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Laser-Induced Modification of Ag and Cu Metal Nanoparticles Formed by Exploding Wire Technique in Liquid

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Abstract

This research aims to find a method to synthesize nanoparticles of important metals in the fields of medicine and electronics, with high purity small in size and narrow size distribution. And it characterized by simplicity, efficiency and high productivity. To achieve this aim the effects of laser irradiation on silver and copper colloids prepared by exploding wire technique in double distilled and deionized water (DDDW) have been studied. The laser irradiation was performed using laser radiation fluence about 4 J/cm^2 at 532 nm wavelength. Additional irradiation of colloids resulted in the changes of particles morphology, which were monitored by absorption spectroscopy and transmission electron microscopy methods. It was found that both the mean size of the nanoparticles and their size distribution controlled by changing the number of laser pulses. It was found that the decrease in particle size depends on the laser wavelength, SPR absorption peak position for the metals nanoparticles before laser irradiation and the exposure time. The combination of the two techniques exploding wire and laser ablation in liquids is possible to synthesize nanoparticles with small sizes less than 5 nm, small size distribution and characterized by simplicity, efficiency and high productivity. Nanoparticles prepared by this method have high purity, where there are no chemicals in the particle synthesis process.

Keywords: Exploding Wire, Ag and Cu Metal Nanoparticles, laser ablation.

استعمال الليزر لتعديل الجسيمات النانوية لمعدني Ag وCu المكونة بتقنية السلك المتفجر في السائل

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الخلاصة

يهدف هذا البحث للحصول على طريقة لتخليق جسيمات نانوية لمعادن مهمة في مجال الطب والالكترونيات، ذات نقاوة عالية، صغيرة في الحجم وتوزيع إحصائي لحجم الجسيمات ضيق. وتتميز بالبساطة والكفاءة والإنتاجية العالية. ولتحقيق هذا الهدف درس تأثير أشعة الليزر على عوالق جسيمات الفضة والنحاس النانوية المحضرة بتقنية السلك المتفجر في الماء المقطر مرتين منزوع الايونات .عرضت عوالق الجسيمات النانوية لأشعة ليزر ذات ذات كثافة طاقة 4 J/cm^2 عند الطول الموجي 532 نانومتر. التشعيع بالليزر أدى إلى تغير في مورفولوجية عوالق الجسيمات النانوية للفضة والنحاس والتي تم التحقق منها باستعمال أطياف امتصاص الأشعة المرئية والفوق البنفسجية والمجهر الالكتروني النافذ.وقد تبين أن كلا من متوسط حجم الجسيمات والتوزيع الإحصائي لحجم الجسيمات سيطر عليه من خلال عدد نبضات الليزر. وقد وجد أن النقصان في حجم الجسيمات يعتمد على الطول ألموجي لليزر وموقع قمة امتصاص سطع البلازمون

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الرنينية، SPR للجسيمات النانوية للفضة والنحاس قبل تعرضها لأشعة الليزر وكذلك على قدرة الليزر وزمن التعرض. الجمع بين الطريقتين انفجار الأسلاك والاستئصال بالليزر في السوائل يمكن أن يقود إلى تخليق جسيمات نانوية معدنية صغيرة بالحجم وذات توزيع إحصائي للحجم صغير وتتميز بالبساطة والكفاءة والإنتاجية العالية. وتمتاز الجسيمات النانوية المحضرة بهذه الطريقة (الجمع بين الطريقتين) بالنقاوة العالية حيث لا وجود للكيمياويات في عملية تخليق الجسيمات.

Introduction

Laser ablation represents dramatic laser-material-interaction phenomenon. Pulsed laser ablation in liquid media has become a gradually more important alternative approach for synthesis of colloidal suspensions with novel functional properties [1, 2]. Silver and copper nanoparticles have been a source of great interest due to their unusual electrical, optical, physical, chemical and magnetic properties and due to their surface plasmon resonance (SPR) related properties that are potentially useful for their applications such as catalysis, information storage, opto-electronics, sensors, fine chemicals synthesis, oil refining processes, fuel cell technology and biological [3, 4]. Despite the multiple benefits of the laser in the synthesis of nanoparticles, but it suffers from low productivity problem, there is another method known exploding wire it is simple and productive method [5, 6]. The combination of these two methods leads to highly productive method and the nanoparticles have the properties of the nanoparticles synthesis by laser ablation in liquids.

This research aims to find a method for synthesize of nanoparticles for important metals in the fields of medicine and electronics, with high purity small in size and narrow size distribution. And it characterized by simplicity, efficiency and high productivity and explains the mechanism of the laser-induced modification of the nanoparticles, which is essential for finding the optimal conditions and control the process. The idea is based on the synthesized silver and copper nanoparticles, where these nanoparticles have a surface Plasmon resonance (SPR) absorption in the visible region of the electromagnetic spectrum [7]. The nanoparticles were synthesized as a first step through the dominant mechanism of spark explosion which is an adaptation of the phenomena called electro-explosion of wires in different liquid. The particles formed in this way are expected to have average diameters up to 50 nm and the particle size distribution relatively large [5, 6]. These particles which formed nano-fluids will be a raw material for the second step to form nanoparticle with smaller and narrow particle size distribution, by using a pulsed laser with a wavelength close to the SPR absorption peak for silver and copper nanoparticles. The laser was work in this case through two mechanisms to minimize the particle size, photo-fragmentation and thermal ablation [8, 9]. In this research, the effect of laser irradiation on silver and copper colloids was studied using laser radiation at wavelength 532 nm. To modify the size and the shape of the nanoparticle, the colloids were irradiated by laser radiation. These studies have shown that the laser irradiation of metal colloids can cause reduction in the particle size through photo-fragmented for copper colloidal were the laser wavelength 532nm is close to the surface plasmon resonance (SPR) peak position at 616 nm while the particle size reduction for silver nanoparticle produced by thermal ablation where the (SPR) peak position at 402 nm far from the laser wavelength.

Experimental Work

Initially the silver and copper colloids fabricated using electrical explosion wire technique in double distilled deionized water (DDDW) media with a concentration of 15mg/l for silver and 20mg/l for copper. After benign the colloidal particles were characterized by TEM and UV-Visible spectroscopy the colloids irradiated by second harmonic Q-switched Nd/YAG laser system providing pulses of 532 nm wavelength with maximum energy of 800mJ per pulse, pulse width of 10 ns, repetition rate 6 Hz and effective beam diameter of 5 mm, and fluence about 4 J/cm^2 to modify the Ag and Cu metal nanoparticles. The laser beams were irradiated the silver and copper colloids without focusing. The metal colloids exposed to different laser pulse less 200,400,600 800and 1000 by sequence each pulse energy was 800 mJ as shown in Figure-1. The colloids particles characterized by TEM (The TEM samples were synthesis by placing a drop of metals colloids onto a carbon-coated copper grid) and UV-Visible spectroscopy(The UV-Visible absorption spectra of the samples were measure from a double beam spectrophotometer equipped with a 1 cm path length quartz cell) after each laser exposer .

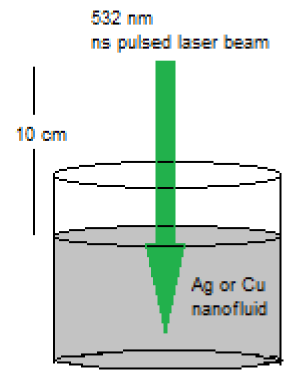


Figure 1- Silver and copper colloids irradiated by Laser.

Results and Discussion

UV-Vis Spectra of Ag and Cu colloids

The UV-Vis spectra of silver and copper colloids were recorded before the reduction. The results are showed in Figure-2, for the silver colloid, there was an obviously SPR absorption peak at 404 nm before exposure to laser pulses, while the silver SPR peaks after exposure to laser pulses 200, 400, 600, 800 and 1000 are 402, 399, 395, 389 and 386 nm respectively. For copper colloid, the surface plasmon resonance (SPR) peaks position before laser irradiation at 616 and after laser irradiation are 609, 596, 589, 583 and 572nm, when exposed to 200, 400, 600, 800 and 1000 laser pulses respectively as shown in Figure 3. From these figures it was noticed that the SPR absorption peak center is shifted towards shorter wave length (blue shift). These changes of the absorption spectrum suggest that the mean particle dimension and the size distribution are reduced by laser irradiation. The diameters of the nanoparticles decrease when number of laser pulses increase. It notes that the change in surface plasmon resonance (SPR) peaks position for copper is more pronounced than the change for silver. This is because the copper SPR absorption peak is close to the wavelength of the laser this allow to obtain the size reduction of copper particles is due to photo-fragmentation while for silver nanoparticles; it is due to thermal ablation (vaporization by heating). It's clear that, the initial spectrum is changed by laser irradiation. The bandwidth of the plasmon resonance is significantly reduced. The narrowing of the plasmon bandwidth is accompanied by an increase in the absorption magnitude. Since the plasmon frequency of each single particle is determined by its dimension and shape, the optical absorption profiles of the whole distributions are in homogeneously broadened. Therefore, irradiation of colloids with laser pulses of definite photon energy yields resonant plasmon excitation in particles with specific size and shape.

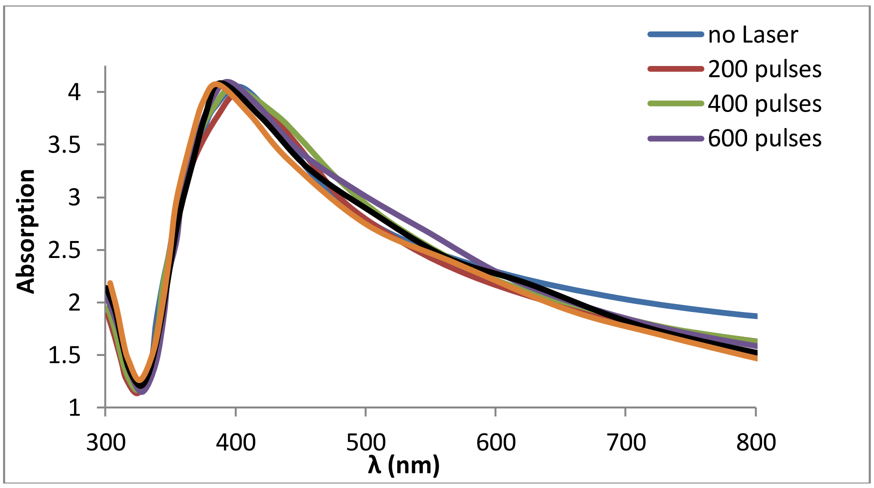


Figure 2- Absorption spectra for silver colloids at different number of laser pulses

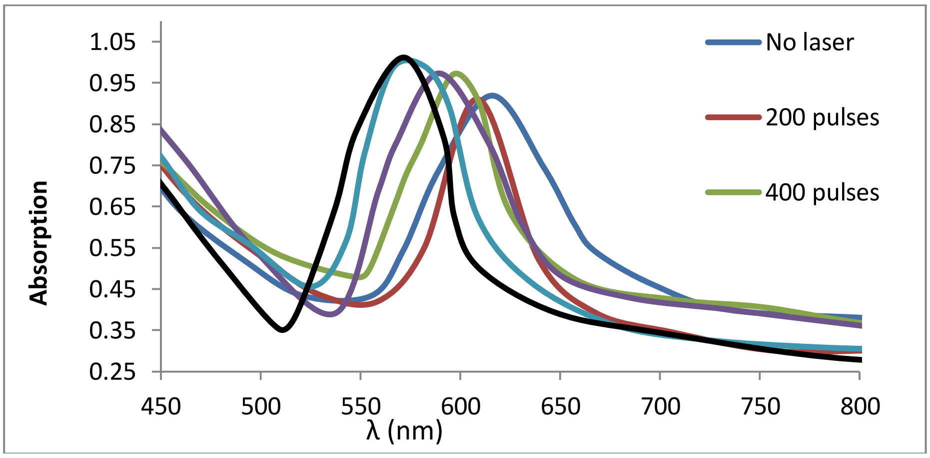
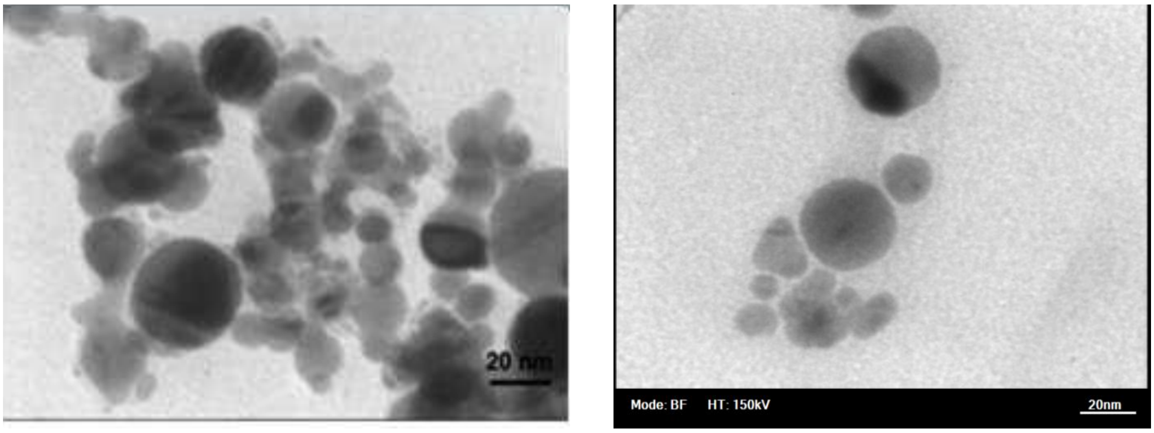


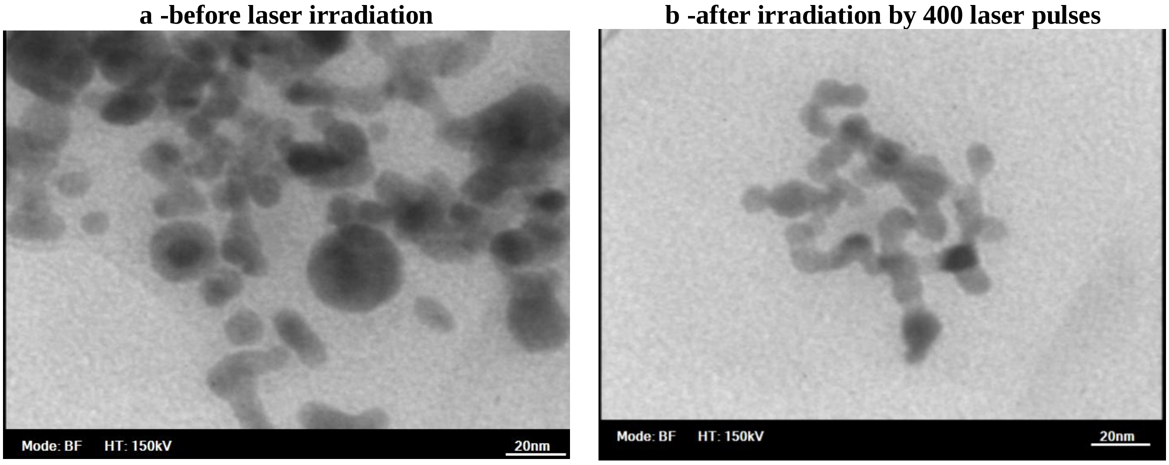
Figure 3- Absorption spectra for copper colloids at different number of laser pulses

Silver and copper nanoparticles analysis by transmission electron microscopy

The morphology and the size of the silver and copper nanoparticles were analysis by the transmission electron microscopy (TEM), before irradiation and after laser irradiation. The colloids consisted of nearly spherical particles 'for the silver and the copper nanoparticles. These nanoparticles exhibited a trivial tendency to an agglomeration with time. Figure-4a shows TEM image for silver nanoparticles before laser irradiation. Silver particles have average diameters of 16 nm. Figure-5a shows TEM image for copper nanoparticles before irradiation, the average diameters of copper nanoparticles were 5 nm. Figures-4b, -c and -d show TEM images for silver nanoparticles after irradiation by 400, 800 and 1000 laser pulses respectively. Figures -5b, -c and -d show TEM image for copper nanoparticles after irradiation by 400, 800 and 1000 laser pulses, respectively.

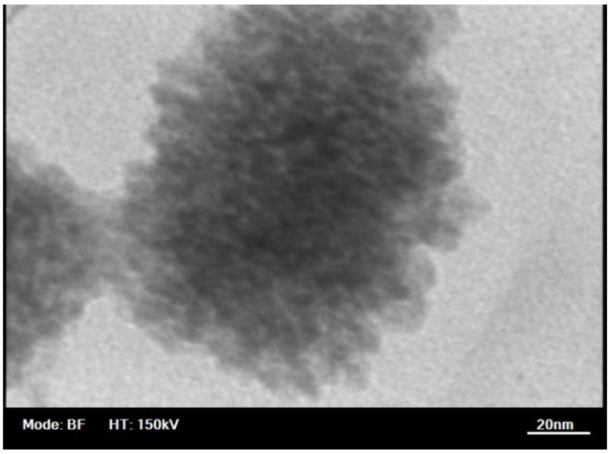


a -before laser irradiation **b -after irradiation by 400 laser pulses**

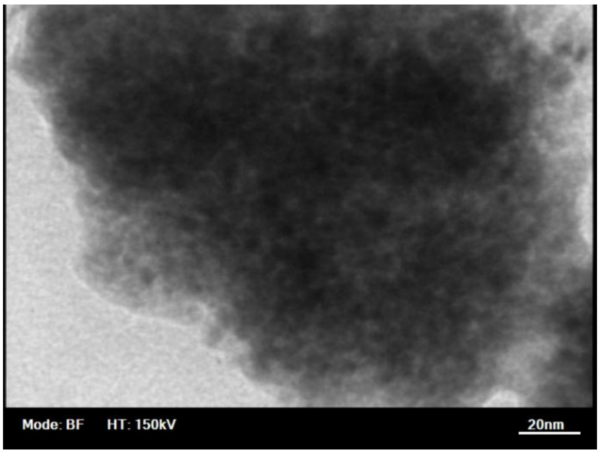


c -after irradiation by 800 laser pulses **d -after irradiation by 1000 laser pulses**

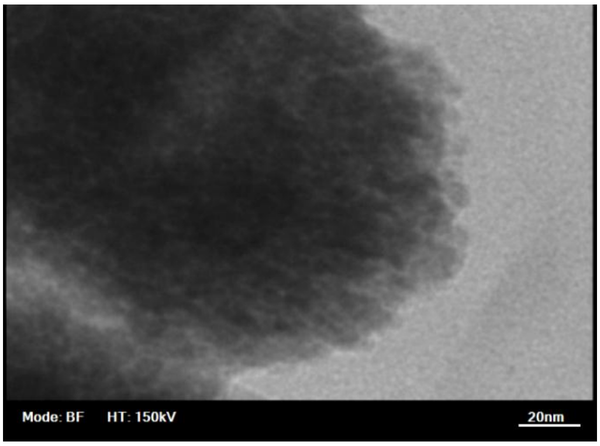
Figure 4- TEM image for Ag NPs a -before laser irradiation, b -after irradiation by 400 laser pulses c -after irradiation by 800 laser pulses and d -after irradiation by 1000 laser pulses.



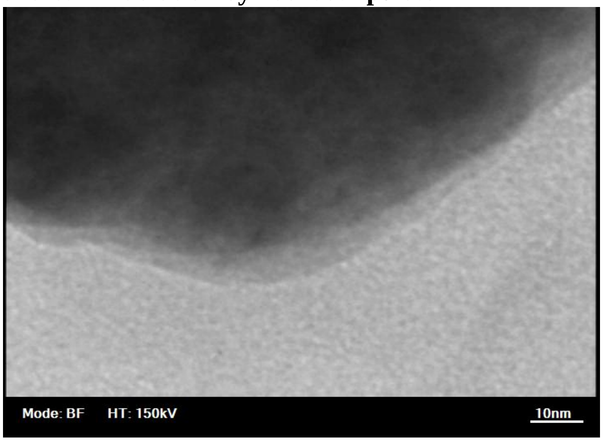
a -before laser irradiation



b -after irradiation by 400 laser pulses



c -after irradiation by 800 laser pulses



d -after irradiation by 1000 laser pulses

Figure 5- TEM image for Cu NPs a -before laser irradiation, b -after irradiation by 400 laser pulses c -after irradiation by 800 laser pulses and d -after irradiation by 1000 laser pulses

These figures explained that the silver and copper nanoparticles decreases with the number of laser pulses, also these figures show that the copper particles decreased more than the silver nanoparticles. This behavior can be attributed to the SPR absorption peak position. The SPR absorption peak position for copper nanoparticles is close to the laser wavelength, so the interaction mechanism was different depending on the SPR absorption peak position.

Conclusions

The observed changes in the UV- Visible absorption spectra caused by laser irradiation appear to correspond to the decrease in the size of the particles in the solution. Decrease in particle size depends on the laser wavelength, SPR absorption peak position as well as on the laser power and exposure time. The combination of two technologies exploding wire and laser ablation in liquids is possible to create nanoparticles with small sizes and small size distribution. Nanoparticles prepared by this method have high purity, where there are no chemicals in the particle synthesis process. And for the same reason, this method is environment friendly.

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