Chinese Chemical Letters 27 (2016) 395–398

Contents lists available at ScienceDirect

Chinese Chemical Letters

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

Original article

GAG-containing nucleotides as mediators of DNA-silver clusters and iron-DNA interplay

Tian-Tian Chen [a], Qiu-Yun Chen [a,b,*], Ming-Yang Liu [a]

[a] School of Chemistry and Chemical Engineering, Jiangsu University, Zhenjiang 212013, China
[b] State Key Laboratory of Coordination Chemistry, Nanjing University, Nanjing 210093, China

ARTICLE INFO

Article history:
Received 4 September 2015
Received in revised form 18 September 2015
Accepted 3 December 2015
Available online 29 December 2015

Keywords:
DNA
Silver cluster
Fluorescence
Iron

ABSTRACT

New types of fluorescence DNA-based silver nanoclusters (DNA$_n$-AgNCs, n = 1, 2, 3c, 4c, 5c) were synthesized by C3T-rich nucleotides as templates. It is found that the assembly of DNA$_n$-AgNCs with nucleotides containing GAG sequences produce silver clusters with an enhanced red emission. Results indicate that GAG is the good enhancer of DNA$_n$-AgNCs constructed by C3T-rich nucleotides. The fluorescence titration reveals that enhanced red emission is sensitive to Fe(III/II) ions with the formation of non-emission nanoclusters. Thus, the GAG-containing nucleotide can be an enhancer for the emission of silver clusters with C3T-rich nucleotide and a mediator of the iron-cluster interplay.

1. Introduction

Single-strained DNA (ssDNA)-templated silver nanoclusters (DNA-AgNCs) have received increasing attention due to their good biocompatibility and low toxicity [1–3]. Especially, C-rich oligonucleotides have been found to be capable of serving as ideal templates to form highly fluorescent DNA-AgNCs due to the specific nature of the C–Ag$^+$ interaction [4–6]. Nucleic acids are also reported to interact with metal ions through nucleobases and the phosphodiester backbone [7]. The fluorescent properties of DNA-AgNCs can be modulated by the change of the conformation and the size. For example, silver nanoclusters constructed by the bifunctional oligonucleotide were used as fluorescence sensors to sense HepG-2 cells because the complementary sequence can assemble with DNA-AgNCs with the change of conformation and the size [8]. Recently, we found that the near-infrared fluorescent DNA-AgNCs constructed by the bifunctional oligonucleotide with parallel homoduplex conformation could recognize one isomer of boradiazaindacenes (BODIPY) based on the different energy transfer in the DNA-AgNCs-compounds conjugated system [9]. Cytosine bases can bind silver ions, which makes C-rich oligonucleotides a good template to synthesize fluorescent silver nanoclusters [10]. The sequence of CGGGCCAAGAGTGTGCTAAA (DNA$_T$) has been used as forward nucleotides in the measurement of Glucose transporter 1 (GLUT1) by the Polymerase Chain Reaction (PCR) method [11]. The combination of C3T-rich aptamer and CGGGCCAAGAGTGTGCTAAA can form a new bifunctional oligonucleotide, which can be used as a template in the synthesis of high luminescence DNA-AgNCs. Herein, we report new types of assembled DNA-AgNCs and their responses to Fe(III/II) ions.

2. Experimental

All chemicals used were obtained from commercial sources and directly used without additional purification. Cytosine-(C)-rich DNA scaffolds were purchased from Sangon Inc. (Shanghai, China), the sequences of different DNA are shown in Table 1. Silver nitrates ($AgNO_3$), citric acid, $NaBH_4$ and $Fe(NO_3)_3$ were all obtained from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). Transmission electron microscopy (TEM) was performed at room temperature on a JEOL JEM-200CX transmission electron microscope using an accelerating voltage of 200 kV. The electronic absorption spectrum was recorded using a UV-2450 UV–vis spectrophotometer at room temperature. Fluorescence measurements were performed on a fluorescence spectrofluorometer Model CARY Eclipse (VARIAN, USA), a 1.0 cm quartz cell, slit width = 5 nm. The mixtures were subjected to fluorescence measurement. The fluorescence quenching constants were calculated according to the formula: $Q = (F_0 - F)/F_0$ (F_0 is the original

* Corresponding author at: Jiangsu University, School of Chemistry and Chemical Engineering, Zhenjiang 212013, China.
E-mail address: chenqy@ujs.edu.cn (Q.-Y. Chen).

http://dx.doi.org/10.1016/j.cclet.2015.12.013
1001-8417/

Table 1
Oligonucleotides designed for use in this study.

Oligonucleotide	Sequence (5′–3′)
DNA_C	CCCTCCCTTCCCTCCC
DNA_T	CGGGCCAAGAGTGTGCTAAA
DNA_1	CCCTCCCTTCCCTCCCCGGGCCAAGAGTGTGCTAAA
DNA_2	CCCTCCCTTCCCTCCCCGGGTGT
DNA_3	CACTGTCCAAGAGTGTGCTAAA
DNA_4	CACTGTTGTGCTAAA
DNA_5	GAGGAGACAACA
DNA_6	GAGGAG
Complementary-DNA_1	GCCCGGTTCTCACACGATTT

fluorescence intensity; F is the fluorescence intensity of the mixture).

DNA-silver nanoclusters (DNA-AgNCs) were synthesized by combining DNA template and Ag^+ solutions in a 10 mmol/L citrate buffer at pH = 5. The final concentration of $AgNO_3$ and DNA is 6.4 μmol/L and 200 μmol/L, respectively. Then the mixture was heated to 72 °C and maintained for 3 min, followed by slowly cooling to room temperature. The whole cooling process is about 3 h. An aqueous solution of $NaBH_4$ was added to give a final concentration of 2 BH_4^-/Ag^+ (molar ratio) at room temperature, and the resulting solution was vigorously shaken for 1 min and left staying for 3 days in the dark at 4 °C [8].

3. Results and discussion

3.1. Design and characterization of DNA-AgNCs and enhancer sequences

DNA-based silver nanoclusters (DNA_1-AgNCs) were synthesized by using a template containing a C3T-rich scaffold (DNA_C) and an enhance sequence (DNA_T) (Table 1). It can be seen that the DNA_1-AgNCs have the sizes of *ca.* 2–4 nm with an emission maximum at 663 nm (Fig. 1A and B). The UV–vis absorption peaks of the DNA_1-AgNCs are at 410 nm and 600 nm (Fig. 1B). In order to investigate the key section of the DNA_T on the emission of synthesized silver nanoclusters, DNA_1 was divided into DNA_2 (DNA_2 = DNA_C + CGGGTGT (GT are linking sites because GT can recognize CA in DNA_3)) and DNA_3 (CACTGT to replace CGGG in DNA_T) (Table 1), and another kind of DNA-based silver nanoclusters (DNA_2-AgNCs) was obtained. The sizes of DNA_2-AgNCs are in the range of 8–10 nm (Fig. S1A in Supporting information). The DNA_1-AgNCs and DNA_2-AgNCs have the same emission maximum at 663 nm due to the same DNA_C used as the template to stabilize the Ag clusters. The quantum yield (Φ) of DNA_1-AgNCs and DNA_2-AgNCs for the emission at 660 nm is 0.33 and 0.25, respectively, using $Ru(bpy)_3Cl_2$ as reference (Φ = 0.062), which indicates that DNA_3 may be an enhancer nucleotide. This will provide an opportunity to synthesize functional DNA-based sliver nanoclusters with red emission by the assembly of DNA_2-AgNCs with a multifunctional enhancer.

It is interesting to find that once adding DNA_3 (a modified DNA_T) to the solution of DNA_2-AgNCs, an enhanced emission at 663 nm was observed, and when the ratio of DNA_3 and DNA_2-AgNCs came to 1:1, the fluorescence was nearly stable (Fig. 2A), indicating that formation of luminescence DNA_3-DNA_2-AgNCs. To explore the key bases in DNA_3, DNA_4 (no GAG containing sequence) and DNA_5 (double GAG containing sequence) were designed (Table 1) and used as replacer of DNA_3. Fluorescence enhancement was observed after the addition of DNA_5 while DNA_4 had negligible impact on the fluorescence of DNA_2-AgNCs. Hence, this further confirms GAG is an emission enhancer of DNA_2-AgNCs (Fig. S2 in Supporting information). Moreover, the

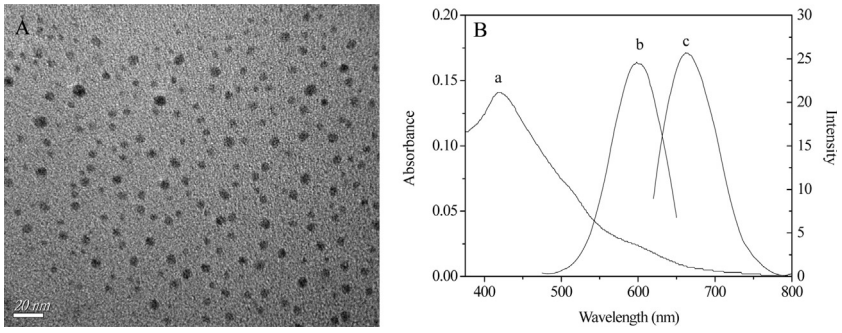

Fig. 1. (A) A TEM image of DNA_1-AgNCs. (B) UV–vis absorption spectrum and fluorescence spectra of DNA_1-AgNCs: (a) the UV–vis absorption spectrum; (b) and (c) the excitation and emission fluorescent spectra, respectively (λ_{ex} = 600 nm, λ_{em} = 663 nm).

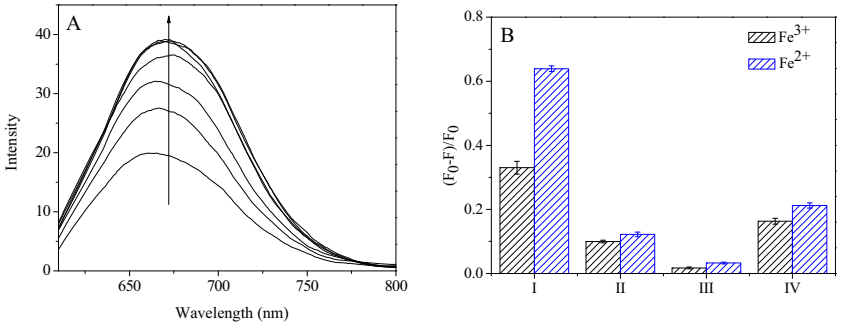

Fig. 2. (A) Emission spectra of the fluorescent DNA_2–AgNCs (λ_{ex} = 600 nm, λ_{em} = 663 nm, 2 μmol/L) in the presence of DNA_3 (the concentration of DNA_3 from the bottom: 0, 0.1, 0. 5, 1.0, 1.5, 2.0, 2.5 μmol/L); (B) the fluorescence quenching constants of the DNA-AgNCs (2 μmol/L) incubated with a concentration of 0.2 μmol/L Fe^{3+} and Fe^{2+} (I: DNA_1-AgNCs, II: DNA_2-AgNCs, III: DNA_{4C}-AgNCs, IV: DNA_{5C}-AgNCs).