Effect of laser energy and ablation time on the formation of aluminum nanoparticles by nanosecond laser ablation of aluminum target in ethanol

Kadhim A. Aadim, Sabreen J. Baadi, Ali A-K. Hussain

Physics Department, College of Science, University of Baghdad

E-mail: Kadhim_adem@yahoo.com

Abstract

In this work we study the influence of the laser pulse energy and ablation time on the aluminum nanoparticles productivity during nanosecond laser ablation of bulk aluminum immersed in liquid.

Aluminum nanoparticles were synthesized by pulsed laser ablation of Al targets in ethanol for 3-8 minutes using the 1064 nm wavelength of a Nd:YAG laser with energies of 300-500 mJ per pulse.The laser energy was varied between 300 and 500 mJ/pulse, whereas the ablation time was set to 5 minutes. UV-Visible absorption spectra was used for the characterization and comparison of products.

Key words

Nanosecond laser ablation, Aluminum nanoparticles, ablation in liquids.

Article info.

Received: Jun. 2014

Accepted: Jun. 2014

Published: Dec. 2014

تأثير طاقة الليزر و زمن الاستئصال على تحضير جسيمات الالمنيوم النانوية باستخدام طريقة الاستئصال بالليزر النبضي النانو ثانوي لهدف من الالمنيوم بالإيثانول

كاظم عبد الواحد عادم, صابرين جودة بادي, علي عبد الكريم حسين

قسم الفيزياء, كلية العلوم, جامعة بغداد

الخلاصة

في هذا البحث درس تأثير طاقة النبضة الليزرية و زمن الاستئصال الليزري على تحضير جسيمات الالمنيوم النانوية بواسطة الاستئصال بالليزر النانوثانوي لهدف من الالمنيوم بالسائل.

تم تحضير الجسيمات النانوية بواسطة الاستئصال بالليزر النبضي لهدف من الالمنيوم مغطس بالإيثانول ولمدة تتراوح من 3–8 دقائق باستخدام الطول الموجي الاساسي 1064nm لليزر نوع (Nd:YAG) ولطاقات تتراوح بين 300 و 500 ملي جول لكل نبضة. لدراسة تأثير طاقة النبضة الليزرية تم تغيير طاقة الليزر من 300 الى 500 ملي جول\نبضة بثبوت زمن الاستئصال (5 دقائق). استخدم طيف الامتصاص في وصف و مقارنة النتائج.

Introduction

Nanoparticles synthesis, nanostructure formation and their characterization are of great interest because of the physics associated with them and are described by the intermediate regime between quantum physics and classical physics[1].

The electronic properties of the nano-sized systems change dramatically since the density of states and spatial length scale of electronic motion are reduced with decreasing size. For nano-entities, Eigen states are determined by the system boundaries and hence the surface effects become very important.

The favorable physical and chemical properties of aluminum (Al) and particularlyits powder make them applicable in a variety of applications due to the large surface area, which gives improved characteristics including catalytic activity compared with bulk aluminum. Al has found uses in numerous fields, most notably in industrial applications such as powder metallurgy parts of automobiles and aircrafts, heat shielding coatings of aircrafts, corrosion resistant, conductive and heat reflecting paints, conductive and decorative plastics, soldering and thermit welding, pyrotechnics and military applications (rocket fuel, igniter, smokes, and tracers)[2]. Al nanoparticles are more explosive than their microsize particles, and their activities significantly increases by further size reduction [3] which is related to the change of materials properties, due to the increase of the specific surface area; and usually, nanoparticles exhibit better performance[4]. Laser ablation of metals immersed in liquid media is the best method among all other methods to generate a large variety of nanoparticles those are free of both surface active substances and counter ions[5,6]. Not only can pure nanoparticles be synthesized in this way, but also oxides, carbides, or alloy nanoparticles are producible if corresponding elements be present either in ablation medium or in target. When the research of liquid-phase laser ablation started, the advantages from technical viewpoints were emphasized. The technical advantages of this method are the low cost because of the absence of vacuum equipment and the easy collection of nanoparticles after the synthesis. The latter advantage is due to the fact that nanoparticles are stored in the liquid as a colloidal solution in liquid-phase laser ablation. Another feature of liquid-phase laser ablation is the easiness to produce plasmas in liquids since just focusing intense laser beams onto solid-state targets immersed in liquids is sufficient, provided that the liquid is transparent to the laser wavelength. Moreover, this method has other significant advantages, such as a relatively simple experimental setup, ease of preparation and size control[7-9]. Synthesis parameters such as laser wavelength, laser energy, pulse width, liquid media type, and ablation time can notable affect the product characteristics[10-17]. Using 1064 nm wavelength of pulsed Nd:YAG laser, the present paper deals with the synthesis of Al nanoparticles by pulsed laser ablation in ethanol and effect of laser energy and ablation time on these nanoparticles.

Experimental details

The experimental setup for the ablation experiment is schematically shown in Fig. 1. The source used for the synthesis of Al NPs was a Nd :YAG laser which provides laser pulses with wavelength of 1064 nm (maximum pulse energy 1000 mJ), 0.5 mm spot size and repetition rate of 6 Hz. Pure Aluminum targets ($1\times 1\times 0.3$ cm^3 dimensions, high purity~99%) were washed with ethanol after sonication to remove the oxide layer and to prevent the simultaneous oxidation.

Aluminum nanoparticles were synthesized by laser ablation of a Al target placed on the bottom of a glass vessel filled with a 5 ml of ethanol (99.9 % purity). The vessel was continuously rotated to minimize the target aging effect and to give some stirring effect during the formation of Al nanoparticles.The optical absorbance in the UV-visible region of synthesized colloidal Al NPs was recorded at room temperature using spectrophotometer (type Metertech SP-8001) after they were homogeneously dispersed by ultrasonic.

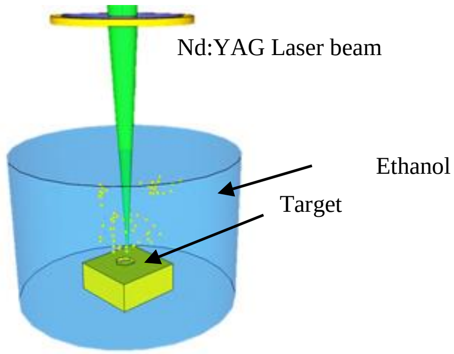

Fig.1: The setup of the colloidal nanoparticles production.

Results and discussion

Ablation time and laser energy play an important role in determining the ablation efficiency, absorbance peak, and the energy of the synthesized particles.

1- Effect of laser energy

Keeping the ablation time constant at 5 minutes, emitted laser energy was varied which ultimately varied the fluence. The effect of different laser energies on UV-Visible absorption peak is presented in Table1.
UV-Visible absorption spectra of products are presented in Fig.2 (for 1, 2, and 3).

Table 1: Effect of different laser energies on UV-Visible absorption peak (λ=1064 nm, t=5 min, in ethanol)

Sample code	Laser energy (mJ/pulse)	UV-Vis. Absorption peak intensity
1	300	2.23
2	400	2.83
3	500	1.04

It is obvious that samples synthesized in ethanol bear the specific absorption peak of aluminum at wavelength approximately 215nm, which proves the presence of Al particles, and not alumina ones[18,19] and the aluminum oxide is not formed due to the prohibition of ethanol surrounding media from oxidation.

Consequently, it can be announced that higher laser energy leads to higher ablation efficiency of Al target in ethanol, but at higher laser energies, the ablation efficiency decrease due to the shielding effect.

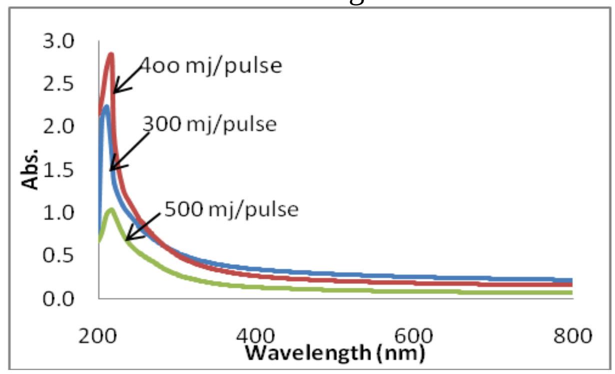

Fig 2. UV-Visible absorption spectra of Al nanoparticles prepared in different laser energies(λ=1064 nm, t=5 min).

2- Effect of ablation time

To investigate the effect of ablation time on UV-Visible spectra, the ablation time was varied from 3 to 8 minutes while the laser energy was kept at 400 mJ/pulse. Table 2 presents the effect of ablation time on UV-Visible absorption peak.

Table 2: Effect of ablation time on UV-V is. Absorption peak of Al target in liquid media of ethanol (λ=1064 nm, E=400 mj/pulse)

Sample code	Ablation time (minute)	UV-Vis. Absorption peak intensity
4	3	0.83
5	5	1.02
6	8	1.91

Fig.3 shows the effect of different ablation times on UV-Visible absorption spectra of the colloidal samples. It can be concluded that increase of the absorption peak intensity by time which means the increase of nanoparticles concentration.
It is clear that more nanoparticles could be generated in higher ablation times, which was previously reported for other elemental nanoparticles in both gas and liquid environment[20-23].

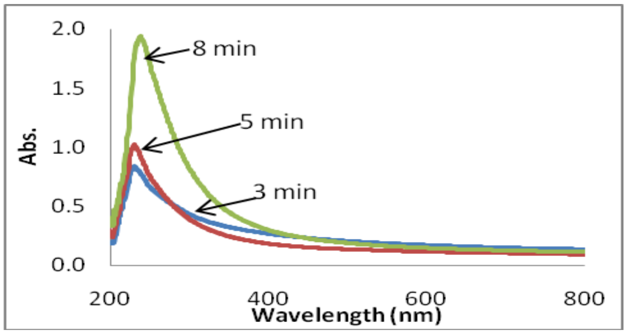

Fig.3: UV-Visible absorption spectra of nanoparticles prepared in three ablation times (λ=1064 nm, E=400 mj/pulse).

Conclusions

In summary, ns laser ablation of bulk Al sample in liquid media of ethanol in an open air environment led to Al nanoparticles generation. The experiments demonstrated that higher pulse energies lead to higher productivity, but due to the shielding effect, the optimum was determined at moderate pulse energies around 400 mJ/ pulse, measured by the highest absorption intensity of the plasmons resonance of the colloids. Comparison of different ablation times clarified that higher times of ablation lead to higher nanoparticles productivity.

References

[1] S. Eliezer, N. Eliaz, E. Grossman, Laser and Particle Beams 23(2005) 15-19.

[2] Powder Metallurgy, ASM Handbook, vol. 7, ASM International, 1993, 572-574.

[3] E.L. Dreizin, Prog. Energy and Combustion Sci., 35 (2009) 141–167.

[4] C.P. Poole, F.J. Owens, Introduction to Nanotechnology, John Wiley and Sons, 2003, pp. 8-9.

[5] G. A. Shafeev, Nova Science Publishers Inc, 1 (2008).

[6] E. Stratakis, V. Zorba, M. Barberoglou, C. Fotakis, and G.A. Shafeev, Nanotechnology 20, 10 (2009)105303-105310.

[7] G.W. Yang, Prog. Mater. Sci. 52 (2007) 648.

[8] M.V. Canamares, J.V. Garcia-Ramos, S. Sanchez-Cortes, M. Castillejo, M. Oujja, J. Colloid Interface Sci. 326 (2008) 103.

[9] N.V. Tarasenko, A.V. Butsen, E.A. Nevar, N.A. Savastenko, Appl. Surf. Sci. 252: 4439 (2006).

[10] G.W.Yang, Prog. Mater. Sci. 52 (2007) 648-698.

[11] M. V. Canamares, J.V. Garcia-Ramos, S. Sanchez-Cortes, M. Castillejo, M. Oujja, J.Colloid Interface Sci. 326 (2008) 103-109.

[12] A.V. Simakin, V.V. Voronov, G.A. Shafeev, R. Brayner, F. Bozon-Verduraz, Chem. Phys. Lett. 348 (2001) 182-185.

[13] N.V. Tarasenko, A.V. Butsen, E.A. Nevar, N.A. Savastenko, Appl. Surf. Sci. 252 (2006) 4439-4444.

[14] S.A. Dolgaev, A.V. Simakin, V.V. Voronov, G.A. Shafeev, F. Bozon-Verduraz, Appl. Surf. Sci. 186 (2002) 546-551.

[15] M.S.F.Lima, F.P. Ladairio, R. Riva, Appl. Surf. Sci. 252 (2006) 4420-4424.

[16] J. Zhang, C.Q.Lan, Mater. Lett. 62 (2008) 1521-1524.

[17] T. Tsuji, T. Hamagami, T. Kawamura, J.Yamaki, M. Tsuji, Appl. Surf. Sci. 243 (2005) 214-219.

[18] E.Stratakis, V. Zorba, M. Barberoglou, C.Fotakis, G.A. Shafeev, Appl. Surf. Sci. 255 (2009) 5346-5350.

[19] E. Stratakis, M. Barberoglou, C. Fotakis, G. Viau, C. Garcia, G.A. Shafeev, Opt. Exprees 17 (2009) 12650-12659.

[20] I. Horn, M. Guillong, D.Gunther, Appl. Surf. Sci. 182 (2001) 91-102.

[21] R. Mahfouz, F.J. Cadete Santos Aires, A. Brenier, B. Jacquier, J.C. Bertolini, Appl. Surf. Sci. 254 (2008) 5181- 5190.

[22] P.V. Kazakevich, A.V. Simakin, G.A. Shafeev, Appl. Surf. Sci. 252 (2006) 4457-4461.

[23] M. Saito, K. Yasukawa, T. Umeda, Y.Aoi, Opt. Mater. 30 (2008) 1201-1204.