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Processing conditions in pulsed laser ablation of gold in liquid for fabrication of nanowire networks

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ABSTRACT

The experimental conditions were investigated enabling one to fabricate Au nanowire networks by pulsed laser ablation in water. The study revealed that it is possible to produce alternatively nanoparticles (or aggregates) or nanowire networks at certain wavelengths depending on the laser fluence. An Au disc immersed in double-distilled water was used as a target. The second (λ_{SHG} = 532 nm) and the third (λ_{THG} = 355 nm) harmonics of a Nd:YAG laser system were utilized to produce different Au colloids. The values of the laser fluence for both wavelengths under the experimental conditions chosen were varied from several J/cm^2 to tens of J/cm^2. The optical extinction spectra of the colloids in the UV/vis region were obtained to evaluate the structure of the dispersed Au phase. Transmission electron microscopy (TEM) was applied to visualize the size and morphology of the colloidal particles. Their structure and phase composition were studied by high-resolution transmission electron microscopy (HRTEM) and selected area electron diffraction (SAED) and used to make an assumption on how they had been formed.

1. Introduction

Noble metal nanocrystals have attracted considerable attention from a fundamental point of view and for technological applications mainly due to the position of their surface plasmon resonance lying in the visible spectral range. The strong dependence of the optical, electronic, magnetic, and catalytic properties of the nanoparticles on their size [1] and shape [2,3] provides opportunities of creating nanostructures for specific applications by the way of controlling the preparation conditions so as to produce nanoparticles having the desired size and shape.

Transmission electron microscopy (TEM) is a method for direct visualization of the characteristics considered, while the profile of the optical transmission spectrum of the corresponding colloid obtained in the UV/Vis range allows their indirect assessment. For example, spherical nanoparticles (up to a certain size) are characterized by a single surface plasmon resonance (SPR) peak in their extinction spectrum. The appearance of two peaks arising from the transverse and longitudinal SPRs is observed at extended shapes, e.g., spheroids or nanorods [4,5]. The positions of these peaks in the extinction spectrum depend on the aspect ratio of the nanostructure considered [5]. The existence of aggregates or nanowires in the colloid influences the corresponding extinction spectrum in a specific way. One-dimensional nanostructures excite substantial interest regarding the fundamental properties of surface plasmon polaritons (SPPs) propagation in nanoscale structured matter [6]. On the other hand, they have potential applications in fields such as microelectronics, optoelectronics, nanoscale electronic devices and sensorics [7–9]. The gold nanowires exhibit excellent electric-conductivity, chemical and thermal inertness, and biocompatibility. Their properties depend on substances absorbed on the surface. The excellent sensitivity observed with respect to small changes in the surrounding dielectric environment originates from their huge surface to volume ratio. Gold nanowires immersed in a range of aqueous solutions of glycerine of different concentrations showed a sensitivity which is two orders of magnitude higher than that currently offered by conventional SPR-based sensors. They are extremely sensitive to H_2O_2 [10,11], which is beneficial for fabricating oxidase-based biosensors. The possibility of attaching biomolecules selectively to their walls is also useful in this respect [12,13]. A large variety

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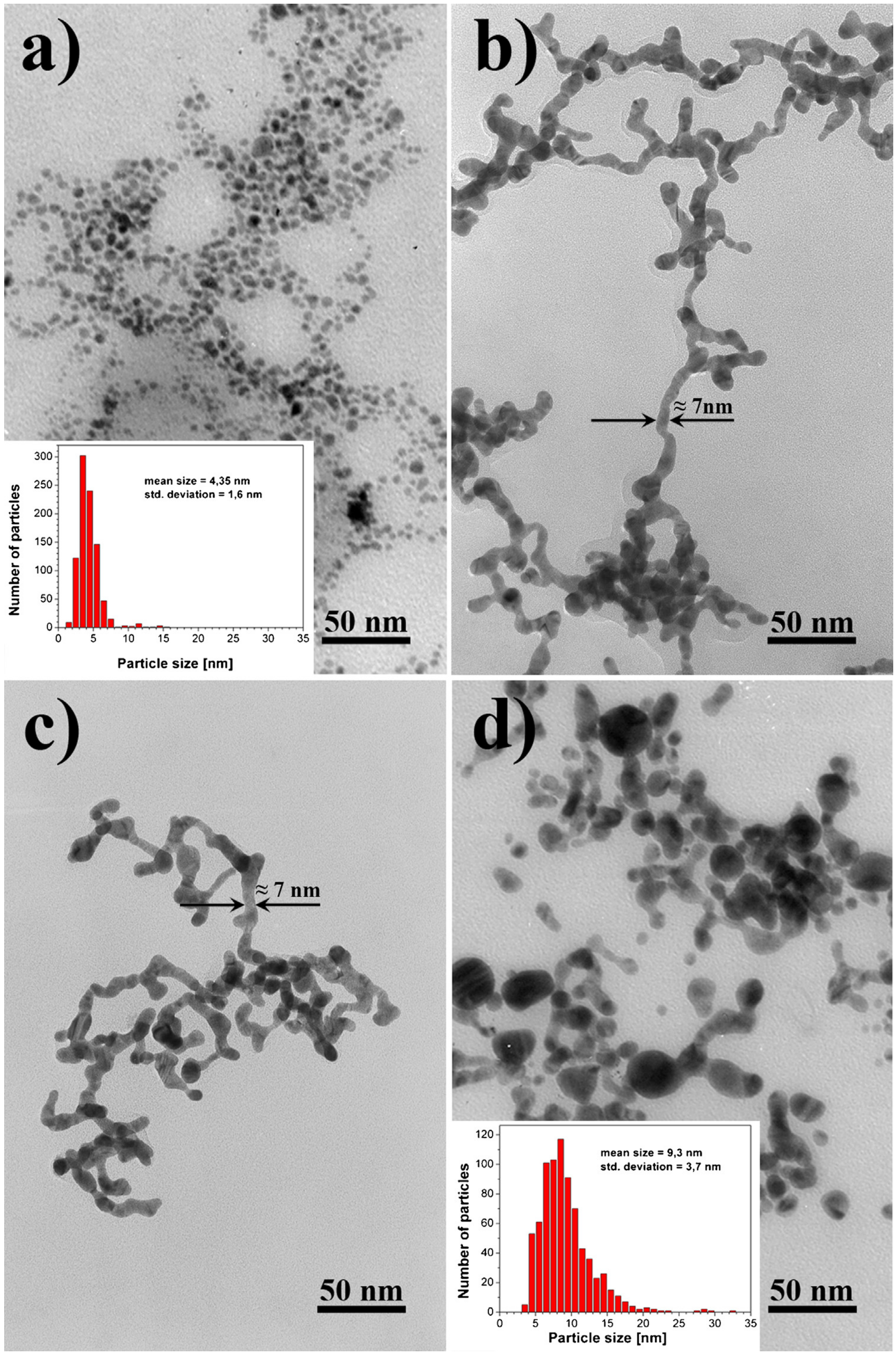

Fig. 1. TEM micrographs and corresponding histograms of nanostructures fabricated by laser light with wavelength 355 nm and fluence of (a) 0.9, (b) 2.8, (c) 9.6, and (d) 14.5 J/cm^2.

of chemical methods for fabricating gold nanowires have been reported in the literature [14–19]. A general disadvantage of the suspensions produced by these methods is the presence of residual ions as byproducts and their potential toxicity which precludes the biological applications. In this study, we used the method of nanosecond laser ablation of an Au disc immersed in double-distilled water to produce contamination-free nanowire networks. The roles of the laser wavelength and fluence were established. Some fundamental conditions specific for their formation are pointed out.

2. Experimental

The experimental setup employed for the fabrication of gold (Au) nanoparticles (NPs) and nanowire networks (NNWs) is shown schematically in Ref. [20], a detailed description of the materials used and the preparation of the samples are given in Ref. [21]. Briefly, a gold target in the form of a disc was placed on the bottom of a polypropylene vessel filled with double-distilled water (3.,7 ml volume). During the experiments, the vessel was rotated slowly at a constant speed and the water level above the surface of the