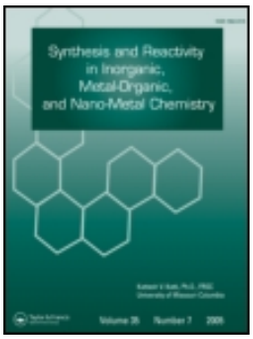

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Characterization of Triangular Gold Nanoparticles Using *Aloe arborescens* Leaf Extract: A Green Synthesis Approach

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Herein, the authors show the use of the *Aloe arborescens* leaf extract for green synthesis of gold nanoparticles in water at room temperature under very mild conditions. The synthesis of the gold nanoparticles was complete in several minutes, and no extra stabilizing or capping agents were necessary. The size of the nanoparticles could be controlled by varying the concentration of the leaf extract. The silver nanoparticles and reaction process were characterized by UV-vis spectrometer, Fourier transform infrared spectroscopy, and transmission electron microscopy. The UV-visible spectra of synthesized nanoparticles showed absorption maxima at 540 nm. Transmission electron microscopy images confirm that the nanoparticles are spherical and triangular in shape.

Keywords: nanostructure, visible and ultraviolet spectrometers, electron microscopy, TEM, Fourier transform infrared spectroscopy, FTIR

Introduction

Nanotechnology is one of the most interesting sections used to describe the formation and consumption of materials with structural characteristics between those of atoms and bulk materials with at least one dimension in the nano range. The fabrications of noble metals nanoparticles have been concerned much interest due to their potential applications in catalysis, photonics, biomedicine, antimicrobial activity, and optics[1–3] and their properties depend on size and shape of the particles.[4] Recently, green synthesis of nanoparticles is gaining more attention due to its cost effectiveness, freedom from hazardous reagents, and mild conditions involved [5]. Nanoparticles of various shapes have been synthesized by plants,[6] microbes,[7] and algal.[8] The nanoparticles synthesized by inactivated plants, plant extract, and living plants are more stable and the rate of synthesis is faster than in microorganisms.[9,10] The reduction of the metal salts usually take place in water under mild reaction conditions where the plant extract acts both as reducing as well as stabilizing agent.[11–13] Plants are exploited as a potential source for the large-scale production of gold nanoparticles (GNPs) owing to their various potential applications in chemical sensing, biological imaging, cancer treatment, gene silencing, and drug and gene delivery.[14]

Aloe arborescens is a species of flowering succulent perennial plant that belongs to the *Aloe* genus. *Aloe arborescens* is endemic to the southeastern part of Africa, specifically, South Africa, Malawi, Mozambique, and Zimbabwe. It has been imported in many countries in the tropics and subtropics as an ornamental and medicinal plant. The split or crushed fresh leaf of *Aloe arborescens* are widely used to treat burns and wounds from ancient time. Jia et al.[15] found that *Aloe arborescens* have a tendency to significantly reduce the wound severity in rat and rabbit with respect to that with saline treatment. Moreover it is used in several medical applications on account of its antipyretic, antioxidative, and cathartic properties.[16–18] By using the extract of its leaf, the fabrication of nanoparticles may find numerous therapeutic applications. Therefore, in this paper we report a very mild and environment friendly method for the synthesis of GNPs from the leaf extract of *Aloe arborescens* at room temperature without any additional capping or stabilizing agents. The GNPs were characterized by UV-visible spectroscopy, transmission electron microscopy (TEM), high-resolution transmission electron microscopy (HRTEM), and Fourier transform infrared (FTIR) studies.

Experimental

Materials and Aloe arborescens *Extract Preparation*

Gold (III) chloride trihydrate ($HAuCl_4\ 3H_2O$) was purchased from Sigma-Aldrich Chemicals (USA, ≥49.0%. Au basis and *Aloe arborescens* leaves were collected from University of KwaZulu-Natal campus. All the aqueous solutions were prepared using ultrapure water having a resistivity of 18 $M\Omega.cm^{-1}$ formed by a Milli-Q Water System (Millipore

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Crop, Bedford, MA, USA). 50 g of *Aloe arborescens* leaf, thoroughly washed and finely cut, were taken in a 500 mL Erlenmeyer flask with 150 mL ultrapure water and then boiled for 10 min. After boiling, the solution was filtered and store.

Synthesis of GNPs

In a typical synthesis, carefully weighed $HAuCl_4$ (final concentration was 1 mM) was added to the *Aloe arborescens* leaf extract or simulated solution of the extract, and the reaction was carried out in a water bath at 30°C.

Characterization of GNPs

GNPs were characterized by following techniques.

UV-Vis Spectra Analysis

UV-Visible spectra of GNPs by reduction of *Aloe arborescens* leaf extract in aqueous solution were recorded in UV-1800 Shimadzu spectrophotometer using 10 mm quartz cell operated at a resolution of 1 nm in absorption mode. The absorption spectra of synthesized nanoparticle concentrations were measured at different time intervals of 5 min, 10 min, 20 min, 1 h, 1 day, and 10 days at UV ranges between 350 and 1100 nm. The solutions of GNPs show intense color due to surface plasmon resonance (SPR) arising from collective oscillation of free conduction electrons induced by an interacting electromagnetic field.[17] The position of SPR band in UV-visible spectra is sensitive to particle size, shape, and its interaction with medium. Figure 1 shows the absorption spectra of GNPs synthesized at 30°C.

Transmission Electron Microscopic Measurement

The samples for transmission electron microscopy (TEM) analysis were prepared by drop-casting the GNPs solution on a carbon-coated copper TEM grid. Before casting to the grid the GNPs solution was centrifuged at 10,000 rpm for 15 min and the isolated GNPs were dispersed in 100 μL double-distilled water and sonicated in a bath sonicator for 30 min. The TEM images were recorded on a JEOL-2010 transmission electron microscope operated at an accelerating voltage of 120 kV.

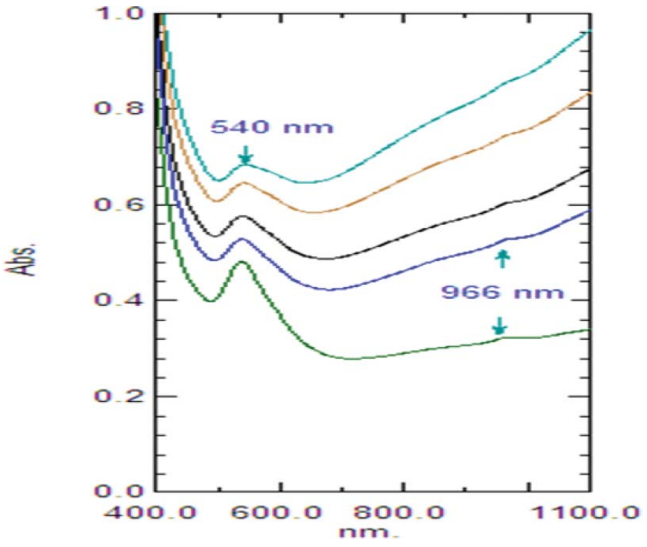

Fig. 1. UV-visible absorption spectra of gold nanoparticles sol at different time intervals.

Fourier Transform Infrared Spectroscopy

For Fourier transform infrared spectroscopy (FTIR) spectrum analysis the GNPs were centrifuged at 10,000 rpm for 15 min to remove free proteins or other compounds present in the solution. The GNPs then resuspended in double-distilled water and again centrifuged. The process was repeated for three times and finally the centrifuged part containing GNPs were redispersed in double distilled water and subjected to FTIR spectroscopy (Perkin Elmer, Spectrum 100, USA).

Results and Discussion

Reduction of the aqueous chloroaurate ions during exposure to the extract of *Aloe arborescens* leaf may be easily followed by UV-vis spectrophotometer. It is well known that the wine color of GNPs arises due to the combination of electrons vibration of metals in resonance and the light wave.[11–13] The gold nanoparticle surface plasmon band occurs in the range 510–560 nm in an aqueous medium.[12] The synthesized GNPs SPR with respect to time (after 5 min, 10 min, 20 min, 60 min, 1 day, and 10 days) shows at 540 nm (Figure 1). Figure 2 shows representative TEM images of the nanoparticles synthesized using different amounts of *Aloe arborescens* extract. TEM analysis clearly reveals the formation of triangular planar gold nanostructures in addition to spherical nanoparticles. Further analysis shows that addition of small amounts of *Aloe arborescens* extract leads to the formation of triangular nanoparticles with larger edge lengths (Figures 2A and 2B). It is well-known that triangular nanoparticles of gold exhibit two characteristic absorption bands referred to as the transverse (out of plane) and longitudinal (in plane) surface plasmon resonance bands.[13] While the out-of-plane transverse absorbance more or less coincides with the surface plasmon resonance of spherical GNPs, the in-plane surface plasmon band is a strong function of the edge length of the triangles. Thus SPR band at 966 nm in the UV-Vis absorbance spectra can be attributed to the transverse and longitudinal surface plasmon resonance band of the triangular GNPs being formed. The ability to tune the optical properties of the biogenic gold nano-triangles can be very useful in applications such as cancer cell hyperthermia, and architectural optical coatings.[16–18]

FTIR analysis was carried out to detect the possible molecules responsible for the reduction of the metal ions and the capping of these nanoparticles. Figure 3 represents the FTIR spectra of the *Aloe arborescens* extract after GNPs synthesis. Here the major absorption peaks are observed at 1012, 1244, 1575, and 1712 cm^{-1}. The band at 1712 cm^{-1} is characteristic of stretching vibrations of the carbonyl functional group in ketones, aldehydes, and carboxylic acids. The 1575 cm^{-1} band can be assigned to aromatic C-C skeletal vibrations.

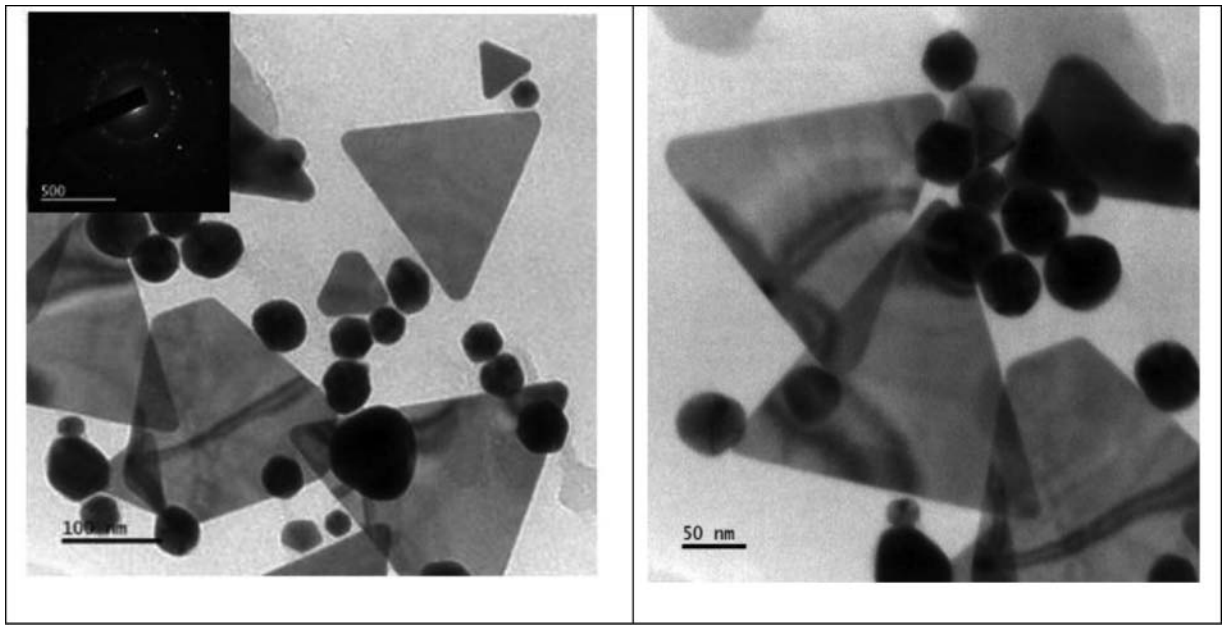

Fig. 2. TEM images of gold nanoparticles synthesized using *Aloe arborescens* extract showing the different shapes of nanoparticles.

Hence it can be inferred that C–O to C–C, COOH, CH_2, and OH could be the functional groups responsible for the catalytic reduction of $AuCl_4$ to form elemental GNPs. These can hence be considered as the capping ligands which give stability to the nanoparticles.[11,12] The similar observation was previously reported on gold nanotriangle synthesis using lemongrass extract and aloe vera wherein carbonyl groups were found to play an important role in the stabilization and capping of the gold nanotriangles.[13]

Conclusions

The synthesis of GNPs using leaf extract of *Aloe arborescens* provides an environmentally friendly, simple, and efficient route for synthesis of benign nanoparticles. The GNPs were characterized using UV-Vis, TEM, and FTIR techniques. From a technological point of view, these obtained GNPs have potential applications in the biomedical field and this simple procedure has several advantages such as cost effectiveness, compatibility for medical and pharmaceutical applications, and large-scale commercial production. The strong NIR absorbance of the gold nanotriangles and the flexibility with which this could be tuned could find interesting applications in cancer hyperthermia and optical coatings.[16,17]

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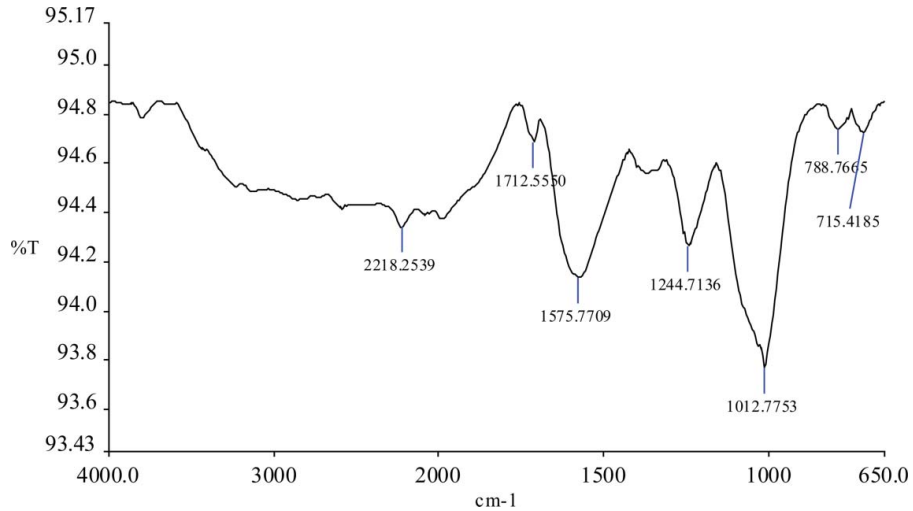

Fig. 3. FTIR spectra of gold nanoparticles synthesized using *Aloe arborescens* extract.

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