Preparation of Aluminum Nanoparticles and Study of the Laser Effect on them by the Laser Ablation Method

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Abstract

In this research, aluminum nanoparticles (AL NPs) were prepared using the Nd-YAG pulsed laser ablation method with a wavelength of 1064 nm with a frequency of 6 Hz and a fixed pulse of 250 pulses. A pure aluminum metal target was immersed in ethanol and aluminum nanoparticles removed using five different laser energies ranging from (400-800) mj and the effect of the laser energy difference on the optical properties of aluminum nanoparticles was studied. The optical properties were studied using UV spectroscopy for both the absorption and transmittance spectrum and according to the change of laser power, and a change in the absorption behavior was observed. The transmittance changes with wavelength and laser energy and the best pulsed laser energy is known to ablate these particles.

Key Words: Aluminum Nanoparticles, Laser Ablation, Optical Properties, Pulsed Laser, Structure Properties.

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Introduction

Aluminum has unique properties that make it one of the most important types of minerals. It has a high intrinsic reflectivity of a wide range of minerals, ranging from far ultraviolet rays to infrared rays and beyond (Sven *et al*, 2020). Aluminum is a shiny, non-magnetic silver element with an attractive appearance, durable, road and ductility, is a good conductor of heat and is of particular importance in the electronic industries. Non-toxic, possesses the crystal structure (FCC) (Bushra *et al*, 2016). Aluminum is added to many oxides and elements to change its optical properties (Maysam, 2018; Mahdi *et al*, 2009). It is also added to many alloys. Aluminum-rich alloys have high mechanical resistance and are considered good resistance to all types of wear, corrosion, fatigue and oxidation. Aluminum alloys are second only to steel and are superior to all types Stainless steel, ductility and ease of manufacture (Faisal *et al*, 2010). The electronic properties of the metal nanoparticles change greatly from its properties in the non-nanoscale due to the difference in the properties of the nanostructure. Aluminum nanoparticles possess physical and chemical properties that make them applicable in a wide and varied fields due to the large surface area, which gives better properties compared to the non-nanostructured aluminum (Kadhim *et al*, 2014). In general, laser systems are of great importance. These systems have been used in many fields according to the different type of laser (wavelength, energy and use) (Tasneem, 2014).

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One of the most important types of lasers that have gained great importance in recent times is the pulsed Nd-YAG laser, as it generates high-energy pulses and this is due to the time life of the electrons in the excited energy level, and the laser affects the material when the laser beam is absorbed so that the interaction process occurs between the material (the target). And the laser, as this absorption process is a main source of energy in the material (the target), as the incident laser pulse heats the target quickly and thus we get a nanoparticle (Rasha, 2014). In this research, we used pulsed laser ablation, as the laser ablation of metals submerged in liquid medium is considered one of the best ways to obtain pure nanoparticles, as the laser ablation technology began to be used in liquids because it is a low-cost technology that ensures obtaining nanoparticles easily. Moreover, we can control Size by controlling parameters such as (laser wavelength, laser power, number of pulses, type of liquid medium, and ablation time) (Kadhim *et al*, 2014). The interaction of the optical ray with the material depends mainly on the optical properties of the material, so it is necessary to shed light on knowledge of these properties of materials. Recently, researchers have been attracted to study the optical properties of metallic nanoparticles to expand their use in multiple applications such as solar cells (Sven *et al*, 2020). In this research, we studied the structural properties and optical properties of aluminum nanoparticles and the extent of the effect of changing the laser energy on these properties, as laser pulses affect the transfer of radiation energy to electrons in solid materials and a layer that is considered strongly unbalanced is formed from electrons that have been heated by the action of the laser energy, which leads to changes in Mechanisms of electron-photon interactions leading to changes in the optical and thermal properties of the solid (Alexander *et al,* 2010).

Experimental

The aluminum nanoparticles were prepared by pulse laser ablation of an aluminum metal target in the form of a circular disc immersed in ethanol. The high purity aluminum target (99.99%) was fixed at the bottom of a glass container (Baker) containing 5ml of ethanol, and the level of ethanol was above the target (Aluminum (4mm), the height of the laser source is 15cm from the target (aluminum), and the ablation was done using a pulsed Nd: YAG laser operating at a frequency of 6Hz by the laser operating at the wavelength of 1064nm with variable laser energies (400,500,600,700,800 mj) and with a constant number of pulses of 250, we obtained A solution was suspended to each laser energy and the aluminum nanoparticle solution was distilled on a glass layer at room temperature to study the optical properties and films were formed with a thickness of (200nm). In this work, all preparation factors such as thickness, pulses, and temperature were established to find out the effect of changing the laser energy on the structural properties and optical properties (absorption, transmittance, absorption coefficient) of the aluminum nanoparticles. The structural properties of thin films were examined using an XRD system (Shimadzu XRD 6000). The UV-visible absorbance was measured by (SP-8001 spectrophotometer).

Results and Discussion

Structural Properties

XRD technique was used to determine the structure properties of Al nanoparticles thin films grain size, The grain size (G.S) of the samples were evaluated for the preferred planes [hkl] using the following equation (the Scherrer's formula) (Maysam, 2018):

$$G.S = 0.94\,\lambda / \beta \cos\theta \quad (1)$$

Where λ= 1.54 Å 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).

Figure 1 shows the results of the XRD measurements showing that all the as-prepared thin films are polycrystalline and have a FCC structure with different values and different preferential orientations. It was observed that an increase in the ablation energy leads to an increase in both the intensity of the diffraction peaks and the grain size with improved crystallization. The prepared thin films are characterized by different ablation energy, the appearance of peaks obtained from the X-ray diffraction patterns of the prepared samples with an increase in the intensity of the peaks to become rather sharp. With the increase of the ablation energy, it is noticed that there is an increase in the height and intensity of the diffraction peaks, which is attributed to the increased crystallization of the thin-film material as a result of the increase in the ablation energy, and this means a decrease in crystal defects because the laser energy provides the atoms with sufficient energy to restore their positions and arrange themselves in the lattice (Bushra *et al*, 2016; Maysam, 2018). From Table (1) it can be seen that the grain size values increase with the increase of ablation energy, while we notice a decrease in

FWHM values because the increase in ablation energy 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 (Maysam, 2018).

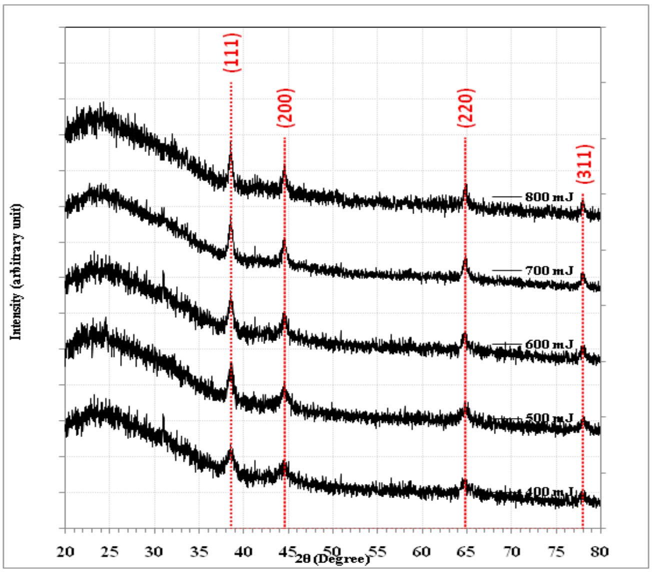

Fig. 1. The XRD patterns of Al thin films

Table 1. The result of the (XRD) of nano Al thin films

Laser Energy (mJ)	2θ (Deg.)	FWHM (Deg.)	d_{hkl} Exp. (Å)	G.S (nm)	hkl
	38.5316	0.9300	2.3346	9.1	(111)
400	44.5512	1.0300	2.0321	8.3	(200)
	64.8216	1.1000	1.4372	8.6	(220)
	78.0711	1.1100	1.2231	9.2	(311)
	38.5426	0.7440	2.3339	11.3	(111)
500	44.5622	0.8240	2.0316	10.4	(200)
	64.8326	0.8800	1.4369	10.7	(220)
	78.0821	0.8880	1.2229	11.5	(311)
	38.5536	0.5952	2.3333	14.1	(111)
600	44.5732	0.6592	2.0312	13.0	(200)
	64.8436	0.7040	1.4367	13.4	(220)
	78.0931	0.7104	1.2228	14.4	(311)
	38.5646	0.4762	2.3327	17.7	(111)
700	44.5842	0.5274	2.0307	16.3	(200)
	64.8546	0.5632	1.4365	16.7	(220)
	78.1041	0.5683	1.2226	18.0	(311)
	38.5646	0.3809	2.3327	22.1	(111)
800	44.5842	0.4219	2.0307	20.4	(200)
	64.8546	0.4506	1.4365	20.9	(220)
	78.1041	0.4547	1.2226	22.5	(311)

Optical Properties

Absorption and Transmittance measurements were performed within wavelength range (300-1100) nm for all samples of different energies. Fig. (2) shows the absorption change as a function of the wavelength of the Al sample in energies (400, 500, 600, 700, and 800) mJ. Absorption (A) calculated using the following equation (Sahar, 2016):

$$A = I_A / I_o \qquad (2)$$

Where I_A is absorbed intensity, I_o is incident intensity.

It shows that the increase in energy leads to a clear increase in the values of absorption. It is noticed that the absorption decreases by increasing the wavelength in the wavelength range (350-400) nm and then is almost stabilized. Physically this means that the fallen photons could not irritate electrons to move from the band valance to the conduction band because the energy of the falling photons is less than the value of semiconductor energy gap (Bushra *et al*, 2016).

Figure (3) shows that the increase in energy leads to a clear decrease in the values of transmittance (T) which calculate using the following equation (Maysam, 2018):

$$T = \frac{I_T}{I_o} \qquad (3)$$

Where I_T is transmitted intensity.

This is due to the increase in the growth rate which is caused by increasing the ablation energy and the particle size, thus aggregates the material content and crystalline growth (Maysam, 2018; Lekaa *et al*, 2010).

Figure (4) shows that the values of the absorption coefficient increase with increasing ablation of energy and decrease with increasing wavelength, and the absorption coefficient is calculated using the following equation (Lekaa *et al*, 2010):

$$\alpha = \frac{2.303A}{t} \qquad (4)$$

Where A is absorption and t is film thickness.

This is due to the fact that the increase in energy led to an increase in the number of collisions with the material, the values of the absorption coefficient increase towards higher energies, as absorption transitions occur directly between the top of the valence band and the bottom of the conduction band (Lekaa *et al*, 2010).

Table (2) shows the values of the optical constants of aluminum at λ=(500)nm.

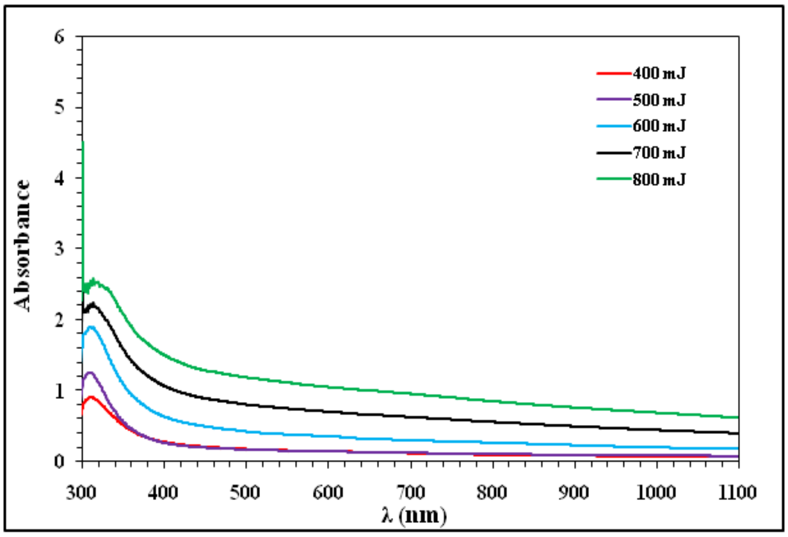

Fig. 2. The absorption (A) of Al Thin Films as function to wavelength (λ)

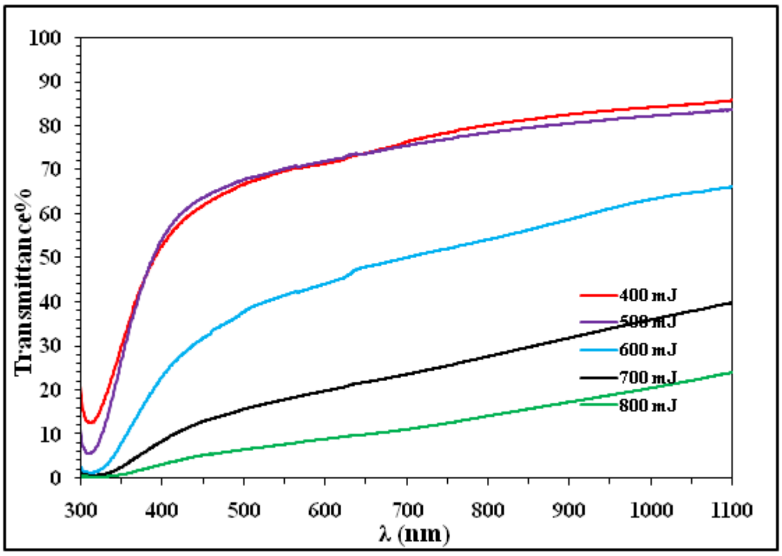

Fig. 3. The transmittance (T) of Al Thin Films as function to wavelength (λ)

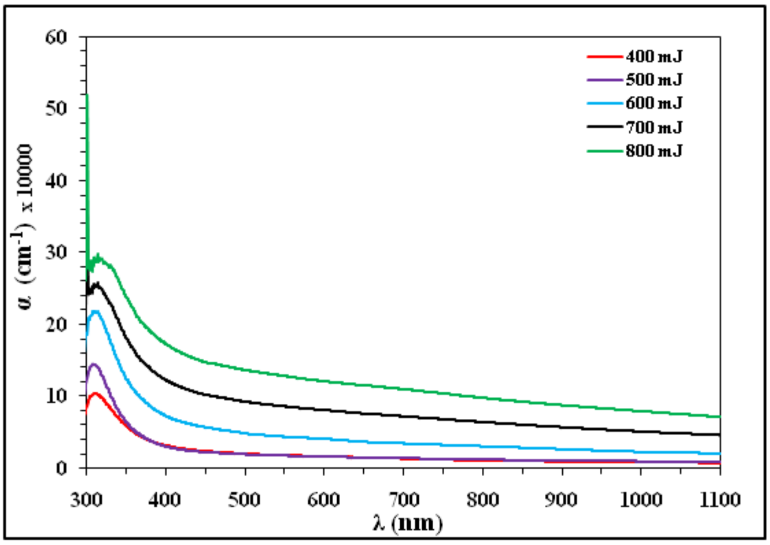

Fig. 4. The absorption coefficient (α) of Al Thin Films as function to wavelength (λ)

Table 2. The values of the optical constants of Al at λ=(500)nm

Laser Energy mj	A%	T%	α (cm^{-1})
400	0.18	66.65	20289
500	0.17	67.68	19518
600	0.42	37.72	48743
700	0.81	15.64	92765
800	1.19	6.48	136787

Conclusion

Aluminum nano-films were prepared by pulsed laser ablation with different ablation energies. It is observed that the absorption increases with the increase of the ablation energy. As a result of the inverse relationship between transmittance and absorbance, the transmittance decreases with the increase of the ablation energy of the laser pulse. The optical properties were controlled by varying the ablation energies and the best value for the ablation energy was 800 mJ. The XRD patterns of the aluminum nano-films show a clear dependence on the ablation energies and the polycrystalline films have been shown to have a FCC structure. It was found that the increase in the ablation energies led to an increase in the crystal grain size with an improvement in the crystal structure.

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