

RESEARCH PAPER

Investigation of structural, Optical and Antibacterial Effect of Silver Nanoparticles (AgNPs) Synthesis by Nd:YAG Laser

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ABSTRACT

AgNPs were prepared using laser ablation method in ultra-pure water using Nd:YAG laser at different pulses (300, 400, 500, 600 and 700 pulse) with energy 500 mJ each time. The optical and structural properties were inspected using UV-vis spectrophotometer, XRD, respectively, and then tested for antibacterial activity against one Gram-positive bacteria (*Staphylococcus aureus*) and one Gram-negative bacteria (*Escherichia coli*) isolated from the feet of diabetic patients. The results showed that when increasing the pulses, all optical properties change. The AgNPs are proven to be pure and of a crystalline structure. The findings demonstrated that AgNPs generated via the (PLAL) method have antibacterial activity.

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INTRODUCTION

Nanoparticles are extremely useful due to their unique properties and applications, particularly in biotechnology, medical imaging, and catalysts [1]. Physical and chemical materials properties greatly differ between nano to micro size [2]. Preparing metal nanoparticles in a simple technique may be made using Pulsed Laser Ablation in liquid environments (PLAL) [3]. Pulse laser ablation in liquid (PLAL) has unique advantages for synthesis of nanostructured like high purity, simple, rapid, does not require sophisticated vacuum equipment and does not require chemicals as in wet chemical methods which contaminate the end product and also pollute the environment [4]. The laser ablation process is affecting strongly with characteristics of a laser beam used (number of pulses, wavelength,

pulse duration, and energy) [5,6]. Laser ablation defines as a process of removing small masses from the material surface with the laser beam. Laser ablation process is based on many applications like modification surface of materials, nanoparticles formation, and deposition of thin film, chemical analysis, and micromachining. Laser ablation process relies on ablated material properties (optical and thermal) as well as laser parameters [7]. AgNPs have piqued the interest of many researchers and scientists due to their unique properties in physical, chemical, and biological fields when compared to their macro scale counterparts [8]. Silver nanoparticles have the potential to be used in biomedical applications due to their high surface Plasmon resonance and anti-microbial properties, as well as being

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less toxic than the bulk form [9]. AgNPs interact with vital organic components on the surface of microorganism cells, resulting in structural degradation [10]. Silver nanoparticles are metallic silver particles with a small size ranging from one to one hundred nanometers. As a result, they have a large surface area relative to their small size, which increases their ability to interact with other elements [11]. energy pulses that are used in the physical method of creating nanoparticles, known as laser ablation, where laser pulses are directed to the surface of any metal immersed in a liquid to start the process of surface ablation and produce nanoparticles [12].

In this study, the laser ablation method is studied. The objective of it is to generate nanoparticles (AgNPs), In addition to study how the particle size, change in different experimental conditions such as laser pulse. Investigate their structural, optical properties and antibacterial activity.

MATERIALS AND METHODS

Sliver Nanoparticles were prepared using the pulsed laser ablation technique in liquid (PLAL) and a pure silver plate and placed in (5 ml) of ultra-pure water in a beaker and at a distance (9 cm) from the laser source, where Nd: YAG laser was applied, rate of repetition (6 Hz), wavelength (1064 nm)

and energy (400 mJ), and the number of pulses (300, 400, 500, 600, and 700 pulses). After that, the samples were structurally by X-ray diffraction and optically by UV-Vis spectrophotometer analyzed. The antibacterial activity of the solution was then tested on one type of Gram-positive bacteria *Staphylococcus aureus*,

and one type of Gram-negative bacteria *Escherichia coli*, isolated from the feet of diabetic patients using the drilling method by placing (8 ml) the solution in the hole. The diffusion method in agar was used to assess the effect of AgNPs on the bacteria types used. This method entails spreading bacteria on agar plates and then waiting a few minutes. The inhibitory potency was determined by measuring inhibition zone diameters from various directions multiple times with a ruler.

RESULTS AND DISCUSSION

XRD analysis

Fig. 1 represents the XRD patterns obtained of the synthesized AgNPs. we notice in all the resulting patterns the appearance of a number of intensities and peaks that belong to AgNPs with a cubic crystal structure.

XRD technique was used to determine the structure properties of AgNPs crystalline size. This size (G.S) of the samples were evaluated for the preferred planes [hkl] using the following equation

Table 1. XRD analysis results of AgNPs.

No. Pulses	2θ (Deg.)	FWHM (Deg.)	d _{hkl} Exp.(Å)	G.S (nm)	(hkl)
300	38.5217	0.9711	2.3352	8.7	(111)
	44.5523	1.0310	2.0321	8.3	(200)
	64.8315	1.1011	1.4370	8.5	(220)
	78.0712	1.1201	1.2231	9.1	(311)
400	38.5314	0.8902	2.3346	9.5	(111)
	44.5522	0.8890	2.0321	9.7	(200)
	64.8326	0.8801	1.4369	10.7	(220)
	78.0922	0.8780	1.2229	11.7	(311)
500	38.5431	0.6891	2.3339	12.2	(111)
	44.5532	0.6621	2.0320	13.0	(200)
	64.8336	0.7101	1.4369	13.1	(220)
	78.0922	0.7121	1.2228	14.4	(311)
600	38.5126	0.4756	2.3357	17.7	(111)
	44.5542	0.5348	2.0320	16.1	(200)
	64.8413	0.5568	1.4368	16.9	(220)
	78.1032	0.5734	1.2227	17.8	(311)
700	38.5316	0.3986	2.3346	21.1	(111)
	44.5512	0.4356	2.0321	19.7	(200)
	64.8245	0.4587	1.4371	20.5	(220)
	78.1135	0.4602	1.2225	22.2	(311)

(the Scherrer's formula) [13]:

$$G.S = K \lambda / \beta \cos \theta \quad (1)$$

Where K = Scherrer constant (0.9), $\lambda = 1.54 \text{ \AA}$ is the wavelength of the X-ray radiation, θ is the angle of diffraction and β is the width of the peak at the half of the maximum peak intensity (FWHM). It was noted that the increase in ablation pulses causes an increase in both the intensity of

the diffraction peaks and the crystalline size with an improvement crystallization. while noting an increase in the intensity of the peaks to become somewhat sharp. With the increase the number of pulses, it is noticed that there is an increase in the high and sharpness of the diffraction peaks, which is attributed to the increase in crystallization of the nanoparticles as a result of the increase the number of pulses and this means a decrease in crystal defects because the laser energy provides

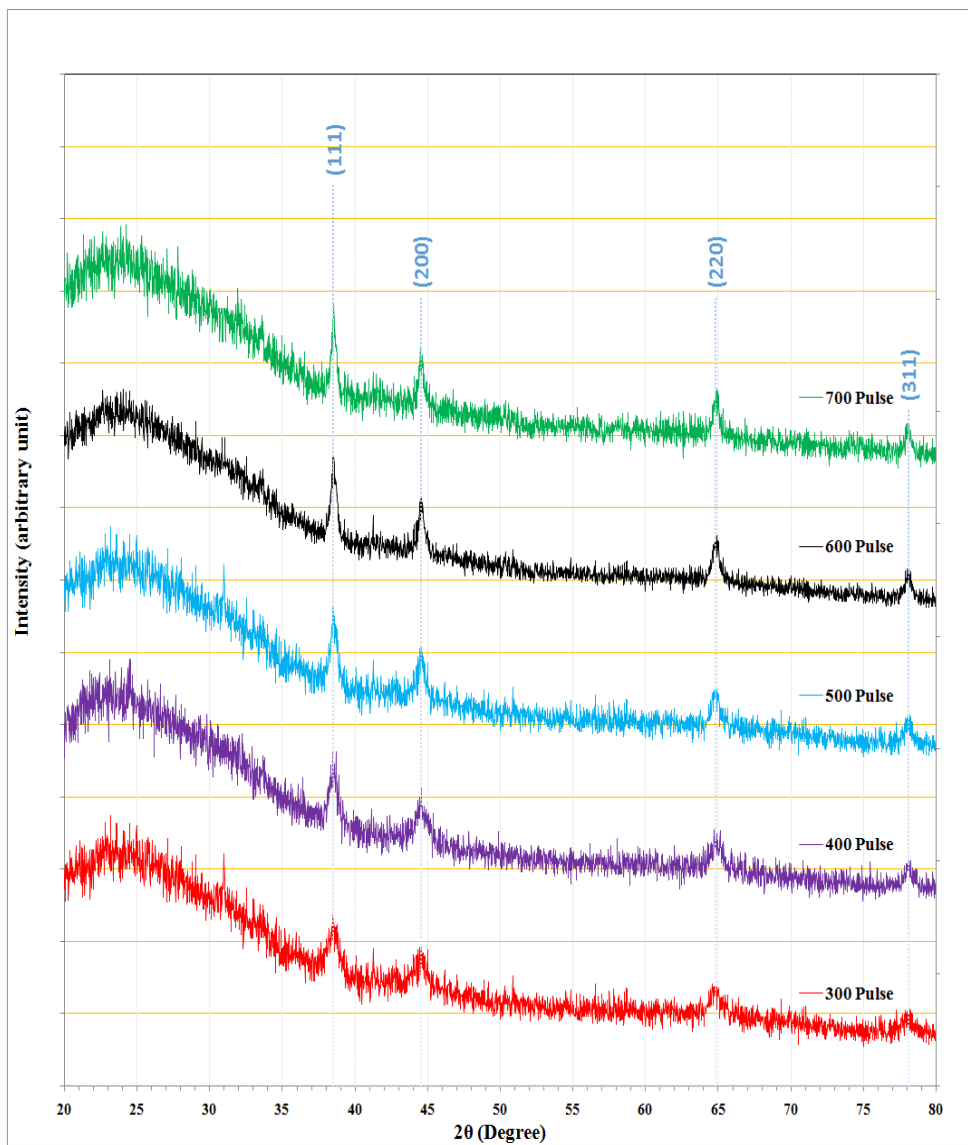


Fig. 1. XRD patterns of AgNPs.

the atoms with sufficient energy to restore their positions and arrange themselves in the lattice. From Table 1 it can be seen that the crystalline

size values increase with the increase the number of pulses, while we notice a decrease in FWHM values because the increase the number of pulses

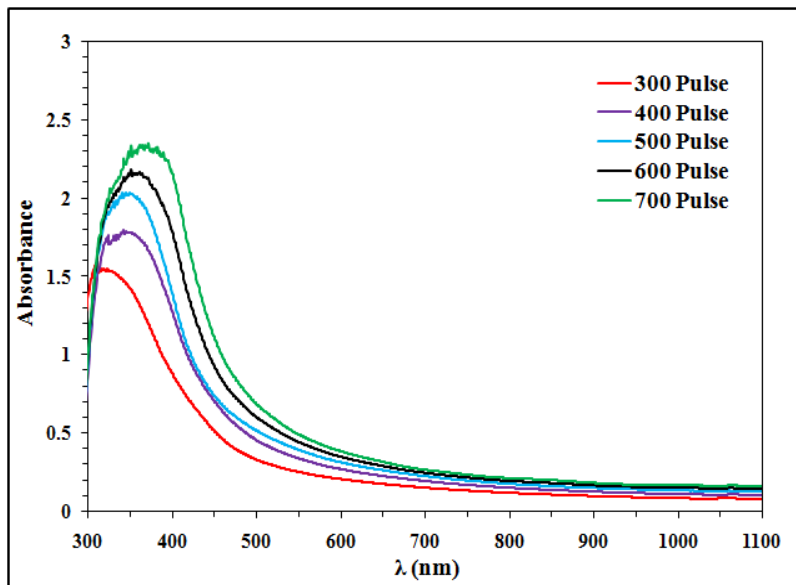


Fig. 2. Absorption spectrum of AgNPs.

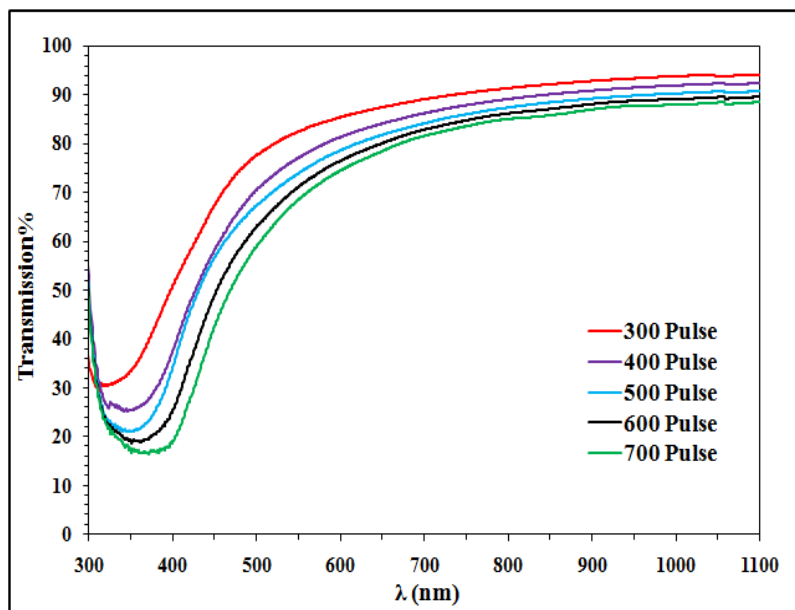


Fig. 3. Transmission spectrum of AgNPs.

causes an increase in the kinetic energy of the ablated atoms and molecules, which makes it easier for them to arrange their places within the crystal lattice, which increases the crystallization size.

Optical analysis

It is one of the most widely used techniques for the identifying of various substances such as transition metal ions, biological molecules, and organic compounds.

Absorption and Transmittance measurements were performed within wavelength range (300-1100) nm of all samples at different pulses. Fig. 2

shows the absorption change as a function of the wavelength of the AgNPs at pulses (300, 400, 500, 600, and 700).

It is noted that the effect of increasing the laser power (at increasing number of pulses) leads to a clear increase in the absorption values. However, the absorption decreases with increasing wavelength within the wavelength range 450-600nm and then almost stabilizes. Fig. 3 shows an increase in number of pulses led to a decrease in transmittance because the nanoparticles absorb more energy from incident electromagnetic radiation. This is due to the increase in the growth rate which is caused by increasing the ablation

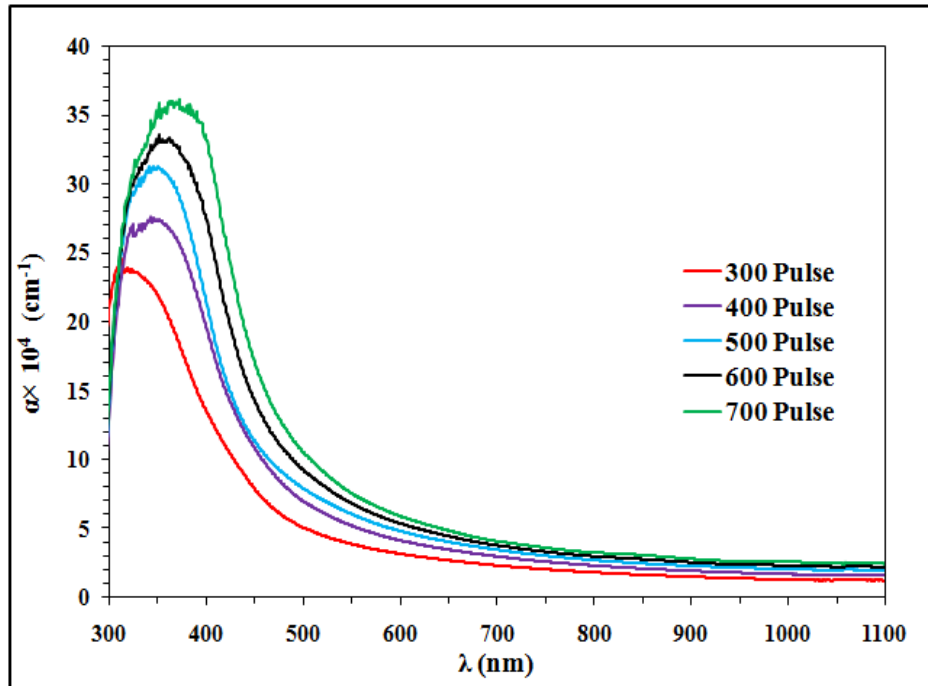


Fig. 4. Absorption coefficient of AgNPs.

Table 2. optical constants of AgNPs at $\lambda= 400$ nm.

No. Pulse	A%	T%	α (cm ⁻¹)	K
300	0.8815	50.8273	135347	0.4310
400	1.2778	37.495	196193	0.6248
500	1.397	34.2158	214496	0.6831
600	1.789	25.3126	274773	0.8750
700	2.1619	19.0207	331929	1.0571

energy and the particle size, thus aggregates the material content and crystalline growth [14].

Fig. 4 shows that the absorption coefficient values increase with increase of number of pulses.

This is due to the fact that the increase in the pulses led to an increase in the number of collisions with the material [15].

Fig. 5 shows the extinction coefficient (k) plotted

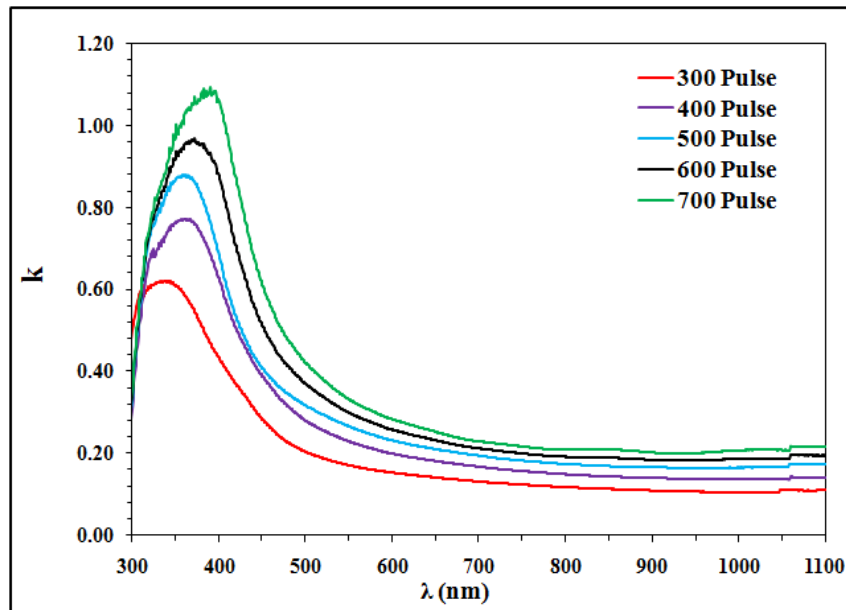


Fig. 5. The extinction coefficient of AgNPs.

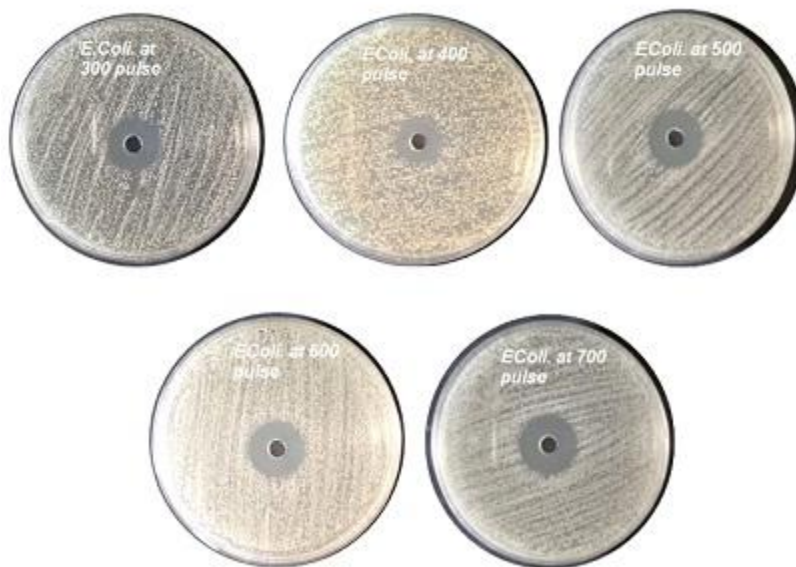


Fig. 6. Antibacterial activity against gram-negative bacteria (*E.coli*) from AgNPs.

against wavelength for the AgNPs. The data reveals a slight reduction in the extinction coefficient across the UV- visible, and near-IR regions with increasing number of pulses. This decrease is attributed to the reduced light absorption at grain boundaries, which affects the overall absorption characteristics of the nanoparticles. The values of extinction coefficient (k) were calculated by the following equation [16]:

$$k = \alpha \lambda / \pi \tag{2}$$

Table 2 shows the values of optical constants of the AgNPs at $\lambda = 400$ nm.

Antibacterial activity

The results of study showed that the AgNPs

prepared the tiny size and high surface-to-volume ratio enable them to interact tightly with microbial membranes, which has a major impact on bacterial inhibition.

we can observe the inhibition regions of AgNPs prepared by laser ablation all pulses (300,400.500.600 and 700) setups as shown in Figs. 6 and 7. Increased inhibition was found to be associated with increased laser pulses. We can see that AgNps affected bacteria High and varying effects against the Gram-positive bacterium *Staphylococcus aurus* and the Gram-negative bacterium *Escherichia coli* because the bacterial cell membrane contains so many sulfur-containing proteins, silver nanoparticles can react with sulfur-containing amino acids both inside and outside the cell membrane, reducing the viability of the



Fig. 7. Antibacterial activity against gram-positive bacteria (*S.aurus*) from AgNPs.

Table 3. Values of diameters that inhibit bacterial growth

No. Pulses	inhibition diameter (mm) (<i>E. coli</i>)	inhibition diameter (mm) (<i>S.aureus</i>)
300	13	12
400	14	16
500	16	18
600	18	21
700	21	23

bacteria. It's also been suggested that Ag ions generated by AgNPs can bind with phosphorus moieties in (DNA), causing (DNA) replication to be inactivated. Nanoparticles are more effective against Gram-positive bacteria than Gram-negative ones, according to studies [9,17]. Table 3 shows the diameters of bacterial inhibition.

CONCLUSION

The ability to synthesize AgNPs using the physical method that is pulse laser ablation in liquid. The results XRD demonstrated the possibility of Obtaining different nanoscale sizes of Ag using one wavelength of Nd:YAG laser (1064nm) in the process of ablation and with different numbers of pulses. The controllability the optical properties, including absorbance and transmittance by varying pulses. Laser-ablated AgNPs demonstrated antimicrobial activity against Gram-positive bacteria and Gram-negative bacteria.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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