Talanta 182 (2018) 116–124

Contents lists available at ScienceDirect

Talanta

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

A turn-on chemiluminescence biosensor for selective and sensitive detection of adenosine based on HKUST-1 and QDs-luminol-aptamer conjugates

Yanna Lin, Yuxue Dai, Yuanling Sun, Chaofan Ding, Weiyan Sun, Xiaodong Zhu, Hao Liu, Chuannan Luo*

Key Laboratory of Interfacial Reaction & Sensing Analysis in Universities of Shandong, School of Chemistry and Chemical Engineering, University of Jinan, Jinan 250022, PR China

ARTICLE INFO

Keywords:
CdTe QDs-luminol-aptamer
Chemiluminescence
HKUST-1
Catalyst
Adenosine

ABSTRACT

In this work, HKUST-1 and QDs-luminol-aptamer conjugates were prepared. The QDs-luminol-aptamer conjugates can be adsorbed by graphene oxide through π-π conjugation. When the adenosine was added, the QDs-luminol-aptamer conjugates were released from magnetic graphene oxide (MGO), the chemiluminescent switch was turned on. It was reported that HKUST-1 can catalyze the chemiluminescence reaction of luminol-H_2O_2 system in an alkaline medium, and improve the chemiluminescence resonance energy transfer (CRET) between chemiluminescence and QDs indirectly. Thus, the adenosine can be detected sensitively. Based on this phenomenon, the excellent platform for detection of adenosine was established. Under the optimized conditions, the linear detection range for adenosine was 1.0×10^{-12}–2.2×10^{-10} mol/L with a detection limit of 2.1×10^{-13} mol/L. The proposed method was successfully used for adenosine detection in biological samples.

1. Introduction

Chemical sensors are commonly used in environmental pollution monitoring [1–5], medical diagnosis [6], biological work [7–9] and other fields. According to the different test objects, chemical sensors can be divided into gas sensors [10], humidity sensors [11], ion sensors [12–15] and biosensors [16,17]. Currently used detection methods are electrochemical, fluorescence, chemiluminescence and surface enhanced Raman spectroscopy. Due to its high sensitivity, simple instruments and wide linearity, chemiluminescence (CL) has been proved to be a powerful technique for trace detection of analytes [18,19]. There are a number of chemiluminescent systems, in which luminol-H_2O_2 is more commonly used. Chemiluminescence resonance energy transfer (CRET) is non-radiative energy transfer from a chemiluminescent donor to an energy acceptor. The conventional CRET was rarely applied to analysis, due to its poor transfer efficiency and a few number of energy acceptors. The introduction of nanomaterials, such as QDs, gold nanoparticles and graphene [20], can effectively improve the inherent drawbacks of CRET.

QDs has large Stokes shifts and high luminescence efficiency, and it is excellent energy acceptor. Due to these merits of QDs, it has been widely used in food [21], disease [22,23] and heavy metal [24] testing. Lin et al. [25] had compared the CL intensity of CdTe quantum dots, CdS quantum dots, and CdSe quantum dots, and they found that CdTe QDs could greatly enhance the CL intensity than that of CdS and CdSe QDs at the same concentration. However, it has been reported that H_2O_2 could oxidize QDs and quench the luminescence [26]. Thus, preventing the oxidation of QDs is particularly important for bioanalysis. Wang et al. [27] synthesized luminol-QDs conjugates for the first time, and they confirmed that an efficient CRET occurred in luminol-QDs conjugates. Duan et al. [28] utilized the QDs@luminol conjugates to construct a sensor for the detection of chrysoidine based on CRET.

Metal-organic frameworks (MOFs) are composed of metal ions or metal clusters and organic ligands. Due to its large surface areas, tunable cavities, controlled pore sizes, and catalysis activity, MOFs have received increasing attention in the fields of gas storage, catalysis, drug delivery and sensing. The group of Dirk E. De Vos [29] observed the well-defined Lewis acid sites and the high selectivities of HKUST-1 for several important isomerization reactions, which are strong incentive for the exploration of MOF as catalysts. In the field of analytical chemistry, the application of MOFs is evolving, especially in biosensors. Luo et al. [30] synthesized a solid catalyst by encapsulating Hemin into the HKUST-1 MOF materials, and constructed a sensor for the detection of H_2O_2 and glucose. They obtained a satisfactory result and shown that the solid catalyst has strong catalytic activity for chemiluminescence. The team of Chen [31] used the catalytic effect of HKUST-1 to construct a sensor for the detection of dopamine, and obtained a satisfactory result. Besides, some other MOFs materials in the biosensor applications

* Corresponding author.
E-mail address: chm_yfl518@163.com (C. Luo).

https://doi.org/10.1016/j.talanta.2018.01.065
Received 26 October 2017; Received in revised form 24 January 2018; Accepted 29 January 2018
Available online 31 January 2018

are also more and more widely [32–37].

The graphene oxide (GO) is mainly composed of carbon atoms in the form of sp^2 hybridized by covalent bonding, having a two-dimensional lamellar structure and a large specific surface area. GO has been widely used in different research areas, such as electronic devices [38], optical communication [39], solar cells [40–42], lithium ion batteries [43,44], DNA sequencing [45], sensors [46,47], supercapacitors [48,49] and adsorbent materials [50]. Since the graphene-based plane has a unoxidized conjugated benzene ring structure, protein and aptamer can be adsorbed on the surface of GO by π-π interaction and electrostatic interaction. Combined with the nature of magnetic graphene oxide (MGO) easy to separate, GO is an important material for building biosensors.

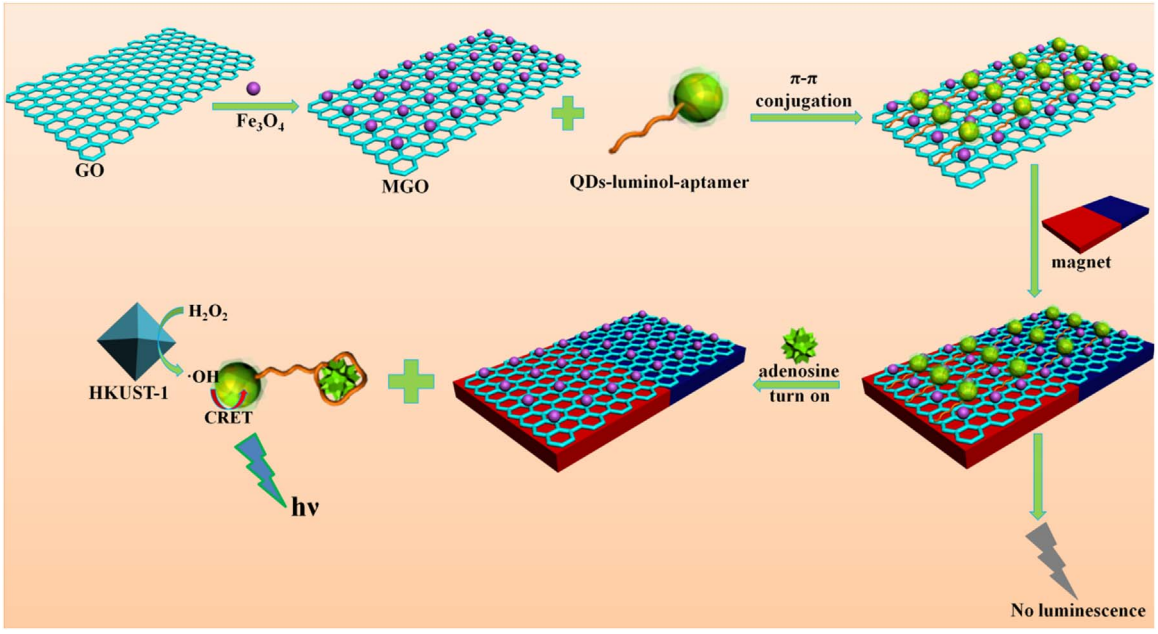
Adenosine is an endogenous nucleoside, and it has physiological effects on the cardiovascular system and other tissues of the body. The study found that the rapid growth of tumors can lead to the degradation of adenine nucleotide and release adenosine, which is highly expressed in tumors [51]. Thus, adenosine can be used as a tumor marker to investigate the development degree of tumor. Sensitive detection of adenosine is of great significance in the diagnosis of clinical diseases. At present, hybridization chain reaction [52], electrochemistry [53,54], fluorescence [55], chemiluminescence [56], and colorimetry [57] have been widely used in the detection of adenosine, the detection limit of these methods range from 3.2×10^{-11} to 4.2×10^{-7} mol/L. In addition, the biological enzyme as a signal amplification factor is also increasingly widely used in the construction of the sensor [53,58,59]. However, the biological enzyme is sensitive to the environment, its activity and stability are difficult to control. Therefore, a new sensitive enzyme-free method for the detection of adenosine is essential.

Herein, coupling with peroxidase activity of HKUST-1 and CRET of QDs-luminol-aptamer conjugates, a magnetic separate "turn-on" chemiluminescence biosensor based on MGO was designed for adenosine detection (Scheme 1). The catalyst was prepared using 1,3,5-benzenetricarboxylic acid as ligand and $Cu(NO_3)_2$ as metal node. Luminol was immobilized on the QDs to improve CRET and prevent QDs from agglomerating and being oxidized. Due to the π-π interaction between aptamer and MGO, the adenosine aptamers were also modified on the surface of QDs to build chemiluminescent switch. In the absence of adenosine, QDs-luminol-aptamer conjugates were adsorbed on MGO, no chemiluminescence signal was detected. When the adenosine was added, the conjugates fell off MGO and the chemiluminescent switch was turned on. For the first time, we combined HKUST-1 with QDs-luminol-aptamer conjugates and used them for the chemiluminescence analysis of adenosine. The resulting QDs-luminol-aptamer composites limit luminol to the surface of QDs, which shortens the distance between the energy donor and the acceptor and improves the CRET efficiency. The ability of aptamers to specifically recognize targets improves the selectivity of the system. The introduction of HKUST-1 accelerates the decomposition of H_2O_2, promotes the chemiluminescence reaction between luminol and H_2O_2, improves the signal to noise ratio, and further improves CRET indirectly. The HKUST-1-based sensor with enhanced light intensity was easily used to detect adenosine with a detection limit of 2.1×10^{-13} mol/L, and shown a great potential in complex samples. The HKUST-1-based strategy has great potential application in signal amplification and monitoring the important biomolecules in the biological system.

2. Experimental section

2.1. Reagents and materials

Cadmium chloride ($CdCl_2$), Sodium thioglycolate (80%), $NaBH_4$ (96%), 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (EDC, 95%) and anhydrous ethanol were purchased from Sinopharm Group Reagent Co., Ltd. (Shanghai, China). Copper nitrate trihydrate ($Cu(NO_3)_2$) was obtained from Tianjin Pepsi Chemical Co., Ltd. (Tianjin, China). Tellurium (Te, 99%), 1,3,5-benzenetricarboxylic acid (H_3BTC, 98%) were purchased from Shanghai Jing chun biochemical Technology Co., Ltd. (Shanghai, China). Methanol, N, N-dimethyl formamide (DMF) were obtained from Tianjin Fuyu Fine Chemical Co., Ltd. (China). N-Hydroxysuccinimide (NHS) was obtained from Shanghai Civi Chemical Technology Co., Ltd. (Shanghai, China). Luminol was purchased from Xiya Co. Ltd. Adenosine purchased from Macklin Biochemical Technology Co., Ltd. (Shanghai, China). Superoxide dismutase and adenosine aptamer were obtained from Sangon Biotechnology Co. Ltd. (Shanghai, China). The sequences of the aptamer is 5′-NH_2-AGA GAA CCT GGG GGA GTA TTG CGG AGG AAG GTT −3′.



Scheme 1. Schematic illustration of CL sensor based on the catalytic effect of HKUST-1.