Inorganic Chemistry Communications 93 (2018) 78–82

Contents lists available at ScienceDirect

Inorganic Chemistry Communications

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

Short communication

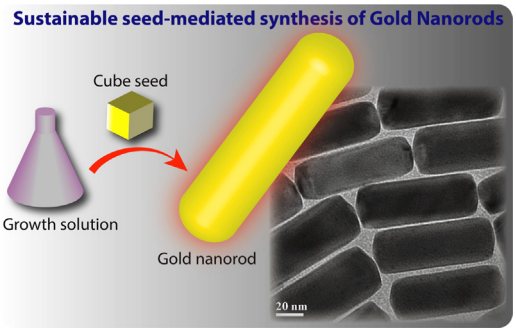
Sustainable synthesis of gold nanorods assisted by cubic-shaped seeds as intermediate particles

Shofarul Wustoni*, Dinh-Tuan Phan

Department of Biomedical Engineering, National University of Singapore (NUS), Singapore 119077, Singapore

GRAPHICAL ABSTRACT

We report a simple and sustainable synthesis of gold nanorods via seed-mediated technique utilizing an essential facet seed prepared in the mild temperature (35 °C). Such kind of seed particles can continuously generate well-defined gold nanorods with tunable plasmonic wavelength.



ARTICLE INFO

Keywords:
Gold nanorods
Nanoparticles
Seed-mediated technique
Sustainable synthesis

ABSTRACT

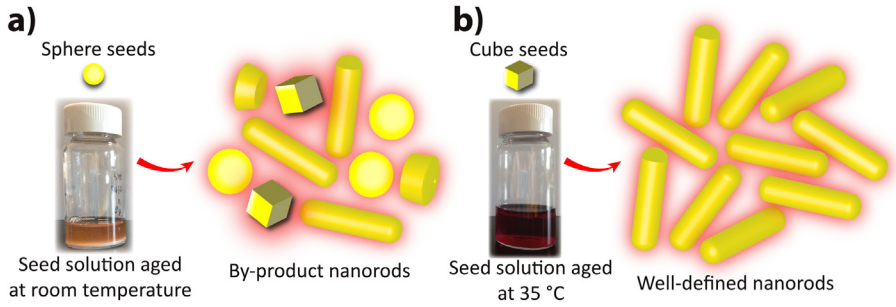
We demonstrate a simple and novel approach for continuously production of gold nanorods via seed-mediated technique. By utilizing a critical shape of seeds (e.g. cubic-shaped particle) which is prepared by incubation at 35 °C, we found that this specific seed can effectively transform into nanorods. The advantage of this synthesis route can offers stable seeds to generate nanorods, even undergo long-term aging process, and would significantly reduce the amount and frequency use of hazardous material (e.g. $NaBH_4$) for preparing the fresh seed solution. Reliability for scalable and repeatable production of this method are discussed.

This work presents a novel finding on the role of seed size and shape, particularly we emphasize a unique approach to use an intermediate shape particle as nucleation sites that can trigger the seed transformation into the growth of gold nanorods (GNRs). GNRs in the past decades have drawn more attentions due to their remarkable physical and chemical properties depending on the size and aspect ratio of rod-shaped structure. It has tremendous potential in forefronts of research applications, for instance, the exceptional and interesting practice of GNRs in the bioengineering field to be incorporated with various biomolecules for photothermal imaging [1], therapeutic system [2], drug carriers [3] and bio-sensing [4–5]. Hence, a simple and versatile approach is greatly desirable and of utmost importance by means of applicable method for routine, long-term and mass production of GNRs.

A wide range of synthetic methods have been established and demonstrated for growing the GNRs for example the use of templates and colloidal synthesis routes [6–7]. The colloidal route involves an active directing agent, mainly surfactant, via electrochemical [8] or seed-mediated growth technique [9]. To date, seed-mediated synthesis routes, which pioneered by Prof. Murphy's group and Prof. El-Sayed's group; have been found as a robust and facile method to produce high yield GNRs [10–11]. Since the widely used of GNRs in the various

* Corresponding author at: Biological and Environmental Science and Engineering, King Abdullah University of Science and Technology (KAUST), Thuwal 23955-6900, Saudi Arabia.
E-mail address: shofarul.wustoni@kaust.edu.sa (S. Wustoni).

https://doi.org/10.1016/j.inoche.2018.05.014
Received 21 January 2018; Received in revised form 8 May 2018; Accepted 10 May 2018



Scheme 1. Synthesis of gold nanorods via seed-mediated technique. Comparison of products from synthesis batches by using aged seed solutions at room temperature 25 °C (a) or oven 35 °C (b).

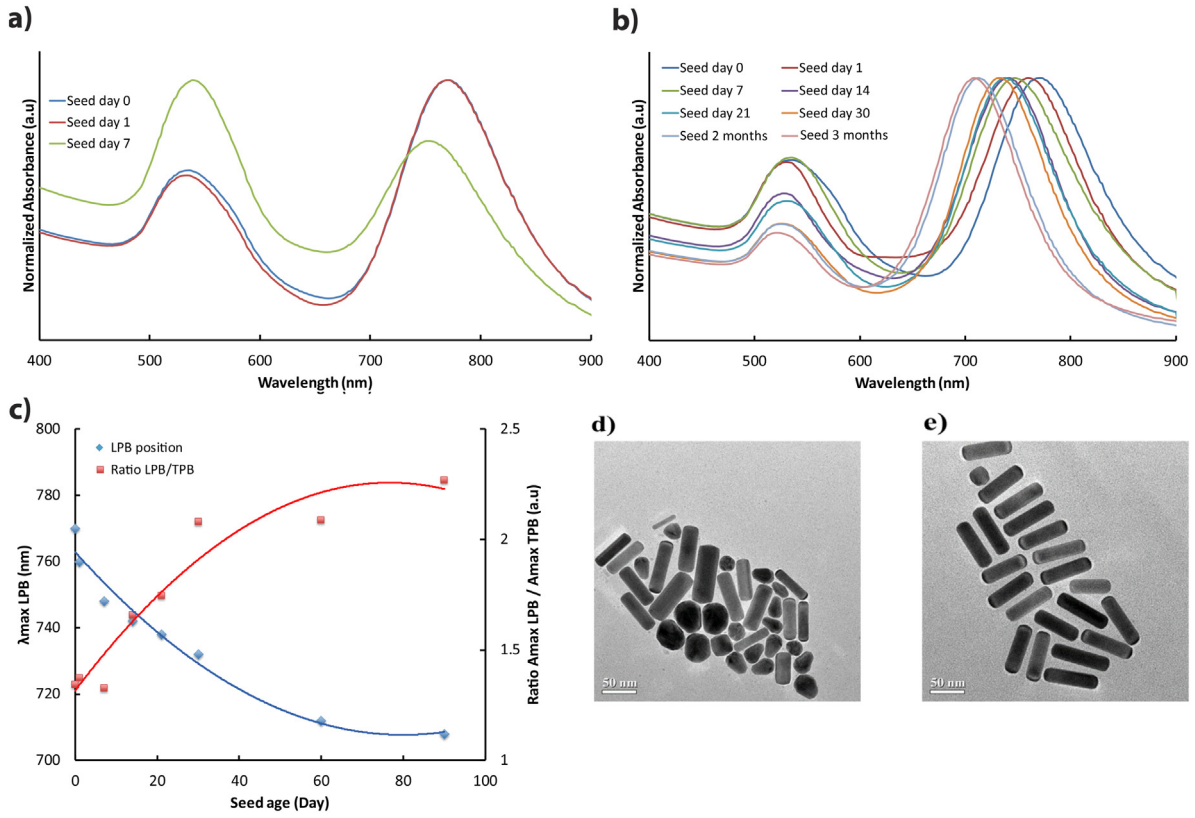


Fig. 1. UV–Vis spectra and TEM images of synthesized gold nanorods (GNRs). Normalized absorbance spectra of GNRs generated using seed A (a) and seed B (b) in the different aging time. (c) Temporal changes of longitudinal plasmon peak wavelength and ratio of maximum absorbance of LPB/TPB corresponding to the age of seed B. TEM images of synthesized GNRs by using seed A aged for 7 days (d), seed B aged for 7 days (e). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

research applications, there is a great interest to use the seed-mediated technique as the most demonstrated and promising technique, which can produces high-quality and large amount of nanorods [12–15].

A variety of experimental attempts had been performed to address deeper understanding in the growth mechanism of GNRs using the seed-mediated technique, it is well known that the seeds play key roles along with other parameters such as solvent, surfactant, etc., to control and tune the oriented growth and better-defined shape of nanorods [16–18]. While a common adopted protocol for conducting seed-mediated synthesis of GNRs is that the small seed, which is initially prepared using strong reducing agent (sodium borohydride, $NaBH_4$), with size range 1.5–4 nm should be in fresh solution and immediately used [19–21], we would be unable to acquire nanorods otherwise. These small and pseudo-spherical seeds are considered to be critical for serving as nucleation sites of anisotropic growth of nanorods particles. During the last decade, a number of studies suggested dramatic decrease in yield of GNRs synthesized using the aged seed, which mostly has converted to be sphere particles, under aging process at room temperature or refrigerator [22–24]. It was concluded that gold seeds with aging process over a period of days are unstable and could not produce well-defined nanorods. This issue technically constrains a routine process of seed-mediated synthesis technique, which requires the preparation of fresh seed solution and also renders frequency use and leave a waste of hazardous material ($NaBH_4$) to prepare the seeds solutions, since it is usually prepared in milliliter scale and just used for a few microliter. To overcome this challenge, we were inspired from findings that cubic-shaped particle [25–26] is an essential intermediate stage for growing anisotropic form of nanorods. Therefore, we attempt, for the first time, to explore the use of this intermediate stage particle as critical and paramount facet of seeds that can continuously transform into nanorods in which these particles seeds can be simply developed by incubation at 35 °C as illustrated in Scheme 1.

In this study, we manipulate initial prepared seed solutions to be differently size and shape seed particles through the aging process by