Synthesis and analysis of gold nanoparticles produced by laser

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Abstract
Gold nanoparticles are produced by employed nanosecond pulses of Nd:YAG laser using laser ablation process in liquid. The two systems used are Nd:YAG of 6 and 10 nanoseconds pulse duration with variable energy in the range (700-760 mJ ). The formation of gold nanoparticles has been revealed using TEM with uniform size distribution. Also, it has been discovered that the mean nanoparticles sizes of 70 and 100 nm for gold respectively when similar laser parameters are used. In addition, theoretical Mie-Gans model was used to estimate the temperature distributions for both gold nanoparticles. Another aspect that has been discovered is that the maximum temperature of about (40 K°) and (60 K°) for gold nanoparticles, especially to prepare nanoparticles in the presence of Nd:YAG of 10 ns.

1. Introduction

The term Nanoscience is defined as a set of technologies and developments that depend on physical, chemical, and biological phenomena occurring at the nanoscale with range from 1 to 100 nanometer, approximately [1]. General speaking, two approaches are used to fabricate nanomaterials: bottom-up and top-down [2]. However, Nanomaterials are distinguished as zero, one, two and three dimensional nanostructures [3,4].

Synthesization methods of nanomaterials are either chemical or physical. Physical methods depend on wire technique, physical vapor deposition, thermal evaporation, sputtering deposition, chemical vapor deposition and laser ablation, where as the formation of NPs using Laser Ablation, has two types of laser ablation: dry and wet. A wide variety of compounds nanoparticles can be possibly produced for various target materials and different parameters such as the laser wavelength, fluency and pulse duration. Furthermore, Pulse Laser Ablation in Liquid (PLAL), includes the interaction between the laser and target can be used to produce colloidal suspension of nanoparticles too [5]. PLAL is defined as a one-step top–down procedure strategy of nanoparticles preparation [6]. This technique has some mints or advantages, However, the main ones are 1- Its ability to produce various kinds of nanomaterials like metals, noble metals, semiconductors, nanoalloys, oxides, magnetic and core–
shell nanostructure [7], 2- No need for vacuum equipment [8], 3- The surfactant molecules can control on aggregation [9]. A mathematical model can be drawn depending on the previous interaction:

\[
T(t) = \frac{2F_0}{k} \left( \frac{e^{-\frac{z}{2(\alpha t)^\frac{1}{2}}}}{\frac{1}{\pi^2}} \right)\left(1 - e^{-\frac{z}{2(\alpha t)^\frac{1}{2}}} \right) - \frac{z}{2(\alpha t)^\frac{1}{2}} \left[ 1 - 1 - (a \cdot b + A1 \cdot b^2 + C \cdot b^3) e^{-\frac{z}{2(\alpha t)^\frac{1}{2}}} \right]^{2.1} \]

Where \( T(t) \): Temperature (K), \( F_0 \): Surface absorbed power W/m², \( K \): Thermal conductivity W/m.K, \( \alpha \): Thermal diffusivity m²s⁻¹, \( \mu \): Time s, \( z \): Depth m, \( t_1 \): Time power off s and \( a, A1, C, b \): Constant [10].

2. **Experimental Details**

In this study work two laser systems are used for the ablation process; Nd:YAG. Nd:YAG laser providing pulses of 1064 nm with maximum energy per pulse up to 1000 mJ, pulse duration of 10 ns with a maximum repetition equal to 6Hz. Whereas the second has a 850 mJ energy and 6 ns pulse duration and 10 Hz maximum repetition rate. The process of focused the Nd- YAG beam is done using a lens of 8 cm focal length onto gold target. The purity of gold plates is very high; it is about (99.999). To suite the experimental arrangement, the plates should be polished, washed with ethanol and distilled water and cut into small pieces. were polished, washed with ethanol and distilled water and cut into small pieces to suite the experimental arrangement. Another important note is that \textbf{DDDW} (Double distilled and deionized water) is essential to prepare all samples and solution in this work.

To study the geometry, size and size distribution of the prepared nanoparticles, TEM is used through morphological investigation. Also, Zeta potential experiments are used, to explore the aggregation of the nanoparticles in the colloidal suspension.

3. **Experimental Details**

A mathematical model results

The temperature distribution of gold nanoparticles was estimated using the convolution of the size distribution with the heat flow theory as follows.
The solution of equations 1 and 2 are represented in fig 1, 2 and 3, the fig 1, fig 2 shows the relation between the temperature and radius for nanoparticles for gold nanoparticles while fig 3 shows between the size distribution of Si and generated temperature.

\[
T(r_1) = \int_0^{r_0} N \cdot D(r_1) \left[ \frac{P(1-\tau) \cdot r_1}{6 \cdot 10^3 \cdot v(r_1)} \right] \left[ \frac{1}{\alpha + t} \left( \frac{z}{2^{(\alpha + t)}} \right)^2 \right] \left[ \frac{1}{\pi} \left( \frac{1}{2^{(\alpha + t)}} \right) \right] - \frac{z}{2^{(\alpha + t)} \cdot (\alpha + t)} \left[ 1 - \left( a \cdot b + A \cdot b^2 + C \cdot b^3 \right) \right] \cdot \left[ \frac{z}{2^{(\alpha + t)} \cdot (\alpha + t)} \right] \cdot dr
\]

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Fig (1) The relation between the temperature and radius for nanoparticles of the laser have the pulse duration 10 ns for 740 mJ for gold nanoparticles.
Fig 2. The temperature and radius for Au nanoparticles of the laser of pulse duration 6 ns and 740 mJ.

A comparison of the theoretical results obtained for both the 10 ns and the 6 ns lasers.

| Laser pulse duration | Molten depth (μm) | Maximum temperature (kº) |
|----------------------|-------------------|--------------------------|
| 6ns                  | 5                 | 50 k                     |
| 10ns                 | 7                 | 40 k                     |

This table shows that when the laser pulse duration decreased from 10 ns to 6 ns, the temperatures increase by 10kk ko.

B Experimental Results

TEM images of gold (Au) nanoparticles generated using laser ablation with pulse length of 6 ns and energy of 700 and 720 mJ are represented respectively in fig 3 A and 3 B. Due to high aggregation of small nanoparticles produced by higher energy, it is found that the sizes of gold nanoparticles increased by increasing the laser energy. The formation of small nanoparticles is attributed to the reduction in the temperature and vapor pressure generated, leading to the ejection of small gold nanoparticles.
Fig 3 TEM images of gold nanoparticles at energy of (A) 700 mJ for 6 ns pulse duration, (B) 720 mJ for 6 ns pulse duration.

At the gold using histogram Fig 4. It is that the size of nanoparticles for gold distribution (the homogeneous distribution) because of high Au absorption coefficient of laser (1064 nm). This also generates temperature and vapor pressure which lead to small Au nanoparticles being ejected subsequently.

Fig 4 TEM histogram for gold nanoparticles prepared by energy of 700 mJ and 10 ns pulse duration.

Figure 5 (A and B) display the Au nanoparticles UV-Vis absorption spectra, respectively. All spectra were calculated for nanoparticles prepared by (700 and 760) mJ / pulse with Nd:YAG laser of 1064 nm wavelength. The peaks of gold nanoparticles UV-Vis spectra prepared with 700 mJ observed at (429 nm) suggest that the principal size was (50 nm). This peak shifts to (414 nm) when the gold particles are prepared with laser energy of 760 mJ. This might be attributed to the effect of smaller nanoparticles being formed due to the high temperature generated.
Fig 5. UV-VIS absorption spectra of gold nanoparticles solution prepared by 200 pulses with laser energy (A) 700mJ and (B) 760mJ.

The presence of single surface plasmon peak indicated that the nanoparticles formed are almost spherical while the absorption spectrum would have two plasmon peaks in the case of ellipsoidal particles.

The stability of produced nanoparticles through their values was normally considered stable between +30 mV and less than -30 mV, and that they agree with criteria values in Z-potential inspection. In gold the Z-potential’s principal value was -49.42 mV.

5 Conclusions

Stable gold nanoparticles of uniform size may be predestine by laser ablation in liquid. Temperature distribution of higher magnitude was observed for gold nanoparticles. The magnitude of maximum will super fat when shorter laser pulses are used. Compiling the experimental data for size distribution in the theoretical model supplies a better understanding of nanoparticles produced by laser ablation.

Acknowledgments

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