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Full Length Article

Transformation of silver nanowires into nanoparticles by Rayleigh instability: Comparison between laser irradiation and heat treatment

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ABSTRACT

We comparatively study the morphological evolutions of silver nanowires under nanosecond-pulsed laser irradiation and thermal treatment in ambient air. While single-crystalline, pure Ag nanospheres could be produced by laser-driven Rayleigh instability, the particles produced by heat treatment were subject to oxidation and exhibited polyhedron shapes. The different results are attributed to the significantly different time scales of the two processes. In this article, we also show that bimetallic Ag-Au nanospheres can be synthesized by irradiating Ag nanowires coated with a thin Au film using a pulsed laser beam. This may provide a facile route to tune the plasmonic behavior of metal nanoparticles.

1. Introduction

Metal nanostructures have attracted a great deal of attention due to their unique properties and functionalities. In particular, noble metals at the nanometer scales exhibit distinct surface plasmon resonance (SPR). The SPR phenomenon can be effectively utilized for bio-sensors [1–3] and novel optical devices such as color filters [4,5], polarizers [6], surface holograms [7], and color printing [8,9]. These plasmonic applications generally require nanostructure arrays. Such arrays can be fabricated by a number of different techniques, including chemical processes based on self-assembly and lithography-based nanopatterning. Meanwhile, one-dimensional nanostructures such as nanowires have the potential for use in a range of electronic, optoelectronic, and electrochemical devices. Metal nanowires are also promising candidates as conductors in future transparent flexible devices and nano-circuits. They can also be used for supercapacitor [10]. However, nanowires can fragment into a chain of nanoparticles above a certain temperature due to Rayleigh instability [11–16]. The thermal stability of nanowires is therefore of practical interest. Experimental and theoretical studies [15,17–20] showed that metal nanowires can easily break up into nanoparticles at elevated temperatures where atomic movements by diffusion become significant. Since this may impose a serious obstacle to the sustained reliability of components based on nanowires, several methods to suppress the Rayleigh instability have also been exploited [21,22]. On the other hand, if the instability-driven morphology change is made to occur in a controllable manner, it can develop into a viable processing route [15,19,23–26].

The optical properties of metals are very sensitive to their shape and size. The transition between one-dimensional wires and zero-dimensional particles is thus significant to the synthesis of nanomaterials for plasmonic applications. Experimental works on the Rayleigh instability of metal nanowires have mostly been conducted by thermal annealing in a vacuum or inert atmosphere. From a practical point of view, it is highly desirable to develop the instability-driven process in ambient air. While laser process has several advantages over thermal process, the morphological evolutions of metal nanowires under laser irradiation have little been investigated. It is time-effective and more importantly, enables the materials to be space-selectively transformed. In this article, we comparatively examine the morphological evolutions of single-crystalline silver nanowires under laser and thermal treatments. In both processes that were carried out in ambient air, the nanowires initially fragmented into shorter nanorods, before transforming into nanoparticles. While single-crystalline Ag nanospheres could be produced by laser-driven Rayleigh instability, the particles produced by heat treatment were subject to oxidation and exhibited polyhedron shapes. These results are attributed to the significantly different time scales of the two processes. We also show that bimetallic Ag-Au nanoparticles can be synthesized by irradiating Ag nanowires coated with a thin Au film using a pulsed laser beam. This

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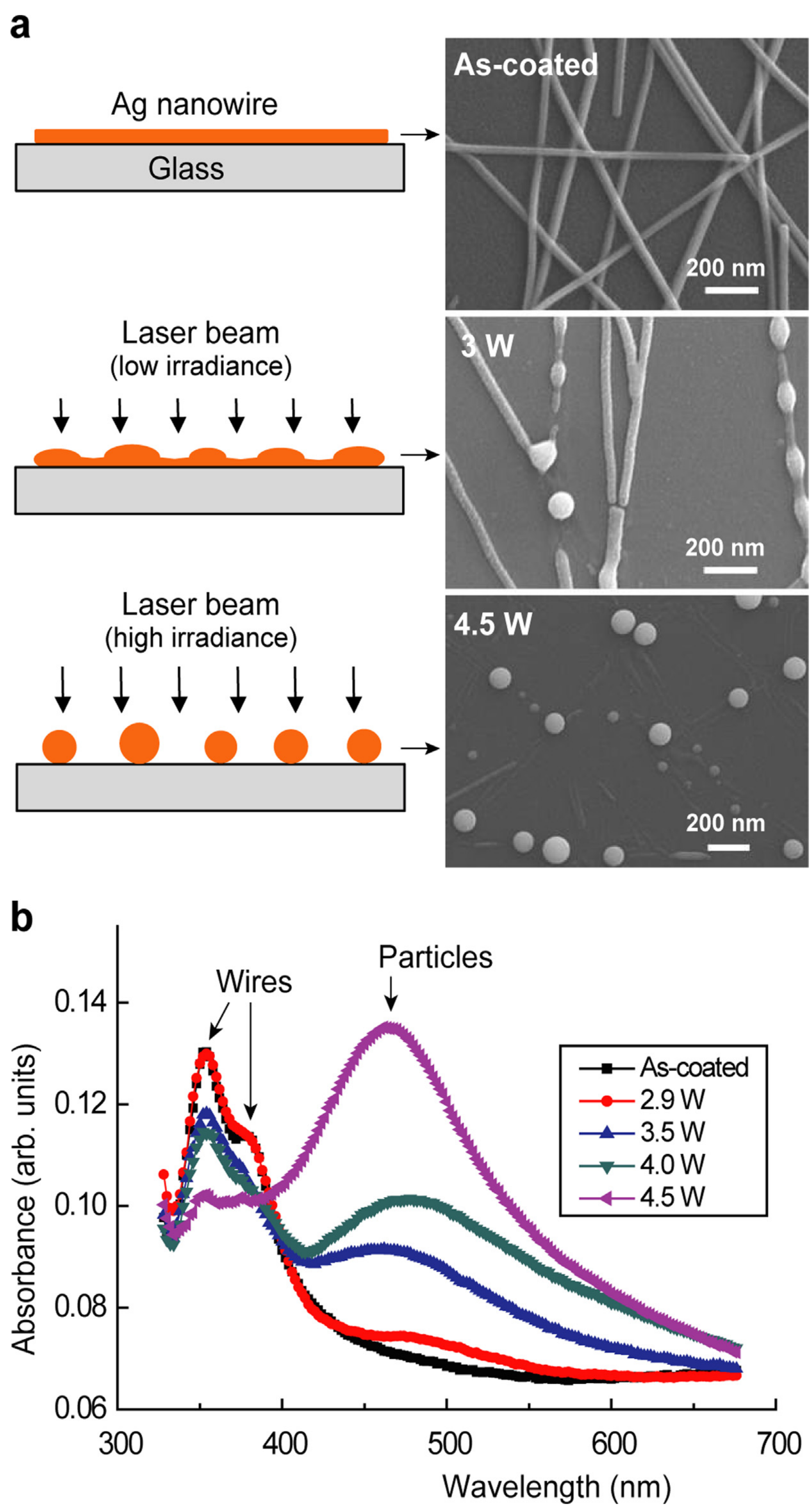

Fig. 1. (**a**) Morphologies of AgNW films before and after laser irradiation. (**b**) Absorption spectra of the samples measured after irradiation at different powers.

finding may be effectively utilized to prepare bimetallic nanoparticles and tailor their plasmonic response.

2. Experimental procedures

A 1 wt% solution of silver nanowires (AgNWs) dispersed in ethanol (diameter = 32 ± 5 nm, length = 25 ± 5 μm) was supplied by NANOPYXIS Inc. After being diluted to 0.3 wt%, the solution was sonicated for 5 min. The sonication step reduced the average length of AgNWs to roughly half the original length. This step was employed to obtain more uniformly coated AgNW films. A 200 μL drop of the solution was spin-coated onto a slide glass substrate (Marienfeld-Superior, microscope slides of 1 mm thickness, 2.5 cm × 2.5 cm wide) at 1000 rpm for 1 min, followed by drying for 5 min at 100 °C. A nanosecond-pulsed ultraviolet (UV) laser (Coherent AVIA 355-5; wavelength = 355 nm, pulse width <20 ns, repetition rate = 30 kHz, maximum output power = 6.0 W, output beam diameter = 2.85 mm) was employed as the laser source. The