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Effect of Incident FS Laser Power onto Gold Thin Films Deposited by PLD Techniques

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Abstract

Gold thin films with different incident femtosecond laser power were elaborated by pulsed laser deposition techniques (PLD) in order to evaluate the effect of incident femtosecond laser pulse onto the formation and the homogeneity of the deposited thin films. The laser pulses that are used for this study are 800 nm wavelength, 20 fs pulse duration time and the repetition rate 1 kHz. The data of thin films were carried at incident femtosecond laser power 400, 500, 600 and 750 mW, pressure 0.3 m Torr and target substrate distance 6.5 cm. Glass substrate kept at temperature 200°C during the deposition time are used. The deposited Au thin films are characterized by atomic force microscopy (AFM), scanning electron Microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX). The experimental data shows a nice formed gold films with developing of particle shape and size which increases with the increasing the average of the incident femtosecond laser pulse. The results also show that, at 400 mW femtosecond laser power the practical density is increased to 60 particles μm^2 (the number of particles in μm^2) and is fixed at laser power 500 and 600 mW while are decreased at laser power 750 mW.

Keywords: Atomic force microscopy; Scanning electron microscopy; Energy dispersive X-ray spectroscopy

Introduction

The applicability and acceptance of pulsed laser deposition in thin film research rests largely in its simplicity in implementation. Pulsed laser deposition is a physical vapor deposition process, carried out in a vacuum system that shares some process characteristics common with molecular beam epitaxy and some with sputter deposition. Several features make PLD particularly attractive for complex materials film growth. These include stoichiometric transferee of material from target, generation of energetic species, hyper thermal reaction between the ablated contains and the background gas in the ablation plasm, and compatibility with background process ranging from ultrahigh vacuum (UHV) to 1 Torr. Multination films can be deposited with PLD using single, stoichiometric targets of the material of interest, or with multiple targets for each element. Also, one need to consider the laser wavelength used for the ablation. Efficient ablation requires the non-equilibrium excitation of the ablated volume to temperatures well above that required for evaporation. This generally requires the laser pulse to be short in duration, high in energy density, and highly absorbed by the target materials. The amount of film growth per laser pulse will depend on multiple factors, including target-substrate separation, background gas pressure, Laser spot size and laser energy density. As Such PLD enable laser shot-to-shot control of the deposition process that is ideal for multilayer and interface formation where sub monolayer control is needed. Nanosecond pulsed lasers, Particularly Excimers, are currently the standard used in PLD, but recent work has explored the benefits of using other systems, particularly ultrafast lasers and high repetition rate lasers. Ultrafast (Pulse widths<10 PS) lasers have shown dramatic benefits in less target damages, lower ablation thresholds, elimination of the problem and the creation of unique ablation conditions such as a highly ionization plasma [1,2]. The rapid advance in the generation of the femtosecond laser pulses has opened new possibilities of micromachining. Micromachining of thin films has wide application in high density data storage and semiconductor micro electrons. Femtosecond laser ablation results in the materials becoming rapidly heated through a combination of multiphoton absorption and avalanche ionization. The pulse duration is shorter than the thermal relaxation of the materials, which can lead to non-thermal ablation mechanisms. The shorter pulse means that the laser light interacts with near-solid density plasma. Rapid heating of the irradiated volume can lead to several mechanisms that do not occur under conventional nanosecond PLD conditions. In fs PLD, the target materials undergo to rapid heating without any significant collateral damage to bulk could potentially lead to a reduction in emission Melton droplets, However, mechanisms such as phase explosion and photomechanical fragmentation can lead to the formation of nanoparticles from the ablated targets, which would deter mental to the quality of films intended for laser waveguide application. Femtosecond laser pulse ablation of thin gold films was studied by Venkatakrishnan et al. [3]. They are reported, that the result suggest that clean and precise micro structurer gold thin films can be achieved with femtosecond pulsed laser by controlling the pulse energy. Gold thin films with different Nano scaled roughness were elaborated by a pulsed laser deposition technique in order to evaluate their ability to form biochip substrate [4]. Nanostructured materials and surfaces have generated great interest in the resent years, much of which is due to the unusual characteristic of matter when its dimension is reduced to the nanoscales [5]. Metal nanoparticles have been the subject of much research, ranging from the exploitation of the optical properties of noble metals nanoparticles in areas such as sensing, plasmonics and surface enhanced spectroscopies to Magnetic nanoparticles and their proposed use for ultrahigh density information storage. The pulsed laser deposition method has been employed to synthesize gold

nanostructures in the presence of oxygen gas on carbon nanotubes and the evaluation of their properties towards glucose oxidation are studied by Maxima [6,7]. Structural analysis of their deposited films conducted by means X-ray diffraction and X-rays photoelectron spectroscopy analysis did not reveal the formation of gold oxide. They have investigated the gold films deposited onto carbon nanotubes in the presence of moderate oxygen (O_2) of 10 to 50 mTorr are better than those delivered golf thin films synthesized under vacuum or inert gas atmosphere. In this paper, the pulsed deposition method has been employed to synthesize gold thin films at different femtosecond laser pulse from 400 mW to 750 nmW. Scanning electron microscopy (SEM) was used for analysis the surface of the thin films, Atomic force microscopy (AFM) are performed to show the topography of deposited films to provide a three- dimensional surface profiles. Also, energy dispersive X-ray (EDX) has done to identify the chemical composition of the deposited films.

PLD at atmospheric pressures has also been achieved and is conventionally performed by placing the target within several millimeters of and at an acute angle with respect to the substrate with target irradiation occurring parallel to the substrate [8]. This technique has been successful for the creation of nanostructured gold and diamond-like carbon films have outlined a novel technique for the deposition of nanostructure thin film utilizing a modified form of pulsed laser deposition. They have demonstrated a confined atmospheric PLD (CAP) for deposition of gold on cyclic olefin polymer substrate [9-11].

Experimental

In pulsed laser deposition (PLD) shown in Figures 1a and 1b, a pulsed laser is focused onto a target of materials to be deposited. Figures 1a and 1b shows the Experimental set up of pulsed laser deposition, b) Vacuum chamber used in deposition of gold thin films with femtosecond laser. For sufficiently high Laser energy density, each laser pulse vaporizes or ablates a small amount of the material creating a plasma plume. The ablation plumes provide the material flux for film growth for multi component inorganics PLD has proven remarkably effective at yielding epitaxial films. In this case, the ablation condition is chosen such that the ablation plume consists of primarily atomic, diatomic and other low mass species.

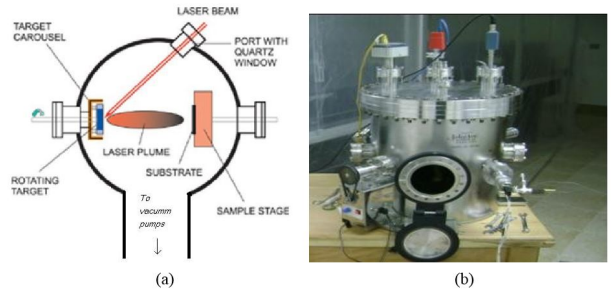

Figure 1: (a) Experimental set up of pulsed laser deposition, b) Vacuum chamber used in deposition of gold thin films with femtosecond laser.

This typically achieved by selecting an ultraviolet (UV) laser wavelength and nanosecond pulse width that is strongly absorbed by small volume of the target materials. Laser absorption by the ejected materials creates plasma. For the deposition of macromolecular organic materials, conditions can be chosen whereby absorption is over a large volume with a little laser absorption in the plume [11]. Donnely et al. have used PLD to deposit nanostructured films of Au on Si and sapphire in vacuum [12]. They have used a time resolving Langmuir probe to characterize their deposition plasma and have investigated how the film morphology and optical deposition depends on the amount of material deposited. Also, with increasing the deposition the nanoparticles thickness varied from 0.5 to 4 nm and nanoparticle size and surface coverage increases.

Results and Discussions

The good results of gold nanostructure thin films deposited by using a femtosecond laser pulse at average power 300 mW enhanced us to carry out this work to study the effect of the incident laser power on the deposited nanostructure gold films. Ultra-short an fs second PLD is an emerging technique offering a new set of opportunities for martial deposition. One of the most important advantages of femtosecond laser is that the energy deposited by the laser pulse does not have enough time to move in the bulk, and thermal energy remaining in target can be negligible and ablation is 'cleaner' than from longer nanosecond ablation [13]. In this study, an investigation of the effect of a femtosecond laser pulse with different incident powers at 800 nm Wavelength and 40 fs duration time focused onto gold target to prepare a gold film in nanoparticle scale. This gold nanoparticle films are deposited onto a glass substrate which is kept at temperature 200°C during the deposition time. All this gold films are deposited in vacuum at pressure 0.3 m Torr at distance 6.5 cm between the target and the substrate. The deposition process was carried at different laser power from 300 mW to 750 mW at the same experimental condition. Scanning Electron Microscopy (SEM) was used to analyze the surface morphology of the thin films. This technique reveals the size and the distribution of the particulates onto the surface of the films and is a good indicator of the surface quality. Figures 2a and 2b demonstrate SEM images of thin film deposited using fs Laser at average power: (a) 300 mW and (b) 750 mW. AS we see from the SEM images a nice gold films deposited by femtosecond laser have small gold particles in micron and submicron size scale and they have a random distribution are formed onto the Si substrate surface. Also, the SEM images show that when the power of the incident femtosecond laser pulse increases the average mean radius of the deposited nanoparticles increase which mean decreasing of particle density (number of particles per μm^2) accompanied with the increasing of the particle size. Energy dispersive X-ray analysis (EDX) was used to identify the chemical composition of the deposited films and is integrated feature for SEM equipment's.

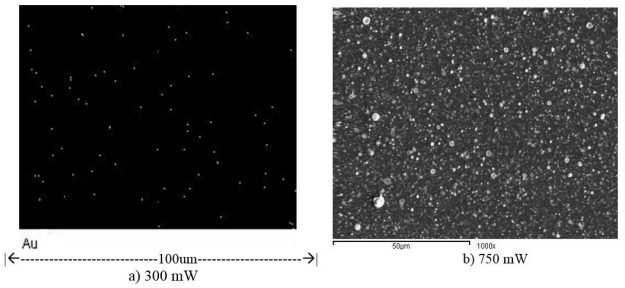

Figure 2: SEM images of thin film deposited at fs Laser average power: (a) 300 mW (b) 750 mW.

As shown in Figure 3 EDX measurements of fs PLD gold thin films at average incident fs laser pulse at 300 mW, 750 mW. Moreover, Atomic force microscopy (AFM) was used to analyze the topography of the deposited films at the same values of the incident fs laser pulses powers. Unlike SEM, AFM provides three-dimensional surface profile. AFM is advantageous since it can reveal information about the height and shape of topographic features with a very high resolution. AFM images of the deposited fs gold films at average power (from 300 to 750 mW) fs laser pulse is carried out and are compared with SEM gold films at the same experimental condition. The 2-dimension SEM images and 3-dimension AFM show that the developing of position and size with increasing of the incident average power of the femtosecond laser pulses. The disadvantage of AFM compared to SEM is the area that can analyze, which is limited roughly 100 μm, compared to millimeter scale possible with SEM.

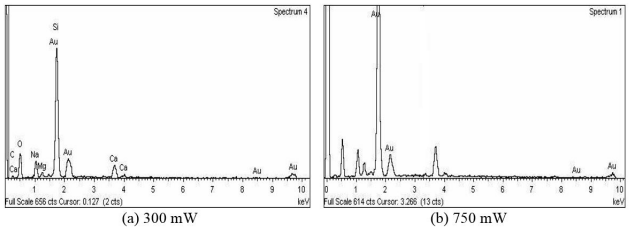

Figure 3: EDX of thin film deposited by fs Laser average powers (c) 300 mW and (b) 750 mW.

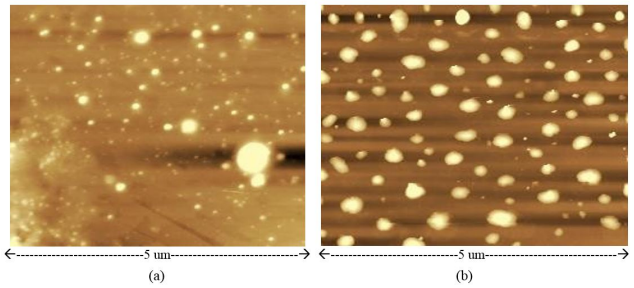

Figure 4: 2D - Atomic Force Microscope (AFM) plane picture of thin film deposited at average fs laser pulse power (a) 300 mW and (b) 750 mW.

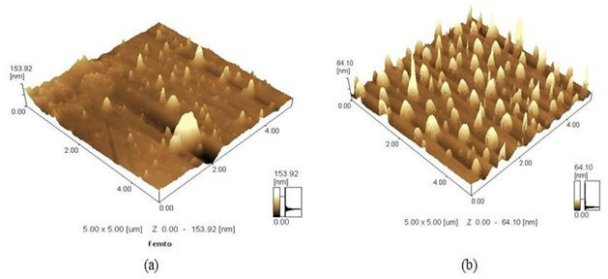

Figure 5: 3D-Atomic Force Microscope (AFM) images of thin film deposited with fs laser pulses of average power: (a) 300 mW and (b) 750 mW.

In Figure 4 shows 2D Atomic Force Microscope (AFM) plane picture of thin film prepared at fs laser pulses power (a) 300 mW and (b) 750 mW. Also, in Figure 5 reveal 3D Atomic Force Microscope (AFM) images of thin film deposited by using fs laser pulses at the same values of average power (a) 300 mW and (b) 750 mW. By using the AFM images data, we get a curve represent the relation between popularity of height versus height, which is the height of the most popular in our samples.

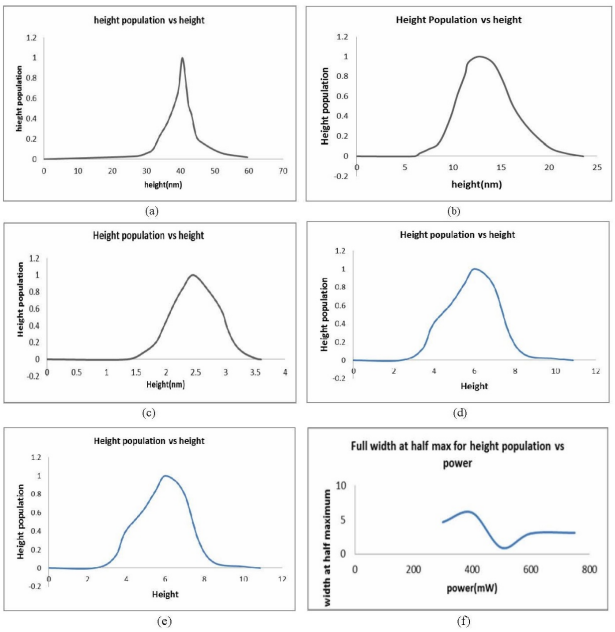

Figure 6: (a,b,c,d and e) shows the height population vs height for thin film deposited with fs laser of average power at (a) 300 mW (b) 400 mW (c) 500 mW (d) 600 mW (e) 750 mW and (f) represents the dependence of the full widths at half maximum for height population vs the incident of fs laser pulses power.

Figures 6a-6e represents the height population versus height for deposited gold films by femtosecond pulse at average power from 300 mW to 750 mW. We can monitor 'Full width at half maximum' for which shows how the height population changes with the power. Figure 6f shows the dependence of height population on the average power of femtosecond laser pulse from 400 to 750 mW. It clears that from effect of laser power on thin films. In addition to, other AFM images gives us information to study the rule of power on statistical behavior of Gold thin film. As shown in Figure 7a the particle density increases to reach 60 particles in μm^2 at power 400 mW and fixed from at 500 to 600 mW, while it falls between 600-750 mW. The average of mean radius Figure 5b increase, this mean decrease in particle density (number of particles per μm^2) accompanied with increase in particle size. Also, in Figure 7c we can see the minimum of height of maximum population at 500 mW, at this power we found thin film of nearly single crystal as clear in Figures 6a and 6b. From this curve at average power 500 mW, we get the minimum height of maximum population. So, we can say that at this value of average power, a gold thin film of nearly single crystal is formed, this can also see from SEM and AFM images for formed gold films at this value of average power. Otherwise not only the laser power effect on the quality of deposited gold thin film but also the type of substrate material was affected the properties of thin films. Figures 8a and 8b shows X-ray diffraction histogram of Gold thin film deposited by 500 mW femtosecond laser using (a) Glass substrate and (b) using sapphire substrate.

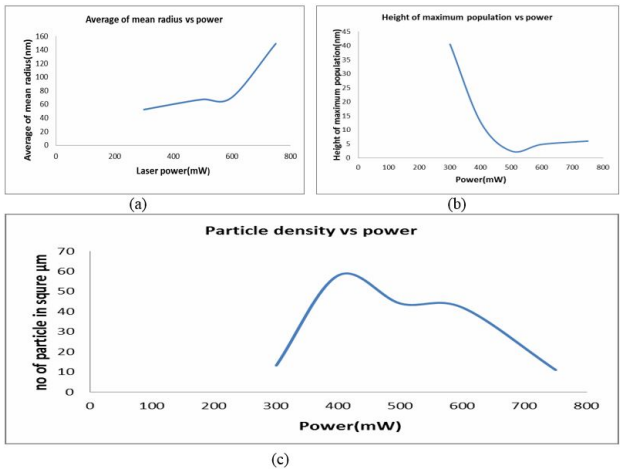

Figure 7: (a) Demonstrates Particle density (number of particles in square µm) vs fs laser power (b) Average of mean radius vs fs laser power and (c) represent the height of maximum population vs fs laser power.

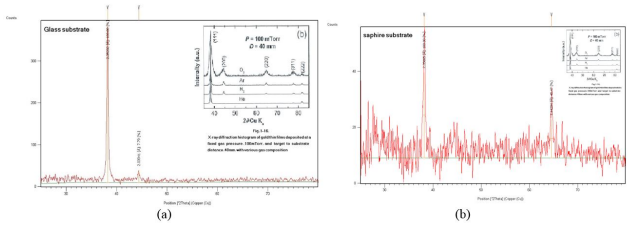

Figure 8: Reveals X-ray diffraction histogram of Gold thin film deposited at I incident fs laser power of 500 mW onto (a) Glass substrate, (b) Sapphire substrate.

X-ray diffraction (XRD) analysis was used to investigate the phase, crystallographic orientation, texture and lattice parameter of the sample. The scattered X-rays will interfere constructively at a given scattering angle due to their long range order, The condition for constructive interface is defined by Bragg's low 2d sin θ=nλ, where θ is the angle of incidence X-ray, d is the spacing of atoms for a given plane, λ is the wavelength of X-ray radiation and n is an integer, representing the diffraction of the peak. Once the phase and the orientation of a film are assigned and the spectrum has been normalized, it is possible to determine the lattice parameter of a crystalline film. For a peak position θ hkl corresponding to lattice plane with miller indices (hkl), the lattice parameter for a cubic crystal is given by $a = \lambda \frac{\sqrt{h^2 + k^2 + l^2}}{2 \sin\theta\, hkl}$. A 2D spectrum is obtained by systematically increasing θ around the peak position and measuring the intensity against ω. The FWHM of this is an indicating of texture or quality of the film. The quality of the filmWas determined from FWHM of XRD peaks corresponding to the desired phase. XRD Histograms in case of using a glass Figure 6a show two diffraction peaks, one at 2Θ =38.2° (111) and the other at 2Θ =45° (200) indicating that, gold thin film on glass at 500mW femtosecond laser is highly oriented [111]. The XRD in Figure 6b has two diffraction peaks,

one at 2Θ =38.2° (111) and the other at 2Θ =65° (220). We have noted in case of using sapphire substrate for gold thin ilm deposition, XRD diffraction peaks are much wider than in XRD peaks in case using glass one. That is means; the size of crystallite of gold thin ilm deposited onto sapphire substrate is smaller than that the size of the gold crystallite deposited onto glass substrate [14-23].

Conclusion

We elaborated gold thin films with nanometer-scale roughness by controlling the parameters of PLD technique. The experimental results have shown that, the particles density of the deposited gold films increases to reach to 60 particles in μm^2 at incident laser pulse power at 400 mW and is fixed at powers 500 mW and 600 mW, while it falls at higher laser power from 600 to 700 mW. Also, as the power of the incident femtosecond laser pulse increases the average mean radius of the deposited nanoparticles increase which mean decreasing of particle density (number of particles per μm^2) accompanied with the increasing of the particle size. We have noticed that, at the 500 mW, a clear gold single crystal is formed. The advantage of femtosecond PLD is the fact, the target material undergoes rapid heating without any significant collateral damage to the bulk could potentially lead to a reduction in emission of Melton droplets. However, mechanisms such as phase explosion and photomechanical fragments can lead to the formation of nanoparticles from the ablated target, which would be detrimental to the quality of films intended for laser wave guide application. fs- Second laser nanostructure gold thin films by pulsed laser deposition techniques have many applications in the field of Nano photonics or Nano optics. Since nanostructures are able to affect light and control it on a nanometer scale, they have given rise to a variety of applications: e.g., surface enhanced spectroscopy plasmonic sensors solar cells superlenses plasmonic beam shaping and collimation chiral metamaterials and medical applications.

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