. ([**1**] = 50 μM, [Cu^{2+}] = 0–50 μM from a to k) and (b) absorbance changes of **1** at 370 nm upon the addition of Cu^{2+}.

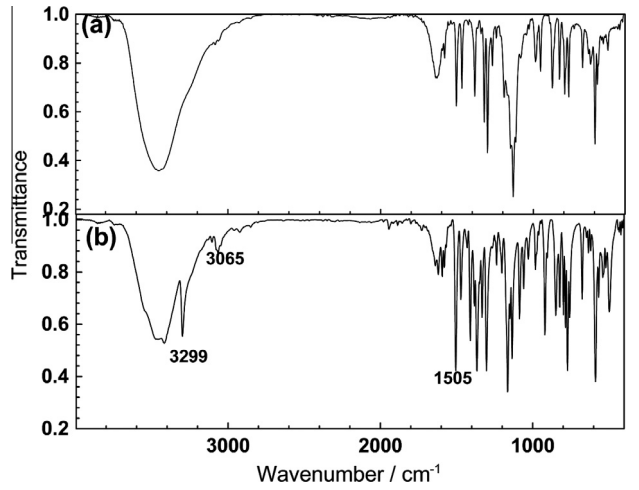


Fig. 2. IR spectra for (a) **2** and (b) **1**.

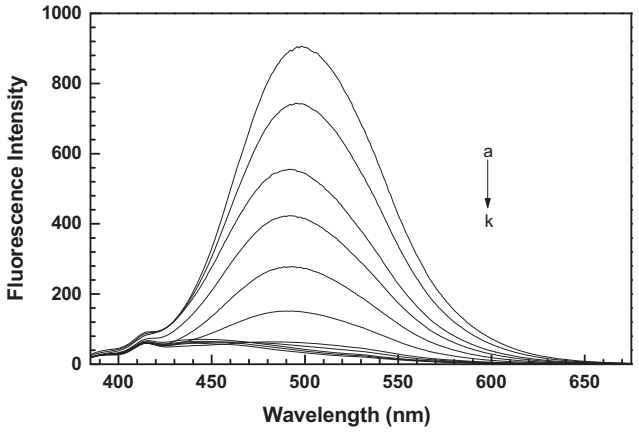


Fig. 3. Fluorescence spectral changes of NSQ (10 μM) with addition of Cu^{2+} (0–10 μM from a to k) in DMF: H_2O (v:v = 1:1) solution at 298 K (λ_{ex} = 370 nm).

(Fig. S4), IR (Fig. 2) and TGA (Fig. S6). Based on these observations, we deduced the coordination mode of **2** as shown in Scheme 1.

Fig. 3 illustrates the fluorescence spectra of **1** with the addition of copper ions in H_2O–DMF (v:v = 2:1) solution. Without metal ions, **1** emitted strong fluorescence. Significantly, the addition of

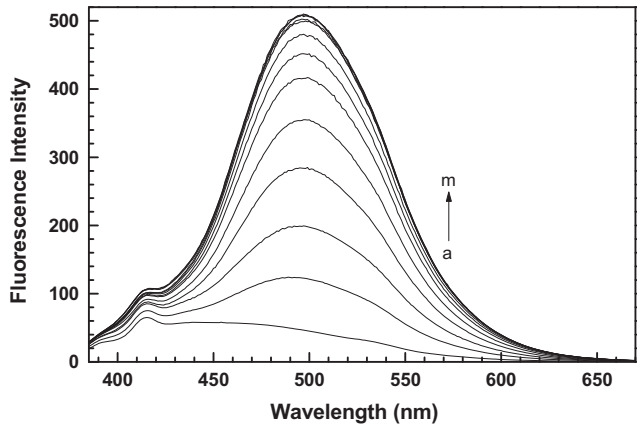


Fig. 4. Fluorescence intensity of **2** with the addition of Sodium Nitroprusside (SNP, to produce NO free radical) in DMF: H_2O (v:v = 1:1) solution at 25 °C. ([**2**] = 10 μM, [SNP] = 0–2.4 mM from a to m, λ_{ex} = 370 nm).

Cu^{2+} led to a remarkably fluorescence "turn-off" of 1 with coordination to Cu^{2+} for the para-magnetism or heavy atom effect.

Since NO can react directly or reversibly with metal ions, [11,12] the excitation spectrum change of **2** with addition of NO has been investigated with a fluorescence spectrometer (Fig. 4). Sodium nitroprusside (SNP) can be used as a nitric oxide (NO) donor for its relatively low cost and well-documented application. [2,17,18] From Figs. S9 and S10, the concentration of NO has been calculated as 12 ± 0.2 μM in SNP (1 mM) aqueous solution with the Griess reaction method. [19] Fig. 4 illuminated the fluorescence intensity of **2** increases in the presence of NO radical. With the addition of NO radical at 1.5 times, the fluorescence intensity (500 nm) for **2** increased about 11 times. And we also done the fluorescence experiments to check the NO sensing ability for different metal ions, and found no clearly change in the presence of NO.

Furthermore, the selective NO fluorescence detection ability of **2** was investigated using a fluorescence spectrometer (Fig. 5). The fluorescence spectra of **2** were also measured with the addition of various radicals, such as superoxide (O_2^-), hydroxyl radicals (·OH), hydrogen peroxide (H_2O_2), hypochlorite (OCl^-), and nitric oxide (NO). The fluorescence intensity of **2** increased significantly (F/F_0 = 11 ± 0.6) with the addition of NO, while the addition of other radicals induced no obvious changes (F/F_0 = 1 for O_2^-, 1.3 for ·OH, 0.9 for H_2O_2, 1.4 for OCl^-). This observation suggests that

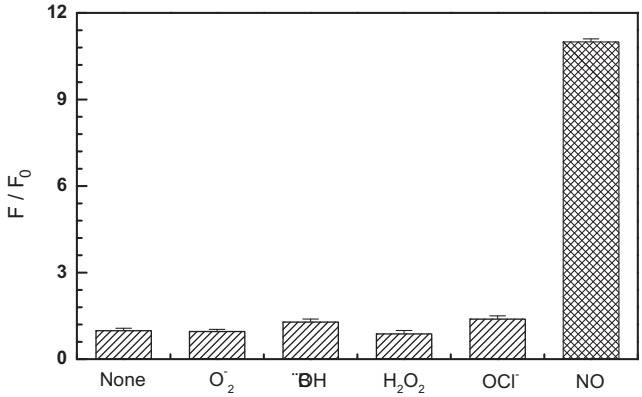
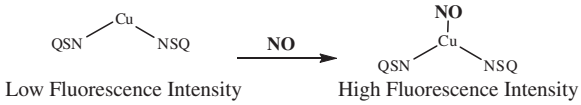


Fig. 5. Relative fluorescence intensities (λ_{em} = 500 nm) of **2** (20 μmol L^{-1}) after the addition of various radicals (λ_{ex} = 370 nm) in DMF: H_2O (v:v = 1:1) at 25 °C. The following donors were used: NaO_2 (O_2^-, 30 μmol L^{-1}), 30 μmol L^{-1} $CuSO_4$/300 μmol L^{-1} H_2O_2/60 μmol L^{-1} ascorbic acid (·OH), H_2O_2 (H_2O_2, 30 μmol L^{-1}), NaOCl (OCl^-, 30 μmol L^{-1}), and SNP (NO donor, 2 mmol L^{-1}).



Scheme 2. The possible reaction mechanism for **2** with NO radicals.

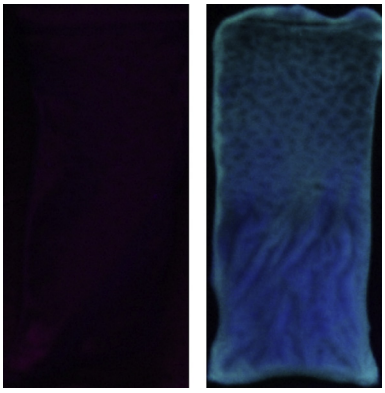


Fig. 6. Images of **2**-contained PCL film in the absence (right) and (left) presence of NO under the low intensity UV light (λ = 360 nm).

2 can be used as a selective fluorescence probe to monitor NO in solution.

In order to investigate the sensing mechanism, the reaction mixture has been characterized with mass spectra. A peak marked with 758.8 appeared in MS (Fig. S5), which corresponding to $[M_{(\mathbf{2}\text{-NO})}–H]^-$, (759.7 calcd for $C_{38}H_{26}CuN_5O_5S_2$). Therefore, the possibly reason for this fluorescence intensity increase phenomena is that the paramagnetic Cu^{2+} react with NO. [20] The possible sensing mechanism of **2** for NO radical has shown in Scheme 2.

Besides in solution, **2** also exhibited the good fluorescence responding ability to NO in organic thin film (Fig. 6), which could be readily distinguished under the UV light. Herein, the organic thin film was prepared by casting the PCL acetonitrile solution of **2** (25 μmol L^{-1}) on glass slips and then obtained as a piece of organic film after dried in air. As can be seen in Fig. 6, the fluorescence intensity of **2** contained PCL film obviously increased after dipped in NO solution, but quite slightly or hardly responded to other radical solution, such as O_2^-, ·OH, H_2O_2, OCl^-, which was basically consistent with the sensing selectivity of **2** in solution.

Conclusion

In conclusion, a quinoline based fluorescence probe has been successfully synthesized and in situ as a selective "off–on" fluorescence probe for NO in either solution or the organic thin film. Considering the convenience in NO-detection, and high sensing specificity for NO over other competing radicals, its copper complex is expected to have potential application to meet the detection requirements of a NO assay by incorporation of an appropriate sensor unit.

Acknowledgement

This work was supported by the National Natural Science Foundation of China (No. 21103061), the Youth Innovation Fund of The First Affiliated Hospital of Zhengzhou University.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.saa.2014.02.177.

References

[1] C.K.B. Ferrari, E.L. França, A.C. Honorio-França, J. Appl. Biomed. 7 (2009) 163.
[2] M.P. Coggins, K.D. Bloch, Arterioscl. Throm. Vas. 27 (2007) 1877.
[3] W. Xu, L.Z. Liu, M. Loizidou, M. Ahmed, I.G. Charles, Cell Res. 12 (5–6) (2002) 311.
[4] A. Besson-Bard, A. Pugin, D. Annu, Rev. Plant Biol. 59 (2008) 21.
[5] T. Nishikawa, E.F. Sato, T. Choudhury, K. Nagata, E. Kasahara, H. Matsui, K. Watanabe, M. Inoue, J. Clin. Biochem. Nutr. 44 (2009) 178.
[6] J.O. Lundberg, E. Weitzberg, M.T. Gladwin, Nat. Rev. 7 (2008) 156.
[7] W. Wang, L. Xue, H. Liu, P. Wang, P. Xu, Y. Cai, Cancer Invest. 28 (2010) 230.
[8] P.N. Coneski, M.H. Schoenfisch, Nitric oxide release part III. Measurement and reporting, Chem. Soc. Rev. 41 (2012) 3753.
[9] G.E. Romanowicz, W. He, M. Nielsen, M.C. Frost, Red. Biol. 1 (2013) 332.
[10] J. Chan, S.C. Dodani, C.J. Chang, Nat. Chem. 4 (2012) 973.
[11] K.J. Huang, H. Wang, W.Z. Xie, H.S. Zhang, Spectrochim. Acta Part A: Mol. Biomol. Spectroscopy 68 (2007) 1180.
[12] M.H. Lim, S.J. Lippard, Acc. Chem. Res. 40 (2007) 41.
[13] L.E. Mcquade, S.J. Lippard, Inorg. Chem. 49 (16) (2010) 7464.
[14] A.W.-T. Choi, C.-S. Poon, H.-W. Liu, H.-K. Cheng, K.K.-W. Lo, New J. Chem. 37 (2013) 1711.
[15] J. Rosenthal, S.J. Lippard, J. Am. Chem. Soc. 132 (16) (2010) 5536.
[16] Y. Liu, M. Yu, Y. Chen, N. Zhang, Bioorg. Med. Chem. 17 (11) (2009) 3887.
[17] P. Filippou, C. Antoniou, V. Fotopoulos, Free Radical Biol. Med. 56 (2013) 172.
[18] J. Bator, J. Varga, G. Berta, T. Barbakadze, D. Mikeladze, J. Ramsden, J. Szeberényi, Sodium nitroprusside, Cell. Mol. Biol. Lett. 17 (2012) 323–332.
[19] L.C. Green, D.A. Wagner, J. Glogowski, P.L. Skipper, J.S. Wishnok, S.R. Tannenbaum, Anal. Biochem. 126 (1982) 131.
[20] D.R. Kearns, A.J. Stone, J. Chem. Phys. 55 (7) (1971) 3383.