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Regular Article

Synthesis of various 3D porous gold-based alloy nanostructures with branched shapes

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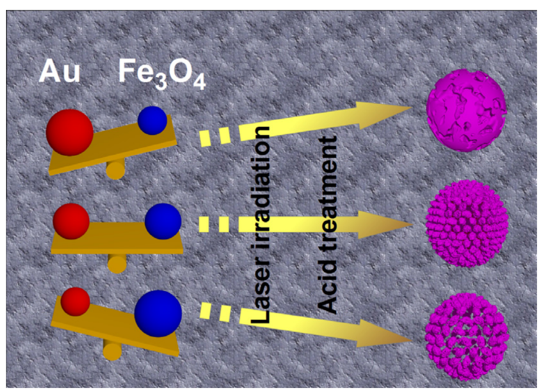
HIGHLIGHTS

- Selective laser heating was shown as synthesis platform for porous nanostructures.
- 3D porous gold-based nanostructures with different morphologies were obtained.
- Various nanoarchitectures were obtained by varying the experimental conditions.

GRAPHICAL ABSTRACT

3D porous gold-iron nanostructures with various nanoarchitectures (brain-like, flower-like, cage-like, or raspberry-like structures) were synthesis by selective laser heating of colloidal nanoparticles and selective acid treatment.



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ABSTRACT

This paper presents a facile and flexible synthesis platform for various 3D porous gold-iron nanostructures based on selective laser heating of colloidal nanoparticles and selective acid treatment. The presented approach allows to create porous gold-based nanostructures with different morphologies. In addition, for the first time, our studies indicate that various nanoarchitectures (brain-like, flower-like, cage-like, or raspberry-like structures) can be obtained by varying the experimental conditions such as size of Au and Fe_3O_4 nanoparticles, solvent, laser fluence, and irradiation time. We believe that these porous structures will find immediate applications in catalysis and separations, where high surface area and magnetic properties are often simultaneously required.

1. Introduction

In the wide panorama of nanomaterials, gold is known to have a unique electronic, and amazing catalytic performance [1,2], as well as excellent and tunable plasmonic properties [3,4]. Especially gold

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nanostructures with porous structures have attracted great attention in several fields, such as catalysis [4–8], sensing [9,10], drug delivery [11,12], medical diagnostics and biomedical imaging [13,14], because of their spatial configuration that displays low density, effective contact area and good fluid transmittance. For these applications, the separation of the porous material from the fluid is a crucial step. The use of porous magnetic particles allows separation by simply applying a magnetic field.

Porous gold nanostructures are usually fabricated, through galvanic replacement reactions with active metals as sacrificial templates and etching bimetallic nanostructures [6,15,16]. However, traditional etching route through a bimetallic precursor, such as Au/Ag, can only fabricate small-sized porous nanostructures. A protocol to fabricate large-sized (>100 nm) porous noble metal nanostructures would not be possible due to collapse or deformation in the process of growth. Unfortunately, small-sized porous nanostructures always suffer from the congregation during their application. Porous micrometer-sized particles are commonly prepared by several swelling methods of template micrometer-sized particles, e.g., polystyrene (PS) template particles obtained by dispersion polymerization, with appropriate monomers and initiators, e.g., multi-step swelling [17–23], dynamic swelling [24,25] and a single-step swelling. The monomer(s) swollen within the template microspheres are then polymerized, which is followed by a dissolution of the template part of the formed composite particles [26].

Thus, fabrication of large-sized porous magnetic noble metal nanostructures is potentially very significant but still remains a challenge.

Among the developed synthetic protocols, the pulsed laser irradiation method is regarded as one of the most effective approaches to obtain highly uniform submicrometer-or micrometer-sized particles [27–34]. In fact, our group recently reported a unique synthetic pathway to prepare Au-based particles with well-defined spherical morphology, uniform submicrometer-size and integrated porosity-magnetic properties (by combining selective laser heating of nanoparticles dispersed in liquid and acid treatment processes) [31].

Inspired by these results, we continued our quest toward the deliberate formation of porous gold-iron nanostructures with magnetic properties, because this novel 3D integration would represent

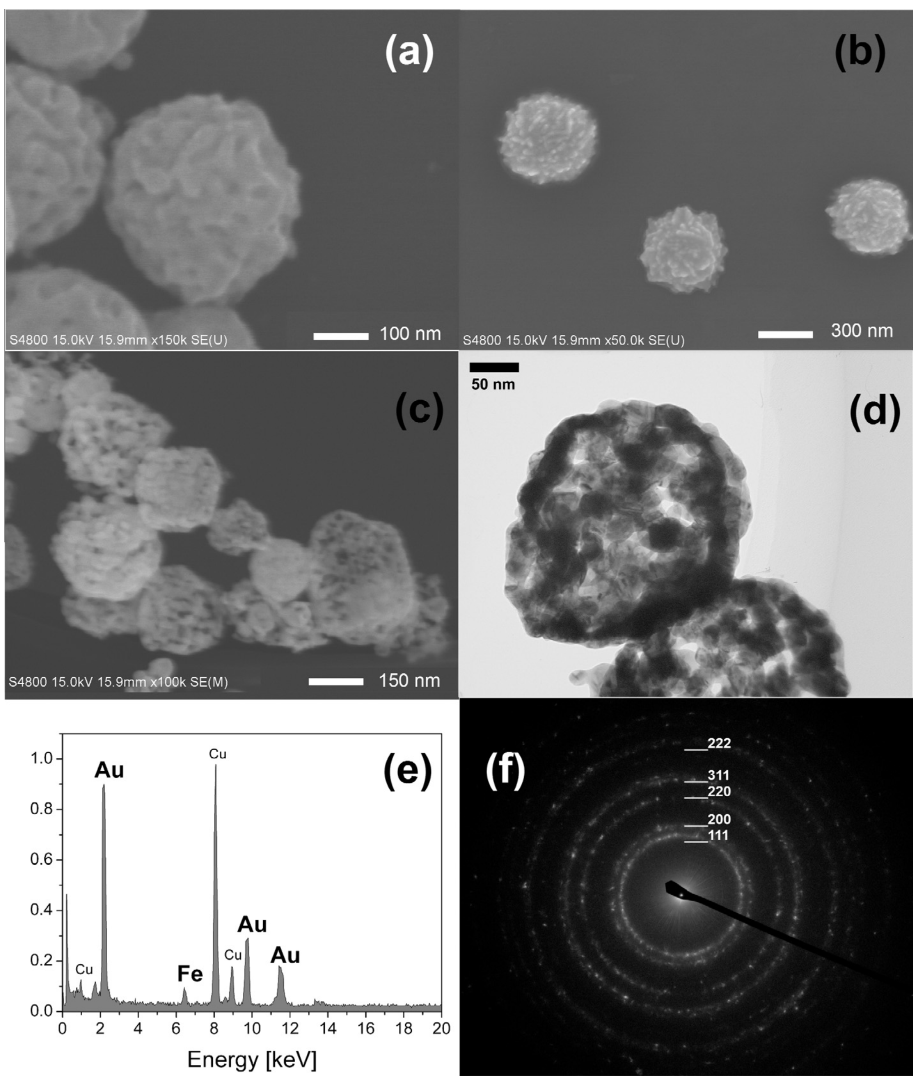

Fig. 1. SEM and TEM results of Au porous nanostructures prepared from Au and Fe_3O_4 nanoparticles solutions with different size of raw nanoparticles. (a) SEM image of Au (brain-like) nanostructures obtained from raw Au and Fe_3O_4 nanoparticles with diameters 20 nm and 6 nm, respectively. (b) SEM image of Au with flower-like structure (raw Au nanoparticles = 5 nm, raw Fe_3O_4 = 6 nm). (c), (d) SEM and TEM images of cage-like Au particles (raw Au = 20 nm, raw Fe_3O_4 = 40 nm). Laser irradiation conditions: laser fluence 100 mJ/pulse cm^2, irradiation time 1 h, solvent ethanol. (e) EDS spectrum obtained at the center of the particle, (f) SAED pattern of Au nanostructures obtained from raw Au and Fe_3O_4 nanoparticles with diameters 20 nm and 40 nm, respectively.