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RESEARCH ARTICLE

IDENTIFICATION OF THE ADVANTAGES OF LASER ABLATION METHOD FOR PREPARING THE NANOMATERIALS: EFFICIENT, RELIABLE and COST-EFFECTIVE.

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ABSTRACT

Laser ablation mechanism focuses a laser beam on a substrate for the removal of any surface material. The removed mass relies on the material itself, pulse length, intensity power and laser wavelength. Numerous benefits of laser ablation as compared to the traditional nanomaterials' processes are utilized for the determination of chemical's concentration level, their incidence or more specifically of the surface material. However, the substitute solutions go through a procedure of multiple steps which is hazardous for environment, time taking, obstinate and expensive. Thus, laser ablation is considered to be cost-effective, dependable, and economical process. The directions for nanoparticles' production consents control of the particle geometry, particle accumulation degree, particle size and various elements's doping ratio. Several techniques have testified the both methodologies for instance combustion, sputtering, chemical vapor deposition, PLA, mechanical milling and other practices. In our current research, we will be concentrating on just those techniques which comprise of the combustion and pulsed laser ablation usage.

INTRODUCTION

Nanotechnology comprises of the study of properties, synthesis and characterization of nanomaterials while containing <100nm as a minimum single characteristic dimension. However, the nanometer scale research has occurred for some period. But in past few decades, the progress in production and characterization practices have catalyzed the nanoscience growth. Moreover, numerous products integrating the nanotechnology have been commercialized while consideration of these fresh materials is insignificant in comparison to the bulk species of the same kind (Hobson, 2011). The smaller size of nanomaterials make them significant and this is also because of the critically enlarged surface areas ratios in relation to the bulk resources. While the other reason is added essential effects of size. The decline in size lower than 100nm turns the features' scale parallel to various physical phenomenon for example, light wavelength, the distance of energy transfer, average free path of phonons and electrons (Chen, 2011). The outcomes indicate the divergence of properties from the standards of bulk materials while persisting discrete from the quantum science's studies. Thus, the usage of quantum theory or classical physics is unable to understand the nanoscale materials' properties especially when size rage is 2 to 10 nanometer (Serrano, 2009). A new material control dimension is formed in an attempt to control the fresh properties via size of features which does not occur for bulk substance. For interpretation, nanoparticles are stated by the way of three dimensional solid particles having a diameter that is less than 100nm. NPs can be synthesized using various techniques and can be single crystalline, non-crystalline and polycrystalline (Byrappa *et al.,* 2007).

Nanoparticles Synthesized By Laser Ablation: A research conducted by Tarasenko *et al.* stated the silver colloids laser irradiation effects formed by laser ablation method in acetone at various wavelengths of 266, 800, 400 and 532 nanometer. The experimental situations preferred a production of spherical sized controlled particles and reduced initial particles' dimension (Tarasenko, 2007; Burakov, 2001). Simakin *et al.* described the gold nanoparticles' synthesis by gold target's laser ablation in water using pulsed Nd: YAG laser which is operated at 2^{nd} or 4^{th}harmonic wavelengths 266nm. Thus, the nanoparticle's properties were observed to be of average size as well as their stability to extra laser irradiation such as 266 and 532 nm (Simakin, 2004). Mafune *et al.* manufactured silver nanoparticles in SDS using metallic silver plate laser ablation (Yoon, 2008). The dependency of concentration abundance indicates a close relation among the charge state, surfactant coverage on the surface of nanoparticle with the in solutions stability of nanoparticles. Yamada *et al.* designated a novel gold nanoparticle having a mean diameter of 8 nanometer which was being irradiated in aqueous SDS solution with a firmly focusing pulse laser at 335 nm wavelength (Yamada *et al.,* 2015). Moreover, the Phuoc *et al.* invented a multi pulse Nd- YAG laser which was being operative at 1064 nm and organized in cross beam configuration while causing the laser ablation of silver inside the de-ionized water. Thus, the outcomes indicated an increase in ablation rate by cross beam ablation, stimulated distribution and reduction of particle size (Glardon *et al.,* 2001). Truong *et al.* considered the Nanospikes' dense array using bulk (Ta, Au, Ti, Ag) target's laser ablation absorbed in liquid. The impact was calculated with smaller laser pulses such as 90ps or 350 ps using lasers of Nd:YAG (Nayak, 2007).

Giusti *et al.* testified the Au nanoparticles' formation while utilizing water based picoseconds laser ablation with an essential picosecond harmonic such as Nd:YAG laser. The linear and nonlinear absorption processes cause the early saturation at 532nm ablation procedure while fragments of already present nanoparticles supported them (Iravani *et al.,* 2014). Jimenez *et al.* presented a fresh technique which contained the solid target laser ablation being submerged in metal salt water solution. From the water based solution of AuCl4 or AgNO3, silicon is selected as a significant target for the formation of gold or silver nanoparticles (Zeng, 2012). To examine the efficiency of method, the Raúl Bola Sampol (2014) attained the silver nanoparticles solutions. Laser utilized for this method was a 1064 nm wavelength Nd: YAG. Categorization was carried out with help of transmission electron microscope and a double beam spectrophotometer for the measurement of absorption spectrum and size pf these NPs (Zahra, 2014). The mean nanoparticles' diameter upsurges from 9 to 22 nm with increase from 9 to 13 mj of laser pulse energy (Zhang, 2014).

Approaches for the Synthesis of Nano materials: The chief methodologies for nanomaterials' synthesis are categorized in bottom–up and top-down approaches while relying on the stability of experimental conditions (Figure 1). However, the structure and properties of produced nanoparticles are controllable. Further, the directions of nanoparticles synthesis permits the control of doping ratio by various elements, particle geometry, particle agglomeration degree and particle size (Zahra, 2018). For various applications, the parameters of such particles give new chemical and physical characteristics to produced material (Zahara *et al.,* 2018). Thus, production of novel structures along with distinctive properties is critical even with a profound synthetic methods' understanding (Newfang *et al.,* 2015). Various techniques have been concerning both approaches like combustion, chemical vapor deposition, mechanical milling, sputtering, PLA, and several other strategies (Elaf Ayad Kadhem, 2015). Our recent research focuses on all those approaches which utilize combustion techniques and pulsed laser ablation.

Bottom-Up approach: By this technique the numerous nanomaterials are produced through an interaction of molecular as well as atomic species in chemical reaction's set (Soni *et al.,* 2014). Normally, a precursor is either gas or liquid which is dissociated, ionized, evaporated or sublimated and finally condensed to produce nanoparticle of crystalline or amorphous form. Thus, this methodology yields nanoparticles having few imperfections such as less contamination, narrow sized distribution particles and uniform chemical composition (Buzea, 2007). The PLS method contemplate three bottom up practices for nanomaterial's formation which comprised of the infrared pulsed laser induced breakdown (IR-PLIB), laser induced dissociative stitching (LIDS) and infrared pulse laser pyrolysis (IPLP) (Henseler, 2016).

Top-Down approach: The preliminary material is bulk particles of the similar material which has to be manufactured and it is further fragmented into the smaller particles by application of energy source (Henseler, 2016). Moreover, the energy used might be laser irradiation, thermal, and mechanical or chemical. Thus, the processes such as Pulse laser deposition (PLD) and Pulse Laser Ablation (PLA) are used and further material immerses energy and then converts into thermal or chemical energy for the breakage of bulk material's molecular (Zhang, 2014; Eason, 2006). This tactic generally forms smaller particles or flakes having extensive area distribution which is also a drawback of top down method. There is a possibility to cover up this disadvantage by synthesizing an accurate sized nanoparticles with help of lithography or focused ion beam but that is costly (Bulgakova, 2001). That is why the bottom up methodology is deliberated as more specific or simple for the production of $<$ 100nm sized nanoparticles. Whereas, the top down is used for producing the $>$ 100 nm sized particles and thin films.

Pulsed Laser Ablation in Liquid Medium (PLAL): The solid target's laser ablation happens in liquid or vacuum surrounding for the production of nanoclusters during the processing of laser based materials. The previous procedure placedthe nanoclusters on a solid substrate causing the nanostructured film formation (Kabashin *et al.,* 2010). While later method freed the nanoclusters in liquid for the formation of a solution for colloidal nanoparticles which further produced the more effective particles. This solvent can offer positive chemical and physical effects including cooling actions, reduction or oxidation for ablation efficiency improvement and plasma imprisonment (Soni, 2014). The nanoparticles can be prepared by a one-step top down strategy which is pulse laser ablation in liquid (PLAL). This method was utilized for the formation of oxide based nanostructures for example oxide nanoparticles, oxide composites, oxide nanostructures as along with high energy ablated types react easily with oxidized and water to form a nuclei which can further react in aqueous medium with organic molecules (Tarasenko, 2007; Leitz, 2011).

Organization of Pulse Laser Ablation in Liquid PLAL Technique: The overall schematic diagram of a distinctive experimental system of PLAL in liquid is exhibited in Figure 2. It comprised of container for holding the liquid and target while a pulse laser beam delivery optics. The target and container as well rotate with magnetic stirrer or rotating stage, for instance, to make sure about no ripple on solution surface and to prevent a profound ablation crater. The PLAH technique's nature is effected by three main components such as liquid media involving potential surfactant ions, electrolyte ions and ions, solid targets and pulses (Figure 2-b). The production formed from ablation may interact with one another. These connections happen in similar system for short time period after laser pulse by powerful bonding. Two phenomena could occur among this procedure. First, the self-focusing and refraction changes the focal length of focusing length by liquid layer for a high intensity picosecond laser. Moreover, the liquid vaporization at liquid-air interface and self-focusing effect the focusing in analysis (Zahra, 2014). Then secondly, laser beam diminishes when passed through a liquid. This decrease is because of the photons absorption and their dispersal with liquid molecules (Zahra'a, 2014). This is also possible due to the matters in liquid such as surfactant ions , molecules or former pulses of laser.

Mechanisms of Pulse Laser Ablation in Liquid PLAL Technique: PLAL technique mechanisms can be briefed in three steps:

- The matter and laser interaction results in electron-phonon linkage and this coupling causes an excessive electronic energy transfer to the heat of lattice. This communication leads to the quick local plasma formation

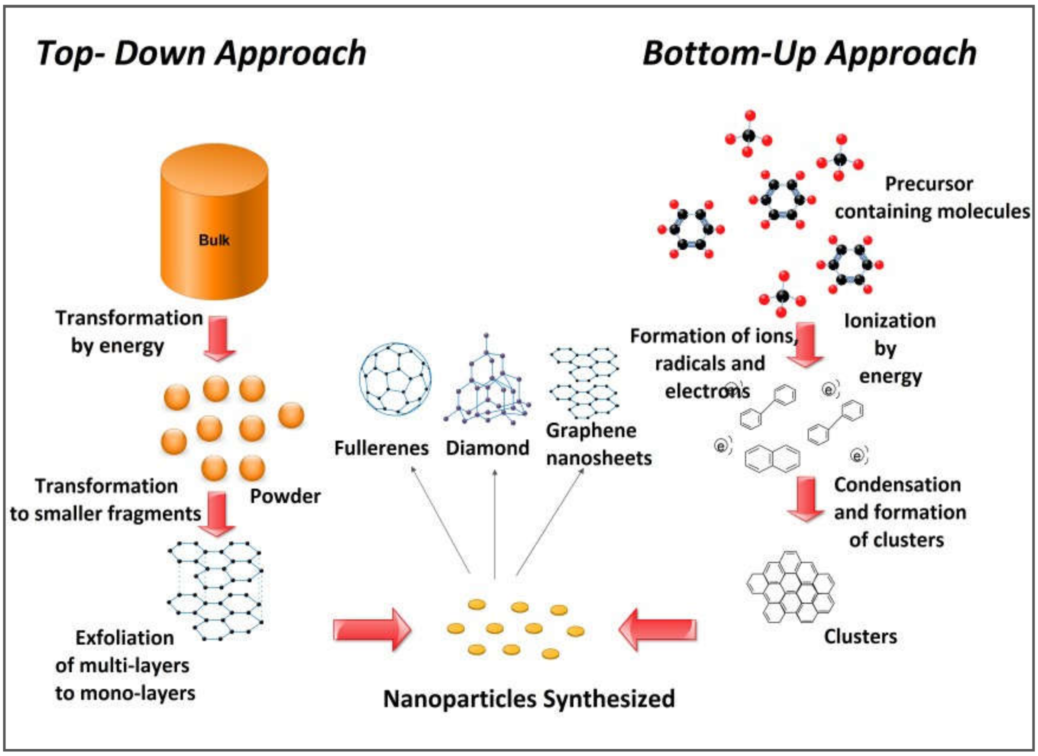

Figure 1. The formation of based nanomaterialsusing bottom–up & top-down approaches (Henry, 2005)

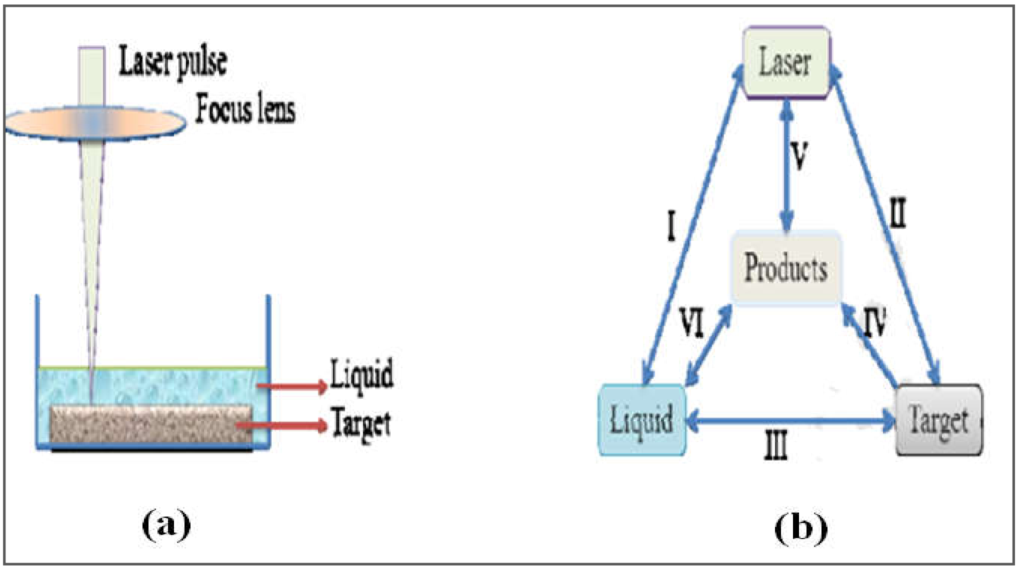

Figure 2: a) general schematic diagram of experimental setup b) interactions and components combination in PLAL: I- laser liquid interaction, II- target's laser ablation, III- liquid hot target interaction, IV- target's products formation, V- interaction of laser products, VI- liquid product interaction (Streubel, 2016)

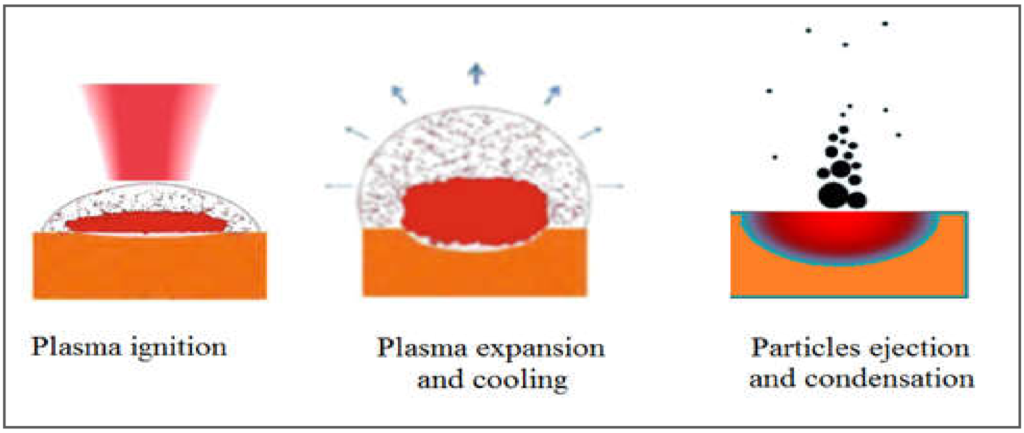

Figure 3. The summarized mechanisms for laser ablation procedures (Dell'Aglio, 2015)

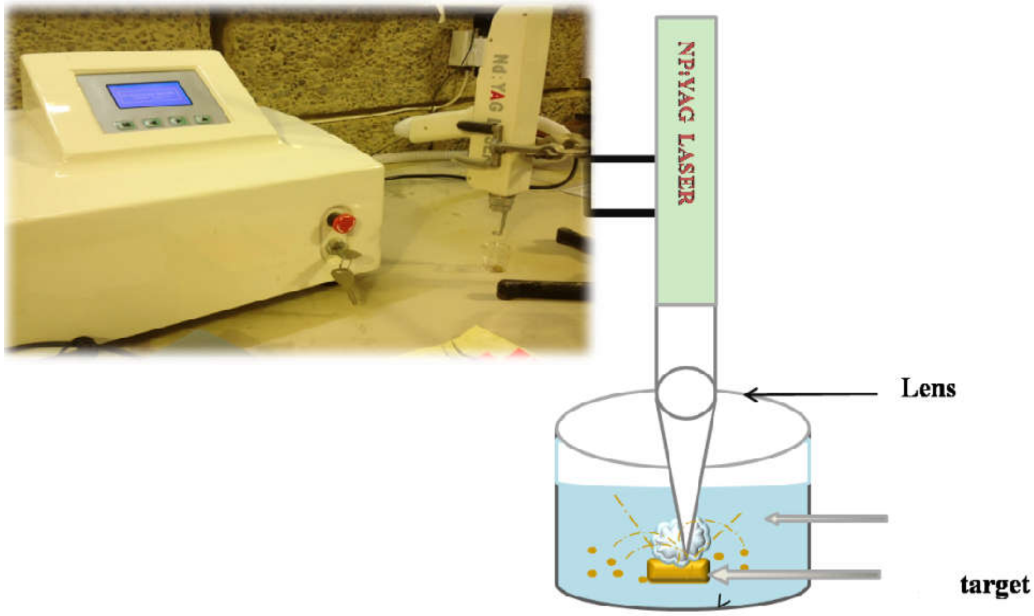

Figure 4. Experimental set up for laser ablation system (Elaf Ayad Kadhem *et al.,* 2015)

in the interface of solid and liquids with an extreme high temperature of about 6000 K (Dell'Aglio, 2015).

- A successive adiabatic and ultrasonic extension causes a rapid plume region's cooling. Thus, the expansion of plasma causes the ablation of particulates into the fragments of crater or target walls to create the clusters of materials. Furthermore, the plasma induction is ascription of second mechanism (Lee, 2012).
- The condensation leads to the synthesis of target NPs and plasma is doused. Likewise, process of nucleation and then in condensation, the clusters are formed. The clusters of material come across as well as interrelate with surfactant and solvent molecules in their adjacent solution while encouraging capping effect and chemical reactions. Throughout the step of condensation, hard agglomerates are formed as fine nuclei strike and stick together or along with the precipitate of new materials. However, the week bonds amongst the hard ones such as covalent-ionic bonds and Van der Wales bonds leads to the formation of soft agglomerates (Streubel *et al.,* 2016). The PLAL technique mechanisms are shown in Figure 3.

The ultimate NPs' morphology and structure depends on the concentration of surfactants in solution or else on the competitiveness amongst surfactant protection and particle's aqueous oxidation (Schaumberg *et al.,* 2015).

Laser Ablation System

The colloidal solution for nanoparticles of MgO in synthesized with laser system is presented in Figure 4. The laser ablation used the type of laser was Q-switch Nd-YAG laser type HUAFEI. Which provided pulse wavelength of 1064 nm having maximum energy/ pulse of 1000 mJ while diameter of effective beam with 5mm, repetition rate of 6Hz and pulse width of 10 ns. Moreover, the laser beam on a metallic target was focused by utilizing a lens of 15mm focal length. While, the metallic target was stabilized by fixture within a flask and submerged at a depth of 3 mm in flask solution. Likewise, the whole ablation procedure was performed at room temperature (Elaf *et al.,* 2015).

Conclusion

All the latest research work which is being considerate from previous decade regarding nanoparticles preparation through PLA technique has been summarized in our current assessment. Laser ablation is considered exceptional because of an extensive range of materials such as ceramic, biological tissues, metal, and plastic. Being a dynamic technology, laser ablation comprises of the intricate, chemical and non-linear physical mechanisms which spread numerous magnitude orders in a given time frame. Moreover, the effectiveness and growth of laser ablation relies on various factors for instance pulse duration and wavelength. The shorter pulse duration is preferred to lessen the thermal damage imposed on surrounding area and as well as to give peak power at its maximum. And wavelength which is cautiously selected having absorption depth at its lowest. Further, the repetition rate of pulse should be elevated adequately to maintain the heat instigated through laser ablation without leaving any cooling time. Thus, reduced energy waste makes ablation more effective. Additionally, an appropriate quality beam is required for effective laser ablation performance.

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