Materials Chemistry and Physics 207 (2018) 373–379

Contents lists available at ScienceDirect

Materials Chemistry and Physics

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

Yeast cells carrying metal nanoparticles

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HIGHLIGHTS

- Yeast cells were used as carriers for hosting metal nanoparticles via *in situ* metal ion reduction.
- Yeast cells carrying metal nanoparticles are "green" hierarchical particle systems without any chemical stabilizers or dispersants.
- Ag nanoparticles with size of about 4 nm were produced inside yeast cells by UV illumination.
- Ag nanoparticles with size of about 9 nm were produced in the cell envelope by chemical reduction.
- Pd nanoparticles with size of about 11 nm were almost evenly distributed in every parts of yeast cells.

ARTICLE INFO

Article history:
Available online 2 January 2018

Keywords:
Yeast cells
Nanoparticles
Metal particles
Silver
Palladium

ABSTRACT

Yeast cells can be used as carriers for hosting metal nanoparticles via *in situ* metal ion reduction methods. We synthesized Ag and Pd nanoparticles (NPs) located in different positions of yeast cells, either in yeast cell envelope or inside yeast cells. Ag NPs were able to grow at the cell wall and inside the cells depending on the preparation methods. Glucans at the cell wall functioned as reductive reagents in Tollens's reaction and Ag NPs with average size of about 9 nm (measured with Scherrer equation) were formed covering yeast cells. By UV illumination on yeast cells with $AgNO_3$ solution imported in cytoplasm in advance, Ag nanoparticles with size of about 4 nm were produced inside yeast cells. UV illumination in the presence of Ag ions could carbonize the yeast cells as indicated by Raman spectroscopic analysis, which may be conducive to establishing new sterilization mechanism. Yeast cells carrying palladium nanoparticles were also synthesized by hydrazine hydrate reduction inside cells. It was found that Pd nanoparticles with size of about 11 nm were almost evenly distributed in every parts of yeast cells, in the envelope and inside cells. Ag NPs and Pd NPs on yeast cells were observed with optical microscopy, scanning electronic microscopy (SEM), and transmission electron microscopy (TEM). Crystal structures of Ag NPs and Pd NPs were confirmed by X-ray powder diffraction (XRD). The sizes of the NPs were calculated based on XRD results and Scherrer equation. The size distribution of NPs was obtained by counting the sizes of NPs on TEM images. Those results showed that easily affordable yeast cells are good bio-carriers for synthesis and stabilization of metal nanoparticles in aqueous environments, and no other chemical stabilizers were needed. The yeast carrying metal nanoparticles structures may find applications in medical or environmental treatment fields.

1. Introduction

Nanoparticles including metal nanoparticles exhibit unique catalytic properties [1–7], and can potentially be utilized in biomedical sciences or many daily necessities fields [8–10], besides in the areas such as optics and electronics [11–13]. For example, silver nanoparticles have a broad spectrum of antimicrobial properties [14–18]. Palladium nanoparticles are the catalyst for the Suzuki reactions [19]. Yusop et al. succeeded in importing palladium nanoparticles (encapsulated in polystyrene particles) into HeLa cells and catalyzing a Suzuki reaction inside HeLa cells [20]. However, nanoparticles' toxicity and the use of toxic chemicals for stabilizing these nanoparticles have become a great concern, especially for their applications in biological and medical fields. Polymers enabling initial strong interaction with metal salts were

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https://doi.org/10.1016/j.matchemphys.2018.01.001
0254-0584/

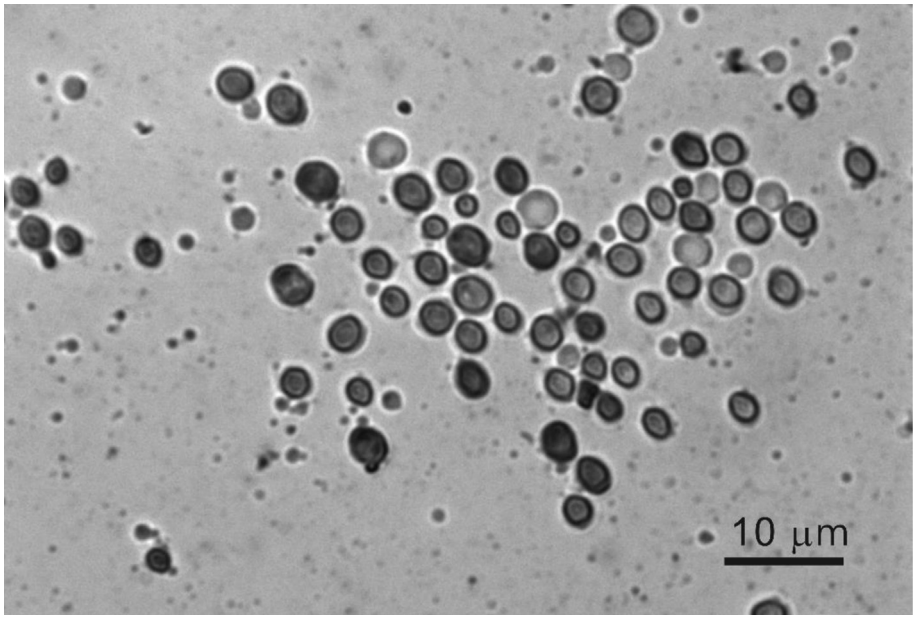

Fig. 1. Optical microscopy image of yeast cells carrying silver nanoparticles by Tollens' reaction.

often used for the stabilization of metal nanoparticles. The synthesis of metal nanoparticles stabilized by some dendrimer [21–25], hyperbranched macromolecules [26–28], polymer micelle [29], and polymer gel [30,31] were reported. Some living microbes are able to enrich metal ions from environments and to produce metal nanoparticles in metabolic processes [32–37]. However, biosynthesis approaches found difficulties in control over size distribution and shape of nanoparticles [38].

Viewed from the perspective of materials science, the cells of baker's yeast (*Saccharomyces cerevisiae*) are not only bio-macromolecular microparticles with envelope composed of glycoproteins, β-glucans, and chitin [39,40], but also micro-containers (or microcapsules) with double barriers i.e., the rigid cell wall and the selective permeable plasma membrane [41]. The plasma membrane plays an attractive role for encapsulation. Compared with biosynthesis by living yeast cells, a chemical synthesis approach is obviously more efficient in producing metal nanoparticles inside cells, however, the latter is scarcely reported in the literature.

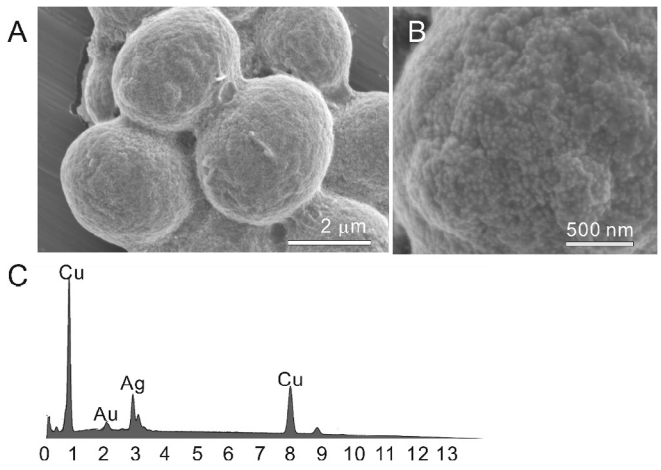

Fig. 2. SEM images and EDS analysis of yeast cells carrying Ag nanoparticles on the surface. B, Details of Ag covered cell surface. C, EDS spectrum.

Recently, we produced polymer nanoparticles inside yeast cells [42]. Our work showed that polymerization of vinyl monomers inside the yeast microcapsules is an efficient way to produce hierarchy particle structures with yeast particles encapsulating polymer nanoparticles. During the course of the investigation of polymerization inside yeast cells, we realized that yeast cells can be also used to host metal nanoparticles. However, the formation of metal nanoparticles in yeast cells is different from that of polymer particles in some aspects. The first, retention of metal salts inside yeast cells is of concern. Metal nanoparticles can be generally formed by intracellular reducing reaction of metal salts, which can be fulfilled in a three-step procedure, i.e. transport of metal salts in aqueous solution into cells via passive diffusion, removal of extracellular salts and then transport of reducing reagents into cells to carry out the reduction reaction. Polar metal salts may be easier to diffuse into cells, however, also easier to be rinsed away than oily vinyl monomers. The second, either the thin cell envelope or the cytoplasm volume inside yeast cells can be used to host metal nanoparticles. Location of metal particles in different parts of a yeast cell may affect their functional performances, immune responses etc., after they have been introduced into the body. Metal nanoparticles encapsulated inside yeast cells may be easily transported into human cells [42]. When metal nanoparticles are supported on the surface of yeast cells, their catalytic performances may be enhanced especially for environmental treatment.

In this work, we use easily affordable yeast cells as a matrix to synthesize and stabilize metal nanoparticles by high efficient chemical engineering method. We intent to control the location of nanoparticles in the cell envelope or inside the cells of yeast.

2. Material and methods

2.1. Materials

Silver nitrate ($AgNO_3$, 99%), hydrazine hydrate (99%), and palladium acetate (99%) were bought from Sinopharm Chemical Reagent Co. and used as received. Active dry Baker's yeast was purchased from Angel Yeast Co. Ltd., China.