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ORIGINAL STUDY

Investigating the Optical Qualities of Aluminum Nanoparticles with Nd:YAG Pulsed Laser Ablation in Liquid Technology

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ABSTRACT

This research investigated the preparation of aluminum nanoparticles using pulsed laser ablation in liquid (PLAL). Ablation was performed on a metallic target in distilled water using a 532 nm Nd:YAG laser at different laser energies (400, 600, and 800 mJ) with a repetition frequency of 1 Hz and 300 pulses. A change in the solution's color is one of the first indicators of nanoparticle formation. We observed a change in the color of the deionized distilled water from light white to dark white, suggesting the production of aluminum nanoparticles. Furthermore, UV-VIS measurements showed an increase in the material concentration with increasing laser pulse energy. This is attributed to the increased number of ablated particles. A blue shift in the absorption spectrum with increasing laser pulse energy was also observed, indicating the formation of smaller nanoparticles. High laser energy effectively enhances the production efficiency of nanoparticles and controls their optical and electronic properties, making pulsed laser ablation a promising tool for high-precision nanomaterial preparation.

Keywords: Nd:YAG laser, Optical properties, Pulsed laser ablation in liquid, Nanoparticles

1. Introduction

Nanotechnology is of interest due to its amazing physical and chemical properties, and the wide variety of its applications. The need for new and varied techniques in both sample preparation and techniques has led to the development of nanotechnology, as is the case in various scientific research in many fields, including physics and chemistry [1]. The main reason for the change in behavior from the conventional state to the nano state is the increase in the relative surface area [2]. The term nano is used to denote the number 10 to the power of negative nine, or one billionth of any unit of measurement. Examples of nanoscale dimensions include the width of a single human hair (approximately 180,000 nm) and the width of a red blood cell (approximately 7,000 nm).[3] Nanomaterials can be defined as materials with at least one structural element that falls within the nanoscale. The extremely small size of these materials leads to behaviors different from those of conventional materials, which have dimensions larger than 100 nm. Since nanoscale dimensions are defined as ranging from 1 to 100 nm, they are referred to as being within the nanoscale or nanoscale range [4]. Nanomaterials occur naturally in the environment, such as viruses and proteins, or they may be produced unintentionally by humans, such as nanoparticles resulting from diesel combustion. They can also be manufactured by humans using specific methods for their synthesis [5] Nanomaterials are synthesized using several methods, all of which share common characteristics. Based on the atomic scale, i.e., atom towards another atom, to

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obtain desired results, the chemical activity varies as the size scale of the substance's mass changes; that is, the smaller the scale, the greater the chemical activity of the substance, [6, 7]. Nanomaterials are synthesized using several methods which can be produced by short-pulse laser ablation of a solid target in a liquid medium [8]. Laser ablation is the process of removing a substance from a solid surface or sometimes a liquid by scattering it with a laser beam. When high laser energy is used, the substance is heated by the laser energy absorbed by the target, causing it to vaporize or sublimate due to the high temperature. When high laser energy per unit time strikes the target, the substance turns into plasma. The ablation process is used to remove substances using pulsed lasers, where the ablation rate (the amount of substance removed by a single laser pulse) depends on the laser energy, depth of penetration, and properties. Aluminum nanoparticles have recently attracted considerable attention due to their diverse and important applications [8–10]. Ideal catalysts for rocket propellant reactions with numerous nanotechnology applications in medicine, such as disease detection: Nanowires are characterized by their extremely small size and high sensitivity, making them useful as nano-biosensors for detecting a wide range of diseases in their early stages. This is achieved by introducing large numbers of nanowires into the body, each coated with a different antibody, which acts as a different sensor. In cancer treatment, gold-coated nano-coatings are used to destroy cancer cells. When these nano-coatings are injected into the body, they automatically adhere to the cancer cells. These cells are then exposed to infrared laser beams, which heat the gold, leading to cell destruction and death [11–13]. Compared to chemical synthesis methods, laser ablation in liquids offers the advantage of producing pure nanoparticles without the need for toxic chemical precursors Laser ablation is widely used for solid targets in a liquid medium to prepare nanomaterials and fabricate nanostructures. There is a wide variety of nanomaterials, such as metal alloys, polymers, semiconductors, metals, and the like, which are fabricated using laser ablation in a liquid medium for solids. Therefore, laser ablation in liquids can be defined as a general and efficient method for synthesizing nanocrystals and fabricating nanostructures [14].

2. Method

To obtain aluminum (Al) nanoparticles, pulsed laser ablation in liquids was used. Figs. 1 to 3 shows an image of the pulsed laser ablation system. This work was carried out at Al-Hamdaniya University – Laser and Photonics Research Center, Laser and Spectroscopy Department, Laser and Spectroscopy Laboratory. The target, made of 50% pure aluminum, was immersed in deionized distilled water in a square tube with a side length of 1.8 mm. Its dimensions were measured with a ruler. The wavelength of the Nd:YAG laser used was 532 nm and the frequency was 1 Hz, with 300 pulses. A 532 mm quartz converging lens was used to focus the laser beam.

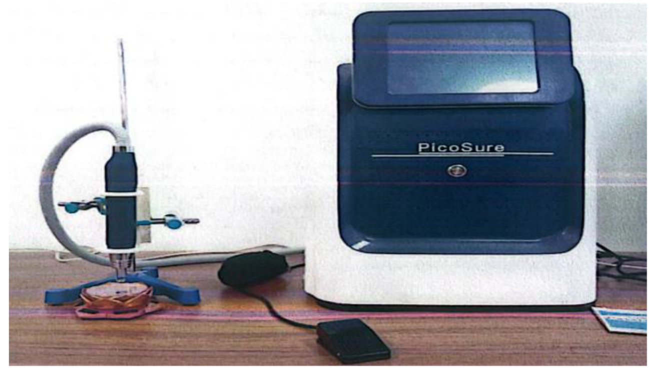

Fig. 1. A photograph of the pulsed laser ablation system.

The water level in the glass container holding the sample was 7 ml, and the distance between the laser beam and the sample was 9 cm. The beam energies used were 800, 600, and 400 mJ, and a carefully prepared aluminum target was used. Before starting the application process, the surface of the metal target was polished with polishing paper to remove impurities. The sample was then placed in deionized distilled water and subsequently in an ultrasonic sterilizer at 50 °C for ten minutes. Fig. 2(a) illustrates the device used. During the ablation process, the glass container with the target material immersed in deionized distilled water is placed on a magnetic mixing device that operates on light and electrical energy, causing the container to rotate in a circular motion as shown in Fig. 2(b) to direct the laser onto the entire sample and not a specific area.

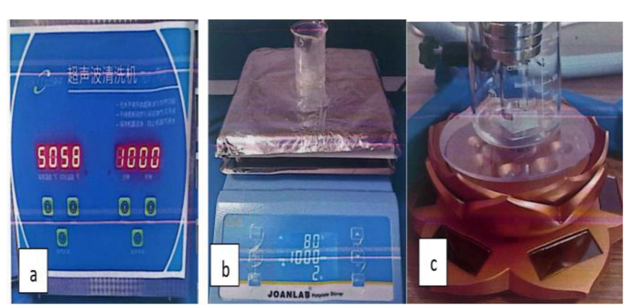

Fig. 2. (a) The sterilizer (b) Magnetic mixing device (c) Photovoltaic and Electrical Power Device.

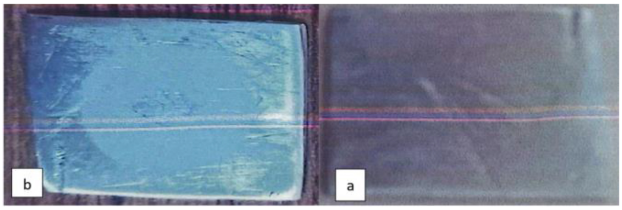

Fig. 3. (a) Sample before excision (b) Sample after excision.

Table 1. Specifications of the pulsed laser device.

Laser used	Nd-YAG laser
Laser wavelength	(355,532,1064) nm
Pulse energy	(400,600,800) mJ
Repetition frequency	1Hz
Pulse time	6 nsec

Then, the laser device is set to the number of pulses until the pulses are finished. Then, the laser is switched off, and the target is removed from the glass container and placed in a clean container. The container holding the aluminum nanoparticles and distilled water is placed on a magnetic mixer to thoroughly mix the mixture at 80 degrees Celsius for 10 minutes and 1000 revolutions Fig. 2(c) Afterward, we obtain the mixture for the first energy level of 400, and so on for the next two energy levels of 600 and 800. We follow the same steps. Fig. 3 shows the aluminum target before and after the ablation process, and Table 1 shows the specifications of the pulsed laser device used.

It should be noted that the laser's temperature must be monitored and controlled to prevent it from exceeding the operating temperature. This is essential to protect the device from damage or malfunctions in the active medium. Water is added to the device for cooling purposes through a designated area to prevent overheating and potential damage. It is also necessary to reset the laser to prepare it for operation by readjusting the wavelength, frequency, pulses, and power required for operation. The device must be switched off immediately after use to prevent overheating. Regarding optical properties, measurements were performed using an ultraviolet spectrometer to study the optical characteristics of the prepared nanoparticles. This spectroscopic analysis of the nanoparticles is crucial because absorption in the visible spectrum significantly affects the color of the chemical under investigation. The instrument used was a photometric spectrometer Fig. 3, located in the Central Laboratory at the University of Mosul. Fig. 4 shows the spectrophotometer used in the experimental measurements.

Fig. 4. The spectrophotometer.

3. Results and discussion

In our current study, aluminum solutions were prepared and the effects of some laser parameters, such as laser energy, on the properties of the prepared nanoparticles were investigated. One of the primary indicators of obtaining nanoparticles is the change in the color of the solution or distilled water. UV-Visible analysis is an effective method for determining the shape and size of nanoparticles [15]. Aluminum nanoparticle suspensions prepared with a pulsed Nd:YAG laser at a wavelength of 532 nm and energies of 400, 600, and 800 mJ in deionized distilled water were examined using UV-Vis visible absorption. Fig. 5 shows that the solution's color starts from pale white and gradually darkens to off-white as the laser energy increases due to the increasing concentration of generated nanoparticles. The absorbance of the prepared aluminum solution was studied at 300 pulses and at energies of 400, 600, and 800 mJ. Fig. 5 shows the relationship between absorbance on the y-axis and wavelength on the x-axis for the three energies in a combined plot to observe the difference between the absorption peaks (the relationship between them is inverse).

We observe from Fig. 6 that with increasing laser energy used in pulsed laser ablation, the absorption peak of the solution increases as the wavelength decreases, since there is an inverse relationship between them. This is logical because increasing laser energy leads to increased nanoparticle formation and conse-

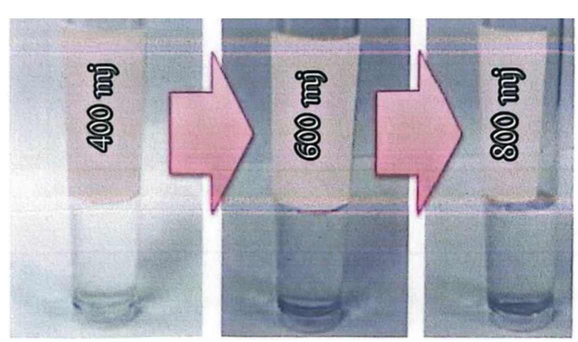

Fig. 5. Shows the color gradient of the aluminum nanoparticle solution change.

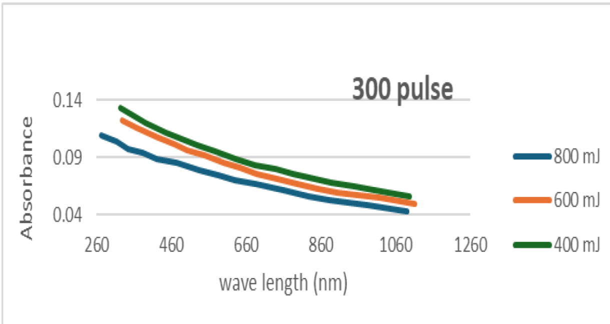

Fig. 6. The relationship between wavelength and absorption of the three energies.

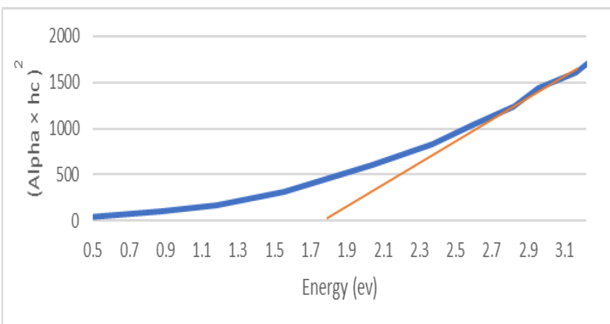

Fig. 7. The absorption coefficient and the photon energy of aluminum particles at an energy of 400 mJ.

quently, increased absorption. Regarding the higher absorption peaks of the aluminum nanoparticle solution at 800 mJ compared to 400 mJ, this is attributed to the concentration of nanoparticles in the solution. The optical energy gap in direct transitions is strongly affected by the chemical bonds of the constituent elements and the particle size. Generally, the energy gap changes with changes in particle size.

To find the optical energy gap, was drawn between the photon energy Energy(ev) on the x-axis, (Alpha $\times$ hc)^2 in the y-axis, then the optical energy gap derived from the equation (Energy = 1240ev / wave length in nm). In Fig. 7 we show that the value of the optical energy gap at energy 400 mJ equal 1.738144ev, in Fig. 8 the value of the optical energy gap at energy 600 mJ equal 1.98 ev, and in Fig. 9 we show that the value of the optical energy gap at energy 800 mJ equal 2.41ev.

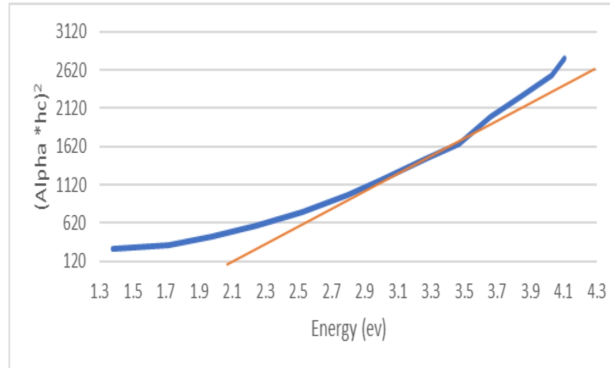

Fig. 8. The absorption coefficient and the photon energy of aluminum particles at an energy of 600 mJ.

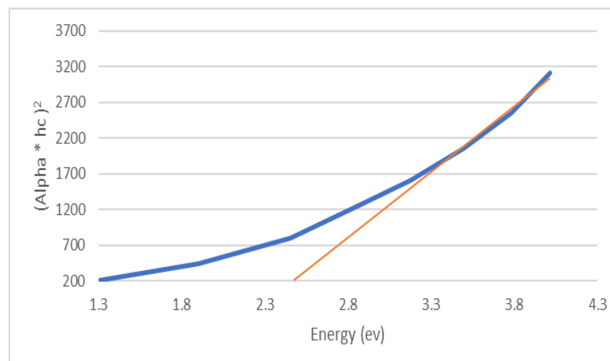

Fig. 9. The absorption coefficient and the photon energy of aluminum particles at an energy of 800 mJ.

We note that the value of energy gap energy is 2.41eV at an energy of 800 mJ and the lowest value at 400 mJ. This means that there is a direct relationship between the laser energy and the gap energy, and this leads to an increase in the alpha concentration. The concentration of the solution was found as shown in Table 2, for each laser energy, a path length of 1 cm, and a constant aluminum absorption coefficient of 0.075 mol cm^{-1}, we can find the concentration of each energy in mol/L. We used Beer-Lambert's law, which is a relationship that relates the absorption of light by a solution to its concentration and properties. The mathematical formula for the law states that the absorption A is equal to the product of the molar absorption constant € multiplied by the concentration C and the path length l of light through the sample, and

Table 2. Shows the nanomaterial concentration and gap energies withmaximum absorption values at all laser energies.

Laser energy (mJ)	Energy Gap (ev)	Absorption	Nano Al concentration mol/L
400	1.738144	0.1099	1.46533
600	1.98	0.1291	1.732
800	2.41	0.1372	1.82933

is written as: A = C€ l. This law allows the concentration of a substance in a solution to be determined by measuring the amount of light it absorbs [16].

Pulsed laser ablation in liquids was used and the results showed that this method was very successful. The first sign that can indicate the formation of nanoparticles is a change in the color of the solution in which the samples are to be prepared. We observe a gradient of the solution's color towards a dark white color, and we conclude that as the energy increases, the color gradient increases, meaning that the nanoparticles have become denser, i.e., smaller in size [17]. We also observe from UV assay measurements that as the laser energy increases, the absorbance increases due to the increased concentration of nanoparticles in the aluminum solution. With increasing energy, the optical energy gap increases. It should be noted that while color change is a useful initial indicator, future work should include X-ray diffraction (XRD) analysis to confirm the crystalline structure and phase purity of the prepared aluminum nanoparticles, and when the energy was 400 mJ, the peak absorbance was 0.1099 The optical band gap was 1.738144, and its concentration value, 1046533, was derived from Beer-Lambert's law. At energy mj600, the absorption peak was 0.1291, the optical band gap was 1.98, and the concentration value was 1.732. At energy mj800, the absorption peak was 0.1372, the optical band gap was 2.41, and the concentration value was 1.82933. This demonstrates that the absorption value increases with increasing energy due to the increasing concentration of nanoparticles.

4. Conclusion

This study demonstrates that high laser energy effectively enhances the production efficiency of nanoparticles and controls their optical and electronic properties, making pulsed laser ablation a promising tool for high-precision nanomaterial preparation. The change in the solution's color to darker white with increasing laser energy indicates an increase in nanoparticle density and a decrease in size. The increase in absorbance, associated with increasing laser energy (from 400 mJ to 800 mJ), was also reflected in an increase in the peak absorption value in UV spectroscopy, confirming the high concentration of nanoparticles in the solution. Furthermore, the widening of the optical band gap with increasing laser energy (from 1.738 to 2.41) indicates a reduction in nanoparticle size, which is related to the smaller particle size resulting from the quantum confinement effect. The results, applied using Beer-Lambert's law, showed that increasing laser power led to an increased concentration of nanoparticles in the solution; that is, higher laser power produces a greater number of smaller nanoparticles. However, this method has limitations, including relatively low production yield and reduced efficiency for highly reflective metals.. Because the size and concentration of nanoparticles can be controlled by adjusting the laser power, this method can be used in various applications such as sensors, nanoelectronics, and nanomedicine.

Conflict of interest statement

The authors declare that there is no conflict of interest regarding the publication of this paper. The research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

1. Y. Khan, H. Sadia, S. Z. Ali Shah, M. N. Khan, A. A. Shah, N. Ullah, Khan, M. I., "Classification, synthetic, and characterization approaches to nanoparticles, and their applications in various fields of nanotechnology: A review," *Catalysts*, vol. 12, no. 11, p. 1386, 2022.
2. E. Grulke, K. Reed, M. Beck, X. Huang, A. Cormack, and S. Seal, "Nanoceria: factors affecting its pro-and anti-oxidant properties," *Environmental Science: Nano*, vol. 1, no. 5, pp. 429–444, 2014.
3. S. S. Ochigbo and R. E. Sadiku, "Introduction to the synthesis and characterization of nanostructured materials," in *Nanostructured Materials for Biomedical Applications*, Elsevier, pp. 1–34, 2024.
4. D. Baird, A. Nordmann, and J. Schummer, Eds., *Discovering the Nanoscale*. Ios Press, 2004.
5. D. Mohan, D. Thiyagarajan, and P. B. Murthy, "Toxicity of exhaust nanoparticles," *African Journal of Pharmacy and Pharmacology*, vol. 7, no. 7, pp. 318–331, 2013.
6. B. Mekuye and B. Abera, "Nanomaterials: An overview of synthesis, classification, characterization, and applications," *Nano Select*, vol. 4, no. 8, pp. 486–501, 2023.
7. A. V. Syroeshkin, E. V. Uspenskaya, T. V. Pleteneva, M. A. Morozova, I. A. Zlatskiy, A. M. Koldina, and M. V. Nikiforova, "Mechanical transformation of compounds leading to physical, chemical, and biological changes in pharmaceutical substances," *The Scientific World Journal*, vol. 2018, no. 1, p. 8905471, 2018.
8. N. G. Semaltianos, "Nanoparticles by laser ablation," *Critical Reviews in Solid State and Materials Sciences*, vol. 35, no. 2, pp. 105–124, 2010.
9. A. M. Mostafa, "The Influence of various parameters on the ablation and deposition mechanisms in pulsed laser deposition," *Plasmonics*, pp. 1–19, 2025.

10. H. R. Ghorbani, “A review of methods for synthesis of Al nanoparticles,” *Orient. J. Chem*, vol. 30, no. 4, pp. 1941–1949, 2014.
11. M. A. Darwish, W. Abd-Elaziem, A. Elsheikh, and A. A. Zayed, “Advancements in nanomaterials for nanosensors: A comprehensive review,” *Nanoscale Advances*, vol. 6, no. 16, pp. 4015–4046, 2024.
12. M. Sultana, *Dispersion of Nano Matrices into Cellulose Network*, 2016.
13. J. Cheng, H. Huang, Y. Chen, and R. Wu, “Nanomedicine for diagnosis and treatment of atherosclerosis,” *Advanced Science*, vol. 10, no. 36, p. 2304294, 2023.
14. G. Krishna Podagatlapalli, “The fundamentals of synthesis of the nanomaterials, properties, and emphasis on laser ablation in liquids: A brief review,” *Discover Nano*, vol. 20, no. 1, p. 98, 2025.
15. M. Ghanipour and D. Dorranian, “Effect of Ag-nanoparticles doped in polyvinyl alcohol on the structural and optical properties of PVA films,” *Journal of Nanomaterials*, vol. 2013, no. 1, p. 897043, 2013.
16. X. Song, “Investigating the absorption and scattering effects of light in different solutions and colloids: An experimental investigation based on Lambert’s law and the scattering theorem,” *Advances in Engineering Technology Research*, vol. 12, no. 1, pp. 936–936, 2024.
17. A. L. González, C. Noguez, J. Beránek, and A. S. Barnard, “Size, shape, stability, and color of plasmonic silver nanoparticles,” *The Journal of Physical Chemistry C*, vol. 118, no. 17, pp. 9128–9136, 2014.