

Optical and Morphological Properties of Silver Nanoparticles Synthesis by Laser Induced Forward Transfer Technique

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ABSTRACT

Various methods could be employed to synthesize nanomaterials. In this work laser induced forward technology was used to synthesize silver nanoparticles. Silver nanomaterials were tested using different measuring instruments such as UV-vis diffuse (DRS), Atomic Force Microscopy (AFM), and optical Microscope to characterize features such as the optical and morphological properties of these nanoparticles. AFM results show that when the laser energy of the pulsed Nd: YAG laser increases, the diameter and roughness of produced AgNPs will be decreased for the same number of pulses and the air cavity between donor and acceptor. Also, results show that when laser energy is (300,400) mJ, the AgNPs diameters are (95.76,88.44) nm and the roughness are (7,6) nm respectively. While, results show that as laser pulses increase, structure to be rougher for different laser pulses and constant laser energy at 300 mJ the same behavior will be found when the laser energy becomes 400mJ. Finally, results show that the reflectance peaks of Ag NPs increase by decreasing the number of pulses to a maximum value of 467 at 2 pulses.

KEYWORDS: Laser induced forward transfer technique; Silver; Nanoparticles; Optical; Morphological Properties.

الخلاصة

طرق مختلفة يمكن استخدامها لإنتاج مواد نانوية مختلفة منها تقنية الليزر الأمامي المستحث، كل جسيمات الفضة النانوية المحضرة تم اختبارها وفحصها باستخدام أجهزة قياس مختلفة منها جهاز الأشعة فوق البنفسجية المرئية المنتشرة (DRS) UV-Vis Diffuse و مجهر القوة الذرية (AFM) والميكروسكوب البصري لقياس صفات وخصائص هذه الجسيمات النانوية مثل الخصائص البصرية والمورفولوجية. أظهرت نتائج AFM أنه بزيادة طاقة الليزر النبضي Nd: YAG ، سينخفض قطر وخشونة AgNPs لنفس عدد النبضات وفجوة الهواء بين الواهب والمستقبل. كما أظهرت النتائج أنه عندما تكون طاقة الليزر (300 و 400) ميغا جول ، فإن أقطار AgNPs ستكون (95.76 و 88.44) نانومتر بخشونة (7 و 6) نانومتر على التوالي. بينما أظهرت النتائج أنه مع زيادة نبضات الليزر ، تصبح بنية جسيمات الفضة النانوية أكثر خشونة نبضات الليزر المختلفة وثبات طاقة الليزر عند 300 ميغا جول ، كما سيظهر نفس السلوك عندما تصبح طاقة الليزر 400 ميغا جول ، وأخيراً ، أظهرت النتائج أن قمم الانعكاس لـ AgNPs تزداد مع نقصان عدد النبضات لتصل إلى قيمتها القصوى 467 عند نبضتين.

INTRODUCTION

Nanotechnology can simply be described as a technology at the size of 10^{-9} m. It is the designing, description, preparation and use of materials, structures, instruments, and systems by controlling the size and shape at 10^{-9} m size. Scientifically, NT is utilized to depict materials, instruments, and work frames with structures and ingredients displaying modern and safely enhanced chemical, physical and biological characterizations beside the phenomena and procedures capable through the capability to control properties at the nanoscale. Materials

show singular characteristics at the nanoscale of 1 to 100 nm [1]. Laser-induced forward transfer (LIFT) is a direct-printing method that relies upon the reaction of a laser to write a little part of matter from a thin donor layer to a receiving substrate through laser pulse action as shown in Figure 1[2, 3]. LIFT is composed of a complex laser-matter interaction mechanism, which contains conversing of energy and transitions phase. There are many variations of the LIFT process but major of them share a common setup and procedures [4].

The mechanism and processes used in LIFT can be summarized as follows.

- **Donor:** That is contained a few layers:

A substrate is transparent to the laser. In close-infrared or visible laser wavelength, glass, quartz, and fused silica could be utilized. A thin film of the material is to be transmitted strata the diaphanous substrate. The depth of this layer is a key factor of the process, usually in the range of 0.1–100 μm [5]. An intermediate layer between the transparent substrate and the donor layer is sometimes placed to prevent the immediate reaction of the laser with the material to be transferred.

- **Acceptor:** Substrate in which the donor is deposited. Often, the dot obtained in a unique transmitting procedure is called voxel (volumetric pixel) and its volume and size find the accuracy of the procedure [6].

- **Gap:** Space between the donor surface and the acceptor surface, which are reminded in parallel. This can be considered as a key parameter of the LIFT procedures, often between 0.1–1000 μm .

- **Laser:** many studies were achieved utilizing short pulses (ns) or ultrashort pulses (ps or fs). Shorter pulses are usually favorable to decrease the heating influence and to find lower voxels [6].

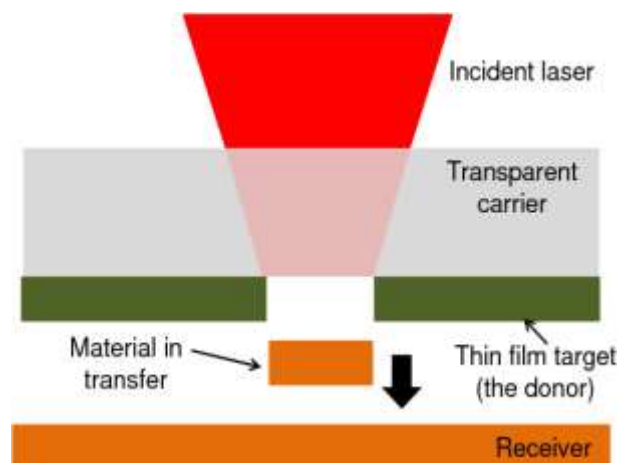


Figure 1. Schematic diagram of the general principle of the LIFT technique [3].

Braudy, 1985 [7] has published his work on using concentrated CW Argon laser beams (488 nm, 7, and 20 mW) that were utilized to transmit various inks deposited previously onto a clear Mylar tape to write lines onto a substrate without and within the air gap. Later on, Colima, *et al.*, 2006 [8] showed that laser-induced forward transfer LIFT is a laser direct-print method that displays the

capability of written styles with a good spatial accuracy of a broad range of materials in a solid or fluid state. Colina, *et al.*, 2015 [9] reported their work for using a laser of 1064 nm, 400 ns to introduce laser-induced forward transfer technique to transmitter phosphorous doped material on p-type c-Si substrates, the implementation of laser-induced forward transfer technique for the transmitter of phosphorus atoms cause a decreasing of the series resistance of a-Si diodes. Munoz, *et al.*, 2016 [10] utilized a 532 nm wavelength pulsed laser to analyze the morphology of singular dots of Ag paste deposited by the LIFT technique. The paste includes particles in micron-grain size, and comparatively thick donors were utilized to prototyping voxels with the highest aspect ratios. Smits, *et al.*, 2017 [11] presented laser induced forward transfer of chemical vapor deposition grown graphene layers at well-defined shapes and dimensions. The transmission is relies upon the photo-decomposition of a triazene-based transmit layer which introduces N_2 gas, which propels a graphene layer from the donor to the acceptor substrate. Raphael *et al.*, 2019 [12] have used Laser-induced forward transfer (LIFT) to produce silver nanoparticle patterns on glass substrates. The authors presented a study on the optimal factors, such as speeding scan and energy, needed to find a micrometric style on the transfer procedure. Spectroscopy analyses confirmed the composition and the formation of silver nanoparticles.

The aims of the present work are to synthesis silver nanoparticles using laser induced forward transfer and Measuring the optical and morphological properties for the synthesis of silver nanoparticles using UV-Visible, UV-vis diffuses (DRS), and (AFM), Optical Microscope

MATERIALS AND EXPERIMENTAL SETUP

Q-Switched Nd: YAG (FQ015-1 JS Company) with the energy of (1-2000 mJ), laser wavelengths of (1064nm), and frequency of (1-10 Hz) was used. Nano-silver paste (Piteny Bowes, USA) with silver concentration: 85% and average particles size (10-20) nm was used

This technique including the following sequence stages:

- This technique including the following sequence stages:
- Put the glass substrate including the nano-silver paste layer. A space of about (1cm) is selected in between the quartz substrate slide surface (accepter) and the nanosilver paste slide (the donor).
- The pulsed Nd: YAG laser is run with different parameters: energy, pulse duration, and frequency. These parameters were,
 - i. Number of pulses (2-5) pulses.
 - ii. Energy range (300-400) mJ.
 - iii. Frequency (1-10) HZ.
- The nanosilver paste is transferred from the glass substrate slide surface (donor) to the quartz substrate slide surface (accepter) by laser pulse action.

Figure 2 shows the experimental set-up of the preparation of Silver nanoparticles using laser induced forward transfer technique (LIFT).

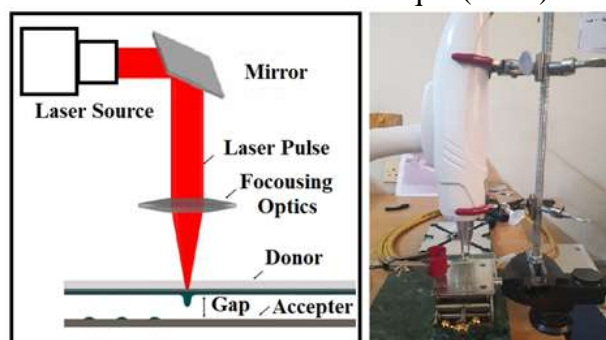


Figure 2. Sketch scheme for the LIFT technique experimental setup.

The Optical Characterizes Measuring Instruments

UV-vis diffuse reflectance spectroscopy (DRS)

AgNPs' reflectance was obtained using a diffuse reflectance spectrum (AvaLight-DH-S-BAL). This device has a powerful deuterium halogen reference of a high dominant alpha top at 656 nm. The light reference transmits a continuous spectrum with maximum accuracy. The maximum stability is in the ultraviolet, visible, and close to infrared range, from 215 to 2500 nm.

Morphological Properties Measuring Instruments

The Microstructure (Optical Microscope)

The optical microscope is a kind of microscope that commonly utilizes visible

light and a system of lenses to create a magnification picture of a little target. In this work all images of nanomaterials sample obtained by Olympus 100x Optical Microscope. All resulting images of tested samples can be stored in a computer through USB with software design for this purpose.

The Nanostructure Atomic Force Microscopy (AFM)

The AFM scans an edge probe upper the surface of a specimen and records the variance in force between the probe peak and the specimen. AFM image data contain root mean square (RMS) roughness and grain size. There are three major modes of mapping topography, tach, noncontact (that utilized in our morphology) and intermittent attach or tapping. The most substantial portion of AFM is the peak with its nanosized radius of curvature. The tip is connected to micron scale silver that reacts to the van der Waals reaction and other forces in between the tip and specimen. The size and morphology of the tested nanoparticles sample were characterized by atomic force microscopy (AFM) (Angstrom AA2000 model).

RESULTS AND DISCUSSION

Optical Properties Results

The reflectance for the Ag NPs prepared by Nd: YAG laser via LIFT technique at (300mJ) laser energy with different pulses (2, 3, 4, and 5). Distance 1cm air cavity between donor and acceptor was used. The reflectance peaks of Ag NPs increase by decreasing the number of pulses to a maximum value of 467 at 2 pulses. The reason for this behavior is related to the surface roughness of the silver nanoparticles which increases with the increase of pulses due to increasing the heating temperature as a result of increasing pulses' duration. Therefore, when using two pulses this means that the surface of silver nanoparticles becomes smoother which leads to an increase in the reflecting characterization of silver nanoparticles as shown in Figure 3 and Table 1.

A similar study was conducted for 400 mJ laser energy and some other conditions as shown in Figure 4 and Table 2.

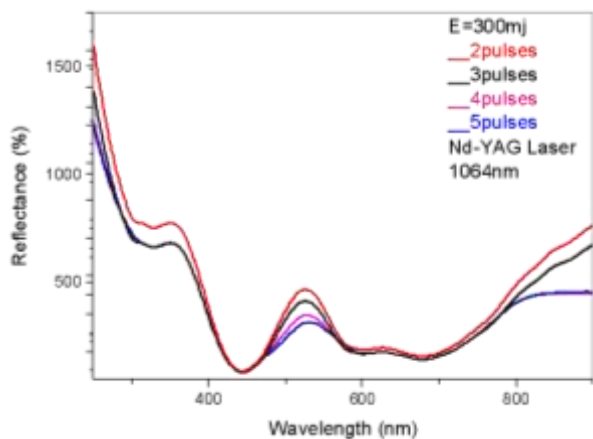


Figure 3. Reflectance of Au-nanoparticles synthesis by LIFT technique using 1064nm Nd: YAG laser with laser energy of 300mJ, 1cm air gap, and different pulses (2,3,4,5) pulse.

Table 1. Reflectance of Au-nanoparticles synthesis by LIFT technique using 1064nm Nd: YAG laser with laser energy of 300mJ, 1cm air gap, and different pulses (2,3,4,5) pulse.

Laser pulses	Reflectance %	λ at the peak position (nm)
2	467	525
3	446	526
4	422	527
5	345	531

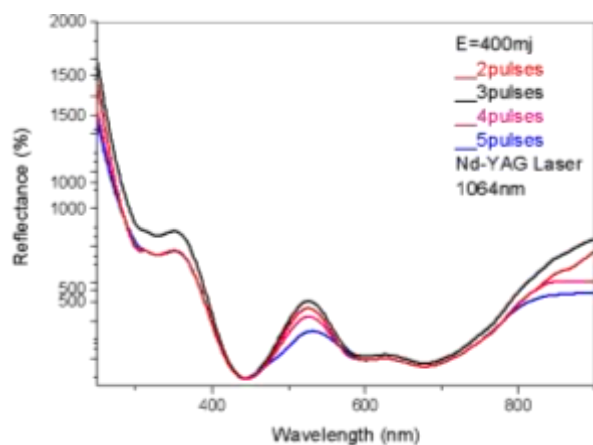


Figure 4. Reflectance of Au-nanoparticles synthesis by LIFT technique using 1064nm Nd: YAG laser with laser energy of 400mJ, 1cm air gap, and different pulses (2,3,4,5) pulse.

Table 2. Reflectance of Au-nanoparticles synthesis by LIFT technique using 1064nm Nd: YAG laser with laser energy of 400mJ, 1cm air gap, and different pulses (2,3,4,5) pulse.

Laser pulses	Reflectance %	λ at the peak position (nm)
2	467	525
3	467	525

4	391	527
5	353	530

Morphological Characterization Results

Figures 5 and 6 show the 3D AFM pictures and the corresponding size distributions of Ag-nanoparticles synthesis by Laser Induced Forward Transfer Technique. Using LIFT technique gives a nanoparticle of spherical shape. Also, this figure shows that when the laser energy of the pulsed Nd: YAG laser increases, the diameter and roughness of produced AgNPs will be decreased for the same number of pulses and air gap between donor and acceptor. The reason for this behavior is as the laser energy increases this means that the heating leads to evaporation and eject smaller nanoparticles which finally causes decreasing the diameter of AgNPs transmitted from the donor to the acceptor. Results show that when laser energy is (300,400) mJ, the AgNPs diameters are (95.76, 88.44) nm and the roughness are (7, 6) nm respectively as given in Table 3.

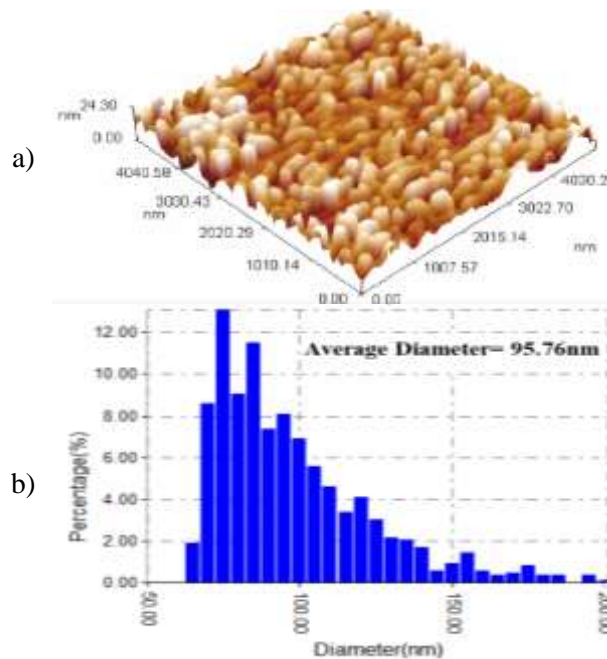
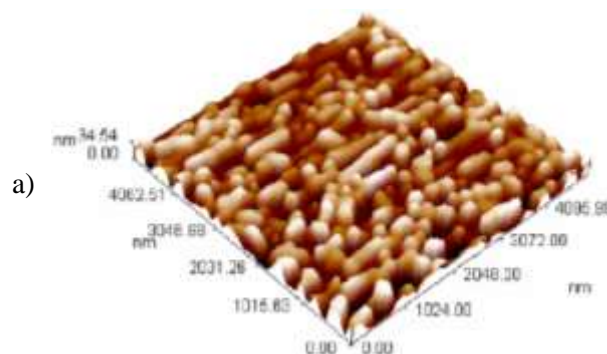


Figure 5. a) 3D AFM picture b) AFM size distribution images of Ag-nanoparticles synthesis by LIFT technique for laser energy is 300 mJ, and pulses shoot=2.



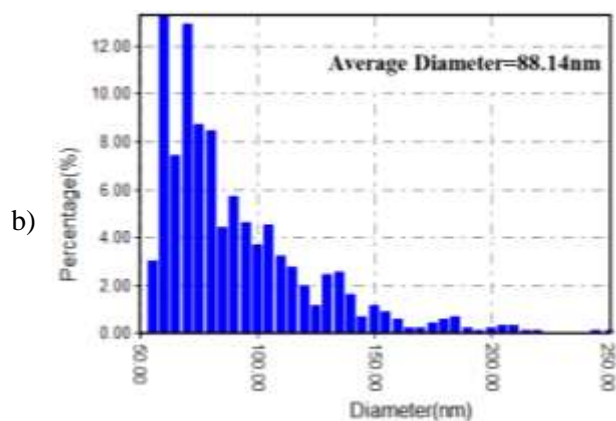


Figure 6. a) 3D AFM picture b) AFM size distribution images of Ag-nanoparticles synthesis by LIFT technique for laser energy is 400 mJ, and pulses shoot=2.

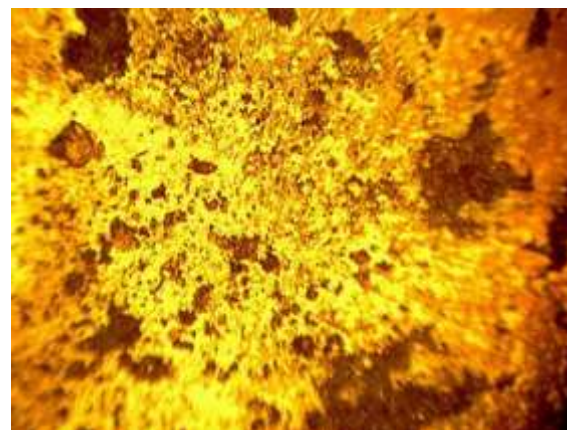


Figure 7. Optical microscopy images of the surface structure for the AgNPs prepared by LIFT with 5 laser pulses and different laser energy a) 300mJ and b) 400mJ.

Table 3. The Average diameter and average surface roughness of Ag-nanoparticles synthesized by LIFT technique for different laser energy and constant pulses and the air cavity between donor and acceptor.

Laser energy (mJ)	Average diameter (nm)	Average surface roughness (nm)
300	95.76	7
400	88.14	6

Surface morphology

Figure 7 shows the formation of ejected micro/nanoparticles when an Nd-YAG laser of 300 mJ and 400 mJ with 8ns pulse duration. It is found that when the laser energy increases the surface structure of ANPs becomes more homogeneous and the roughness becomes smaller. The reason for this behavior is as the laser energy increases this means that the heating leads to evaporate and eject smaller nanoparticles which finally causes decreasing the diameter of AgNPs transmitted from the donor to the acceptor this means that the surface roughness of the resulted silver nanoparticles becomes smoother.



CONCLUSIONS

Some findings can be drawn from the results and discussions presented in the study; these can be summarized as follows:

- LIFT method is a very acceptable technique to produce Ag nanoparticles with suitable optical and morphological characterization
- Increasing the laser energy of the pulsed Nd: YAG laser leads to an increase in the diameter and roughness.
- When the laser energy is (300,400) mJ, the AgNPs diameters are (95.76,88.44) nm and the roughness are (7.39,6.55) nm respectively.
- Increasing the number of laser pulses increases the surface roughness.

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