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A FACILE SYNTHESIS OF GOLD NANOPARTICLES-ALGINATE COMPOSITE SPHERES

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***Abstract*- Gold nanoparticles have been shown to have interdisciplinary applications in multiple fields. In literatures, several fabrication processes have been developed, but the improvement of the stability and dispersion of the synthesized particles is very important to increase their applicability. In this article, facile approach for the synthesis of gold nanoparticles-alginate composite spheres was presented. The proposed method can stabilize and immobilized gold nanoparticles in alginate matrix simultaneously, and form alginate spheres in one pot process. The fabricated spheres are potential for multi-filed applications, such as bactericide, drug carriers, micro sensors, etc.**

Keywords **-** gold nanoparticles; alginate; one pot synthesis

I. INTRODUCTION

Gold nanoparticles have interdisciplinary applications in multiple fields as preferred materials due to unique optical and physical properties, such as labeling, imaging, catalysis, medicine, environmental science, and photochemical [1-5]. Due to the attractive properties and widely applicability of the gold nanoparticles, several synthesis approaches have been developed, such as chemical reduction, UV photo-activation, laser induction, lysozyme-directed generation, antibiotic mediated synthesis, bioreduction, *etc* [6-13]. The development of facile methods for the preparation of gold nanoparticles with desired sizes, shapes and functions is usually a challenge but intellectually rewarding task [14]. In addition, the stability, dispersion and aggregation of the gold nanoparticles are still important issues that need to be carefully manipulated.

Compared to the abovementioned synthesis method, the approach based on the use of (co)polymers is clearly a useful route for the fabrication of gold nanoparticles with well dispersed and stable structure [15-17]. In the latest decade, several researchers have paid attentions to the synthesis of gold-polymer hybrid structures due to their important applications in biomedical fields, such as bactericides, catalysis, *etc* [18, 19]. Recently, incorporation of nanoparticles in polymer matrices has attracted particular interests for materials engineering and the synthesis of gold nanoparticles [15, 16]. Thiolterminated polystyrene and poly(ethylene oxide) ligands were used to prepare polymer-coated gold nanoparticles with the "grafting-to" approach [16]. A green photochemical approach to make gold nanoparticles grown on calcium alginate gel beads, which was used as both a reduction agent and a stabilizer for the nanoparticles, but a UV irradiation was required [17, 20].

A single-step/single-phase synthesis of hybrid polymeric core–shell gold nanoparticles were fabricated by using amino-functionalized amphiphilic block copolymers for reduction agents and stabilizers simultaneously [21]. The abovementioned researches indicated the importance of gold nanoparticles embedded microspheres.

Synthesis of gold nanoparticles in aqueous media with controllable size, shape and stability could be conducted by using commercial and environmentally beneficial polymers, especially polysaccharide due to its wide applicability in biomedical fields [22, 23]. Alginate, one kind of polysaccharide, is a commonly used biopolymer that can be employed for multiple biomedical applications, such as cell culture, tissue engineering, drugs release, immobilization of enzymes or metal for catalyst, *etc* [24-26]. Alginate hydrogels, due to their mild reducing ability, excellent biocompatibility and inexpensive price, have shown to be good stabilizer and template of metal nanoparticles synthesis, such as Ag, Co, Ni and iron oxide, *etc* [25, 27, 28]. Although aqueous sodium alginate is very suitable as a scaffold matrix for metal nanoparticle synthesis, there are few reports on alginate reduced and stabilized gold nanoparticles [20].

Herein by using alginate as a reductant and stabilizer, we present a facile one-pot approach to fabricate gold nanoparticles-alginate composite spheres. Gold ions were reduced to nanoparticles in sodium alginate solution, and immobilized in an alginate sphere after solidification (**Fig. 1**). The characteristics of the fabricated spheres were characterized by optical microscopy, scanning electron microscopy (SEM), energy dispersive spectrum (EDS), UV-Vis spectroscopy and Fourier transform infrared spectroscopy (FTIR).

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II. MATERIALS AND METHODS

2.1 Materials

Hydrogen tetrachloroaurate (III) trihydrate, ACS, 99.99% (metals basis, Au 49.5% min) was purchased from Alfa Aesar-A Johnson Matthey Company (Alfa Aesar 26 Parkridge Rd Ward Hill, MA 01835 USA). Calcium chloride ($CaCl_2 \cdot H_2O_2$, granular) was purchased from J.T.Baker®. Alginic acid sodium salt (viscosity ≥ 2,000 cP, 2 % (25 °C)(lit.)) was purchased from Sigma-Aldrich (Sigma Chemical Co., St. Louis, MO, USA). All the chemicals were used as received without further purification.

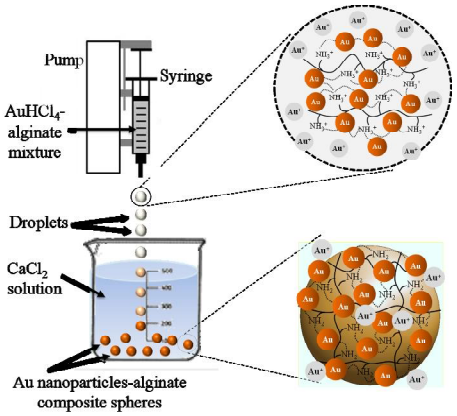


Fig. 1 Schematic graph for the synthesis strategy of gold nanoparticles-alginate composite sphere.

2.2 Synthesis of the alginate spheres

The 2 % alginic acid sodium salt (0.2 g, dissolved in 10 mL dd-water) were dropped into 5 % $CaCl_2$ solutions (12.5 g, dissolved in 250 mL dd-water) by means of a syringe and pump. Alginate spheres were obtained in 15 minutes. Spheres were then collected and washed twice with 30 mL dd-H_2O to remove residues. The synthesized spheres were then put in a freeze dryer (EYELA FDU-1100) in vacuum at -54 °C for 48 hours. The dried spheres were stored at 25 °C until use.

2.3 Synthesis of the gold nanoparticles-chitosan composite spheres

The hydrogen tetrachloroaurate (III) trihydrate ($HAuCl_4$) was diluted as 4 mM and then added to the 2 % alginic acid sodium salt (0.2 g, dissolved in 10 mL dd-water) to form a $HAuCl_4$-alginic acid sodium salt mixture. The blended solution was kept still for various time intervals (0.5 hour, 1 hour, 2 hours and 4 hours, respectively). The color of the solution became more and more reddish due to the gradually formation of gold nanoparticles. It was shown that Au^{3+} can be reduced as gold nanoparticles at the existence of alginate [20]. According to our previous studies, the one-step production of gold nanoparticles-alginate composite spheres was implemented (**Fig. 1**). The gold-alginate solution was then dropped into 5 % $CaCl_2$ solutions (12.5 g, dissolved in 250 mL dd-water) by means of a syringe and pump. Gold nanoparticles-alginate composite spheres having a reddish color were obtained in 15 minutes. Spheres were then collected and washed twice with 30 mL dd-water to remove residue alkali. The spheres were then put in a freeze dryer (EYELA FDU-1100) in vacuum at -54 °C for 48 hours. The dried spheres were stored at 25 °C until use.

2.4 Characterization process

The average diameter of the particles, expressed as mean ± standard deviation, was obtained from the photographs by random sampling of about 50 individual particles to minimize selection bias. Fourier transform infrared spectroscopy (FTIR) spectra were recorded with a Spectrum RXI FTIR Spectrometer, using KBr pellets, in the range of 400 ~ 4000 cm^{-1}, with a resolution of 4 cm^{-1}. The morphology of the gold-alginate composite spheres was analyzed using a scanning electron microscope (SEM, Hitachi, S-2700, Japan) equipped with an energy dispersive spectroscopy (EDS) capability. Further characterizing the existence of gold nanoparticles was carried out with an UV-Visible absorbance spectroscopy (Thermo scientific Spectrascan UV 2700 spectrophotometer).

III. RESULTS AND DISCUSSIONS

3.1 Morphology

Figure 2 shows the gold-alginate composite spheres obtained from $HAuCl_4$–alginate mixture with various time interval of mixing before solidification. The fabricated spheres looked more and more reddish with increasing time interval of mixing (**Figs. 2A ~ 2C**), especially that with 4 hours (**Fig. 2D**). The color changes provided some clues to the formation of gold nanoparticles [27].

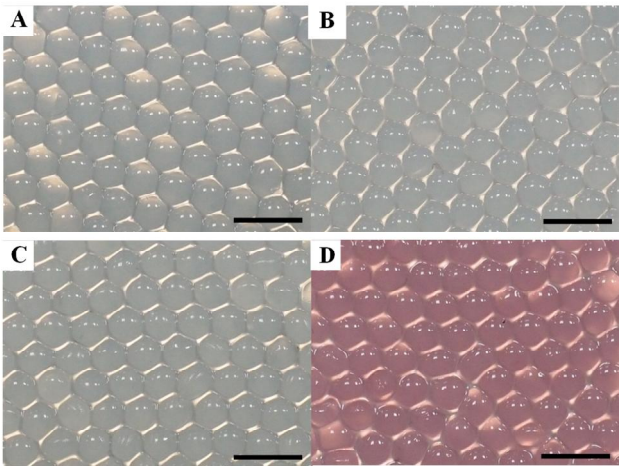


Fig. 2 Photographs of the synthesized spheres with various time intervals of $HAuCl_4$ and alginate mixing before made as droplets and dropped into the solidification solution. **(A)** mixed for 30 minutes, **(B)** mixed for 1 hour, **(C)** mixed for 2 hours and **(D)** mixed for 4 hours. Hydrogen tetrachloroaurate (III) trihydrate ($HAuCl_4$) of 4 mM was added to 2 % of alginate to form a $HAuCl_4$ – alginate mixture. All scale bars are 2 mm.

The appearances and diameters of spheres have no obvious alterations with various time intervals of mixing. The relative standard deviation of the sphere diameters with various mixing time of $HAuCl_4$ and sodium alginate solution was less than 10 %, suggesting that the manufactured spheres meet the typical criterion for monodispersity (**Table 1**).

TABLE I AVERAGE SPHERE DIAMETER

Mixing time (hours)	Sphere diameter (mm)	S.D.* (mm)	R.S.D.** (%)
0.5	922	48	5.2
1	879	41	4.7
2	875	54	6.2
3	912	53	5.9
4	890	55	6.2

* S.D. : standard deviation; ** R.S.D. : relative standard deviation

Figure 3 shows the effect for the viscosity of alginate on the synthesis of gold nanoparticles. It is found that alginate with low viscosity (cps = 150, 250 and 350, **Figs. 3A** ~ **3C**) the reddish color was not as apparent as that with high viscosity (cps = 3500, **Fig. 3D**). The color changes indicated that high viscosity of alginate was advantageous for formation of gold nanoparticles.

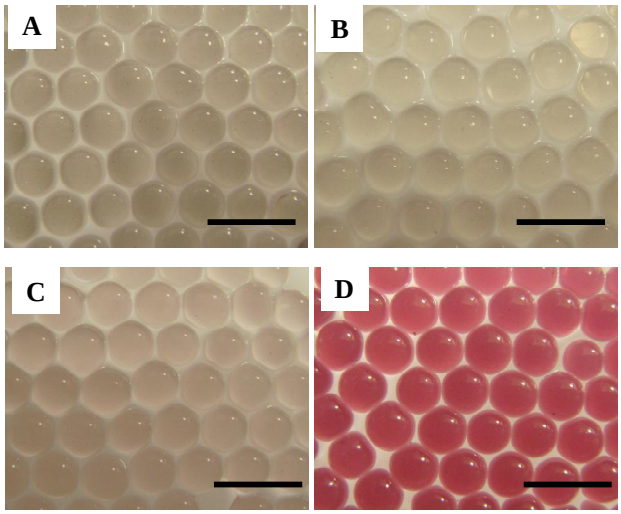


Fig. 3 Photographs of the synthesized gold nanoparticles-alginate spheres with various cps of alginate. **(A)** 150 cps, **(B)** 250 cps, **(C)** 350 cps and **(D)** 3500 cps. The concentration of alginate was 2 %. All scale bars are 2 mm.

Generally there are two different approaches utilized for gold nanoparticles-polymer composite structures. One is a more conventional method that polymerize the matrix around pre-synthesized metal nanoparticles [24, 26]. This approach can fully control the desired size of nanoparticle and the polymer structures to generate various composite materials [15]. A basic limitation for this approach is that the combination of two synthesis processes is always required. The other approach is the *in situ* preparation of the nanoparticles before or during the gelation of the polymer matrix [13, 18, 19, 21, 28].

The common features for this one-step approach are the facilitation of polymers as reductants and stabilizers simultaneously, which is more facile and greener in some aspects. Some limitations, however, are that external processing such as heating, photo-activation or surfactant were usually required [19, 21, 28], or the efficiency may be influenced by the metal salts dissolvability in the polymer matrix [21]. Alginate hydrogels have mild reducing ability for gold nanoparticles with excellent biocompatibility. To our knowledge, this is the first report to fabricate gold nanoparticles composite-alginate spheres in one pot. A similar study on the synthesized gold nanoparticles composite-alginate non-spherical structures were show to process medical and biological applications [20].

3.2 **Characterization**

Figure 4 shows the SEM photographs and EDS of the prepared spheres (with 4 mM $HAuCl_4$, 2 % alginic acid sodium, and 5 % $CaCl_2$ solution). **Figures 4A** ~ **4B** show the SEM graphs of an intact alginate sphere and its sectioned counterpart. **Figures 4C** ~ **4D** show the SEM graphs of some intact gold nanoparticles-alginate composite spheres and the sectioned counterpart. Compared with the appearance of alginate spheres with and without gold nanoparticles, we found the former has smoother surface than the latter including the outer and intra surfaces. **Figure 4E** shows the zoom in counterpart of **Fig. 4C**. **Figure 4F** shows energy dispersive spectroscopy (EDS) of the gold nanoparticles deposited on the outer surface (**Fig. 4C**) of the synthesized Au-alginate composite spheres. The data indicate that gold nanoparticles were embedded in the synthesized spheres [20].

Figure 5A shows the UV-Visible absorbance spectra of the synthesized gold-alginate composite spheres. It is known that neat alginates solution has no optical absorbance in UV-Visible range and therefore did not contribute to the absorption spectrum [17, 27]. The UV-Visible absorbance spectrum of the synthesized spheres has two main peaks: one is at 275 nm which is the characteristic peak of Au^{3+}, while the one at 520 nm is the characteristic peak of gold nanoparticles with diameter of 10-20 nm. Therefore both the gold nanoparticles and Au^{3+} ions were embedded in the alginate spheres.

Gold nanoparticles-alginate interactions were studied by FTIR analysis. **Figure 5B** shows the FTIR spectra of the gold-alginate composite spheres. **Curve a** indicated the FTIR spectrum of pure alginate spheres, while **curve b** represents the FTIR spectrum of gold nanoparticles-alginate composite spheres. The bands around 3481 cm^{-1} to 3483 cm^{-1} were related to the stretching vibrations of O-H groups. The bands around 1619 cm^{-1} to 1637 cm^{-1} were corresponding to alkane C=O stretching. The band around 1425 cm^{-1} corresponds to C-OH groups. These bands are characteristic of the carboxylate ions. The band around 1023 cm^{-1} to 1028 cm^{-1} corresponds to C=C stretching of OC-OH groups, which is related to O-glycosidic bonding between β-D-mannuronic and α-L-guluronic acid residues and is an indication of the degree of stability of the linear chain in the alginate. All bands of gold nanoparticles-alginate composite spheres (**curve b**) show a lower intensity than pure alginate spheres (**curve b**) due to the degradation of the alginate structure.

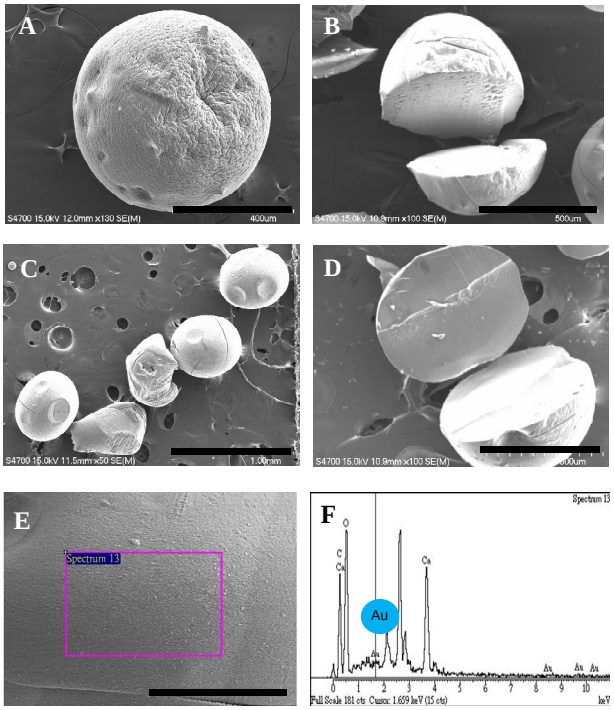
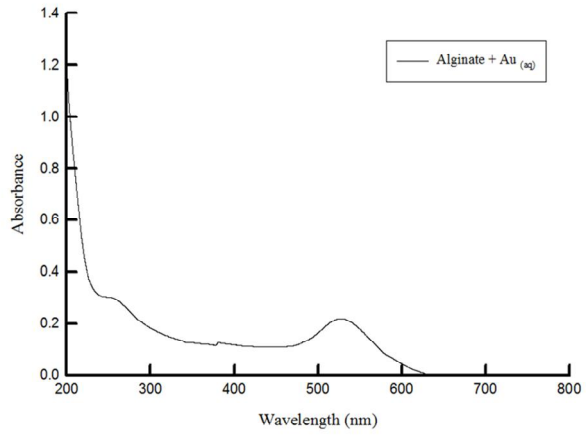


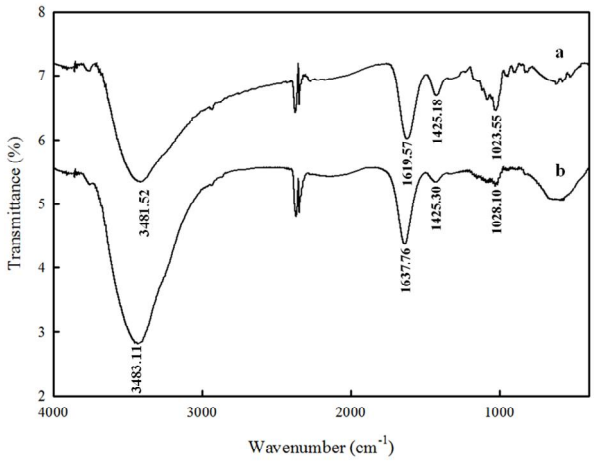
Fig. 4 The SEM photographs and EDS of the synthesized spheres. Panel **(A)** is the SEM photograph of an intact alginate sphere. Panel **(B)** is the SEM photograph of a sectioned alginate sphere. Panel **(C)** is the intact Au nanoparticles-alginate composite spheres. Panel **(D)** is the SEM photograph of a sectioned Au nanoparticles-alginate composite sphere. Panel **(E)** represents the zoom in counterpart of panel **(D)**. Panel **(F)** represented the EDS of the corresponding area indicated in panel **(E)**. The scale bars are 400 μm for panel **(A)**, 500 μm for panel **(B),** 1000 μm for panel **(C)**, 500 μm for panel **(D)**, and 200 μm for panel **(E).**

IV. CONCLUSION

We propose an approach for the manufacture of gold nanoparticles-alginate composite spheres that can stabilize and immobilize gold nanoparticles and form alginate spheres in a one pot. Currently the diameters of the fabricated spheres were about 890 μm to 922 μm, but it is possible to significantly reduce the particle size by employing electrostatic or microfluidic droplets technology in the future. The successful formation of gold nanoparticles was evaluated with UV-Visible, FTIR and EDS spectroscopy. UV-Visible spectroscopy shows a characteristic peak around 520 nm, corresponding to gold nanoparticles size of 10 nm to 20 nm. Due to the specific properties of gold nanoparticles, the prepared gold nanoparticles-alginate composite spheres are potential for use in multidisciplinary applications. Compared with other approaches, the main advantages of this approach are: (i) uniform-sized spheres can be continuously fabricated in one step process, (ii) gold nanoparticles could be obtained, and stabilized and immobilized simultaneously in alginate matrix, and (iii) spherical shapes can have wider-range applications compared with other structures.



(A)



(B)

Fig. 5 The UV-Vis and FTIR spectrum and XRD graphs of the fabricated Au nanoparticles-alginate composite spheres

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