

Applications of Nanoparticles via Laser Ablation in Liquids: a review

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Abstract

Laser ablation of any solid target in the liquid leads to fabricate nanoparticles (NPs) with metal or different compositions of materials such as metals, alloys, oxides, carbides, hydroxides. The fabrication of NPs in liquids based on laser ablation has grown up rapidly in the last decades compared to other techniques. Nowadays, laser ablation has been improved to prepare a different types of NPs with special morphologies, microstructures, phases and sizes, which can be applied in various field. The paper reviews and highlights the different sizes, shapes and application field of nanoparticles that are produced by laser ablation under different liquids and materials. Also the paper provide a case study for producing a titanium NPs produced by laser ablation submerged in distilled water. The Size of NPs is an important parameter especially for their usage and applications. The size and shape has been analyzed by SEM, (EDAX) was applied to evaluate the oxidation and elements of titanium NPs and the XRD was used to evaluate the phase composition and the peaks of both titanium and some element. SEM technique showed that the synthesized NPs size ranges were between 15-35 nm which can be applied in various field such as annihilator for cancerous cell etc.

Keywords: Nanoparticles, Laser Ablation, Titanium NPs

1 Introduction

In the last decades, the Nano-science has progressed, laser ablation (LA) become a one of the important technique for the synthesis of nanostructures. The laser ablation techniques of nanoparticles can be produced in two different environments: in a vacuum, or gas or in a liquid (Zeng et al., 2012). Laser ablation of solids materials in liquids is a physical approach for NPs creation of various elements. The layer molten on the target material is created by laser pulse which can be dispersed around the liquid as NPs. The NPs made of composite materials that contain an alloy of two or more metals which has the ability to produces a NPs with stoichiometry which similar to the target alloy (Semaltianos, 2016). Nanoparticles (NPs) depends too much on the material and liquid type for their usage in various applications such as in chemistry, physics, engineering or biology. Moreover the size and shape of NPs can be controlled by selecting the appropriate material and liquid used (Semaltianos, 2016).

Metallic nanoparticle research is an attractive field in scientific studies due to the wide and varied ranges of potential and available applications, from biological to industrial areas. Recently, researchers have published various preparation methods of metal nanoparticles, including chemical and physical methods (Darroudi et al., 2011). NPs has been received an increasing attention from researchers in various field such as manufacturing, biology, medical etc. However, this paper summarizes the articles reported on producing NPs by laser ablation in liquid from 2010 through 2016 which include liquids, materials used and application areas.

The paper organized as follows: methods of nanoparticle synthesis that can be prepared by the breakdown (top-down) technique and the build-up (bottom-up) technique in Part 2. Part 3 summarizes the literature review (summary) on size, shape and application of NPs that produced by laser ablation under different materials and liquids. Part 4 shows the Classifications of NPs and their applications. Part 5 presents the discussion and case study for a titanium NPs produced by laser ablation submerged in distilled water. Part 6 shows the paper conclusion and some recommendations for future study.

2. Methods of Nanoparticle Synthesis

The nanoparticles can be prepared by various techniques as shown in Figure1. Two common methods has been defined to prepare the NPs that comes from the old times. Firstly the breakdown (top-down) technique which has an external force to be applied to a solid materials that can break-up the material into small particles. Secondly the build-up (bottom-up) technique in which individual atoms are piled up one at a time on the substrate to form molecules (Brinker & Scherer, 2013).

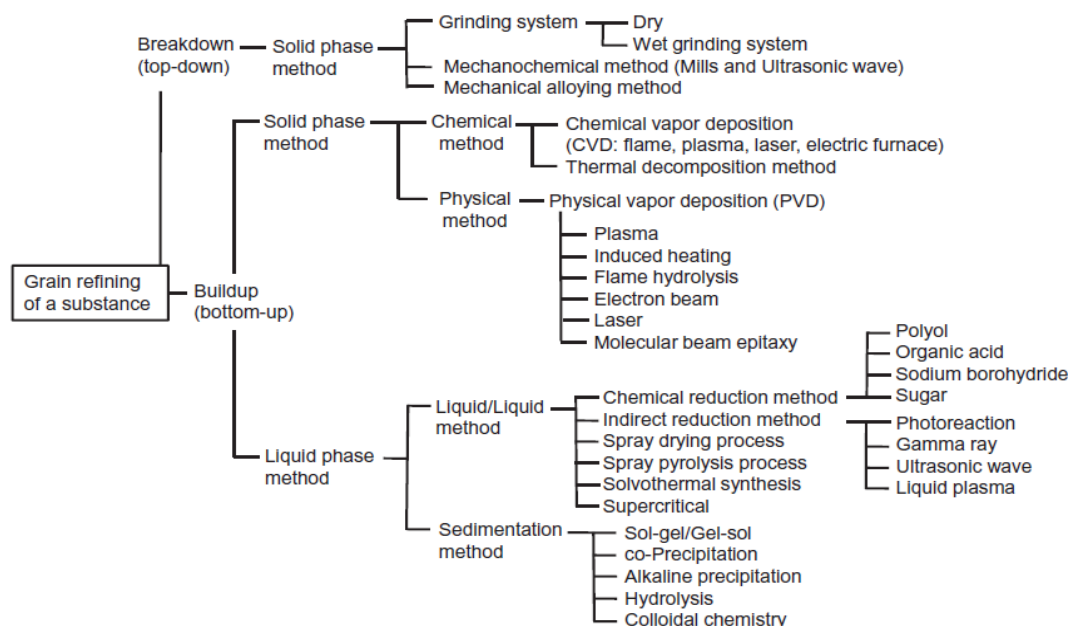


Figure 1. Typical synthetic methods for nanoparticles for the top-down and bottom-up approaches (Brinker & Scherer, 2013) .

3. Literature review (summary)

Nowadays, nanoparticles have received increasing attention from researchers in various field. This section focuses on the different sizes, shapes of nanoparticles that has been produced by laser ablation and their application fields. The size is one of the important parameter for NPs, so the liquid can control the size and shape. Moreover, this survey will come out with the articles that have been reported on producing NPs by laser ablation in liquid from 2010 through 2016 which include the type of liquids and material used. Figure 2 shows the number of reported papers on NPs producing by laser ablation in liquid.

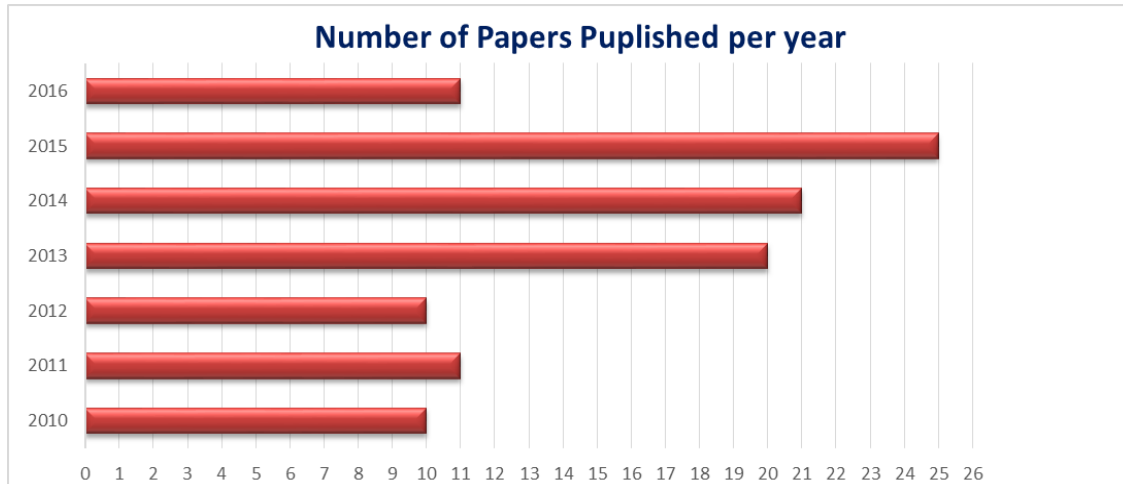


Figure 2. Number of articles per year NPs in liquid.

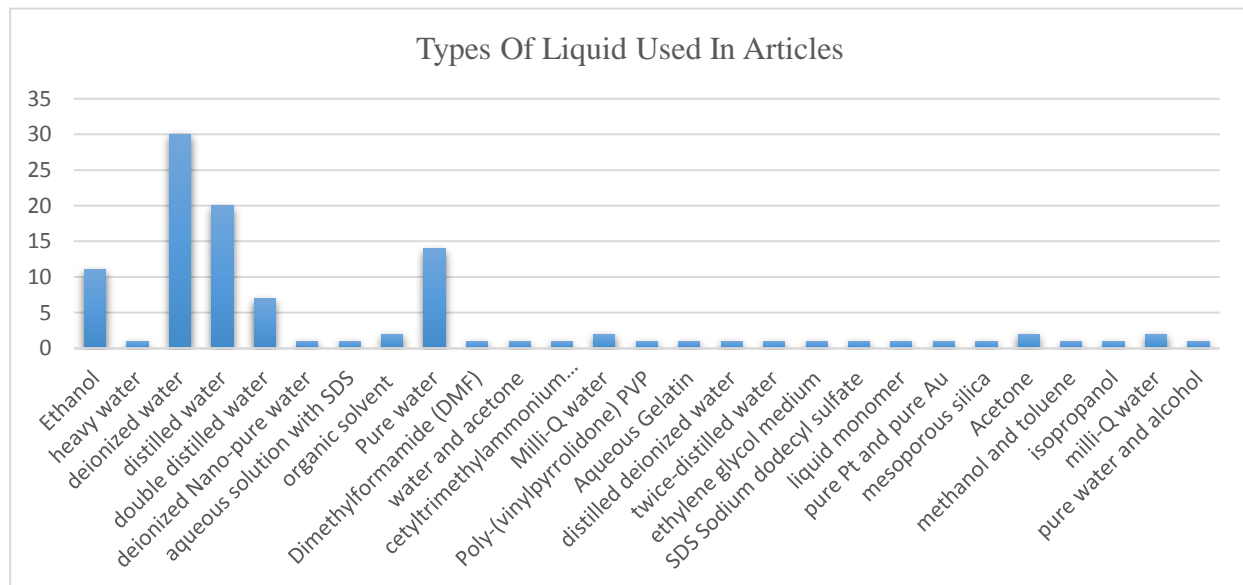


Figure 3. Types of liquids use in different articles

Figure 3 presents the different liquids that has been used to produce a NPs with different sizes and shapes. Deionized water is the most liquid used in producing a NPs by laser ablation technique regarding to their ability to produce a NPs with different size also due to their cheapest cost compared to other liquids. In general the selection of liquid is too important to control the size and shape of Nanoparticle, so the liquid should be chosen properly. Figure 3 comes out with a very important summary about the most commonly used liquid (deionized water) to produce NPs due to its huge application

4 Classification of Nanoparticles and their applications

NPs has taken more attention from authors and researchers in terms of different sizes, shape and application areas. Figure 4 present the classification of nanoparticles. The figure shows that, NPs in terms of size have been classified into four categories: the size with less than 50 nm, between 50-100 nm, greater than 100 nm and others. The NPs has been classified in into four categories: size with less than 50 nm, size between 50-100 nm, size greater than 100 nm and others.

Figure 5 present the classification type with number of papers in each type. The figure shows that, 54 % of the collected papers are with size less than 50 nm, 40 % with other size than the three mentioned types of classification, 4% with size between 50-100 nm, and only 2 % with size greater than 100 nm from the collected articles. However, Figure 5 present that most of studies are focused on producing the sizes with less than 50 nm regarding to their wide usage. In general, the efficient and suitable NPs size is less than 80 nm which can be efficient and appropriate to be applicable in various areas. The review also concludes that, the most of NPs shapes were spherical and few articles produce NPs with cubic shapes as presented in classification section.

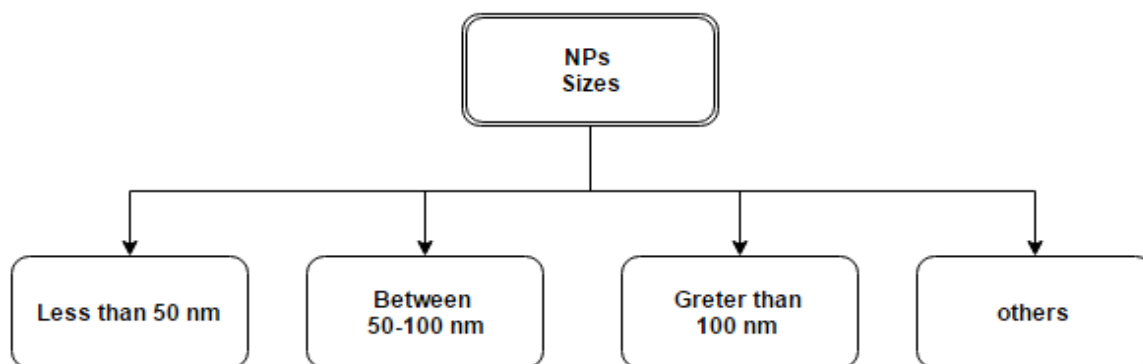


Figure 4. Classification of NPs in terms of size

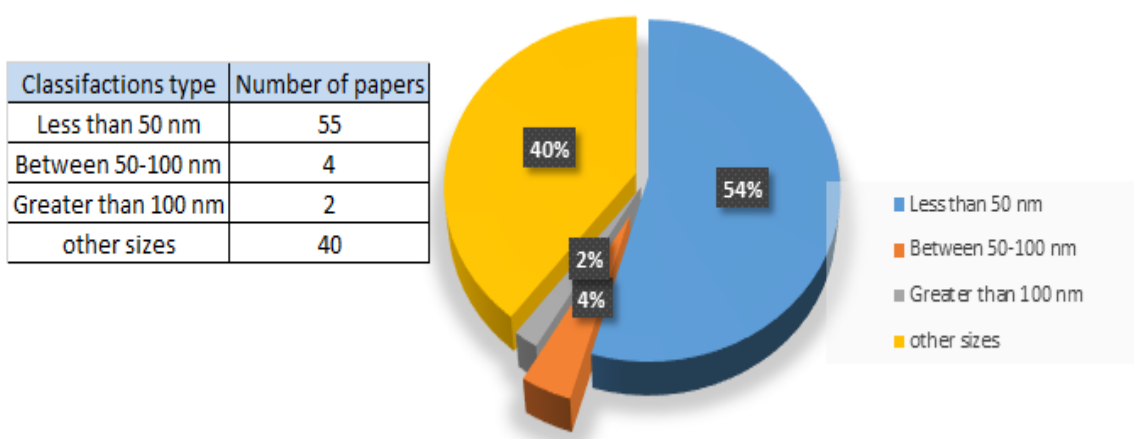


Figure 5. Number of paper per classification

Table 1. NPs (some selected paper with less than 50nm)

Reference	Liquid	Material	Size	Shape	Application field
(Ismail, Ali, Ismail, & Hassoon, 2011)	Double Distilled Water	Zinc Oxide (Zno)	average size 35 nm	spherical	Applied in optoelectronic devices.
(Donato et al., 2011)	distilled water	indium oxide	10–20 nm	spherical	Can be used for gas sensing applications

(Nath, Laha, & Khare, 2011)	distilled deionized water	titanium oxide	2-50nm	.....	Used as annihilator for cancerous cell etc.
(Nikolov et al., 2012)	twice-distilled water	Ag	average size of 12 nm	spherical	Applied in Nano-medicine.
(Eroshova et al., 2012)	distilled water and liquid nitrogen	Silicon	average 2.4 nm	spherical	It applied as biocompatible photoluminescence marks.
(Mendivil et al., 2013)	SDS Sodium dodecyl sulfate& distilled water	silver	10–35 nm	cubic and hexagonal	Used in electrical double Layer which used to prevent the growth and aggregation.
(Menéndez-Manjón et al., 2013)	liquid monomer	gold–silver	(8.6 nm) - (11.1 nm)	spherical	Applied in injection-moldable optical components
(Hamad, Podagatlapalli, Tewari, & Rao, 2014)	Pure water	Copper complex	21 and 3.7 nm	spherical	Applied as catalysts.
(Menéndez-Manjón, Schwenke et al. 2013)	liquid monomer	gold–silver	(8.6 nm)	liquid monomer	gold–silver
(Muniz-Miranda, Gellini et al. 2013)	pure water	Copper	4-50 nm		Applied in biology catalysis, electronics, and information technology.

There are 55 articles collected in this part as presented in Figure 4 due to the various application areas. Table 1 just shows some of the collected papers. To illustrate more, (Ismail et al., 2011) applied a Double Distilled Water to produce a Zinc oxide nanoparticles (mention the size here as well) that can be used in optoelectronic devices and some other devices due to the high purity of the NPs. (Donato et al., 2011) produced indium oxide NPs in various small sizes between 10-20 nm by laser ablation submerged in distilled water to be used in gas sensing applications. From this category, it can be concluded that, the NPs with less than 50 nm in size have dominated the rest categories due to their wide spread applications.

Table 2. NPs (the size between 50-100nm)

Reference	Liquid	Material	Size	Shape	Application field
(Nikov et al., 2013)	double distilled water	gold	50-100 nm	.....	Used in Nano- electronic devices and in optical labeling.
(Serkov, Barmina, Kuzmin, & Shafeev, 2015)	pure water	Au	Between 50 and 100 nm	.....	Applied in higher polarizability field.
(Serkov, Barmina, Shafeev, & Voronov, 2015)	Pure water	titanium	50–100 nm	Elongated shape	Applied in electric field.
(Shimotsuma, Yamada, Sakakura, Hirao, & Miura, 2013)	ethanol	Si	51 nm.	.....	Applied to various target materials in an ambient atmosphere.

Table 2 shows all paper reported in producing a NPs with size between 50-100nm. There are a few studies reported on that. However, (Nikov et al., 2013) prepared a Gold NPs which were submerged in double distilled water which can be applied in various fields such as Nano-electronic devices and for optical labeling. Sterkov, et al., prepared Au nanoparticles submerged in pure water so the NPs sizes was found between 50-100 that can be applied in higher polarizability (Serkov, Barmina, Kuzmin, et al., 2015). Shimotsuma et al., has use a high efficient synthesis of nanoparticles of Si submerged in ethanol with a diameter below the diffraction limit of laser light with 51 nm in size which can applied to various target materials in an ambient atmosphere (Shimotsuma et al., 2013).

Table 3. NPs (size Greater than 100 nm)

Reference	Liquid	Material	Size	Shape	Application field
(Soliman, Takada, Koshizaki, & Sasaki, 2013)	Pure water	ZnO	>200nm	.....	Applied in higher polarizability field.
(Ikehata et al., 2015)	DI water	Er,Yb	100-200nm	polygonal	The nanoparticles generated singlet oxygen that killed cancer cells

Table 3 presents that, there are just 2 reported articles on producing a NPs with size greater than 100 nm from 55 collected papers. (Ikehata et al., 2015) produced a very special Er,Yb NPs submerged in deionized water by laser ablation which generated singlet oxygen that can kill the cancer cells. (Soliman et al., 2013) prepared ZnO nanoparticles that has been submerged in pure water so the NPs sizes was found greater than 200 nm which can be applied in higher polarizability field (Serkov, Barmina, Shafeev, et al., 2015) produced Titanium NPs with different sizes between 200-500 nm which can be applied in electric field.

Table 4. NPs (other sizes than the 3 classifications type)

Reference	Liquid	Material	Size	Shape	Application field
(Lin et al., 2010)	Ethanol	Bi ₂ O ₃ (Bismuth oxide)	Between 10 -60nm	.....	Can be applied in photo-degradation of indigo carmine under 365nm light emitting diode irradiation.
(Nishi et al., 2010)	heavy water	Palladium	Between 20 -160nm	.....	Applied in various field like hydrogen storage, fuel cell and catalyst.
(Semaltianos et al., 2010)	deionized water	titanium monoxide	2-200nm	cubic	used in environmental engineering such as photocatalytic degradation of water pollutants and paints industry,
(Mahfouz et al., 2010)	deionized water	Alumina	less than 100 nm	spherical	Applied in various field such as fire retard, catalyst, insulator, surface coating, composite materials, thermal protections etc.
(Viau, Collière, Lacroix, & Shafeev, 2011)	Ethanol	Al	5-200 nm	.....	Can be used in surface-active substances.

Other sizes means the size of nanoparticles that not included any type of the 3 classification types mentioned above. To illustrate more, during the production of nanoparticles some of the particles got sizes with less than 50 nm and other with more than 100. Table 4 shows the NPs with other sizes that have been mentioned earlier in Table 1, 2, and 3. There are 40 articles reported on this section with different application areas. (Lin et al., 2010) produced a nanoparticles with 2-200 nm in sizes from bismuth oxide in ethanol which can be applied in photocatalytic activity on the photo-degradation that emitting diode irradiation. (Nishi et al., 2010) proposed a heavy water as a liquid to produce a Palladium nanoparticles which is one of the most requested functional materials regarding to the large variety of applications to hydrogen storage, fuel cell and catalyst as presented in Table 4.

Case study

The case study was done on producing titanium NPs as shown in figure 6 which has been conducted via laser ablation Nd: YAG laser of solid target that has been submerged in distilled water to produce a NPs with different sizes. The analysis were done by SEM, EDX and XRD.

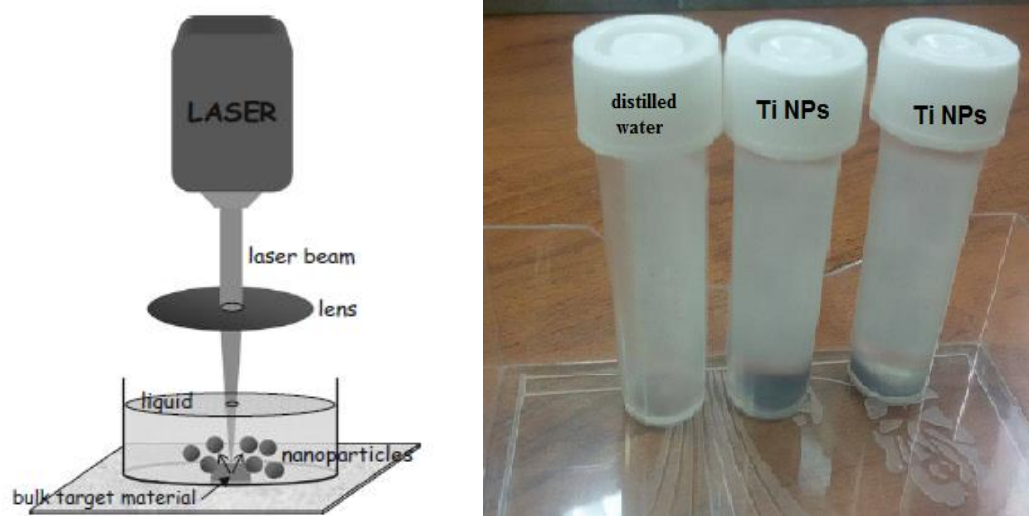


Figure 6. Laser ablation technique and photographs showing the opacity of distilled water before and after laser ablation for Ti NPs

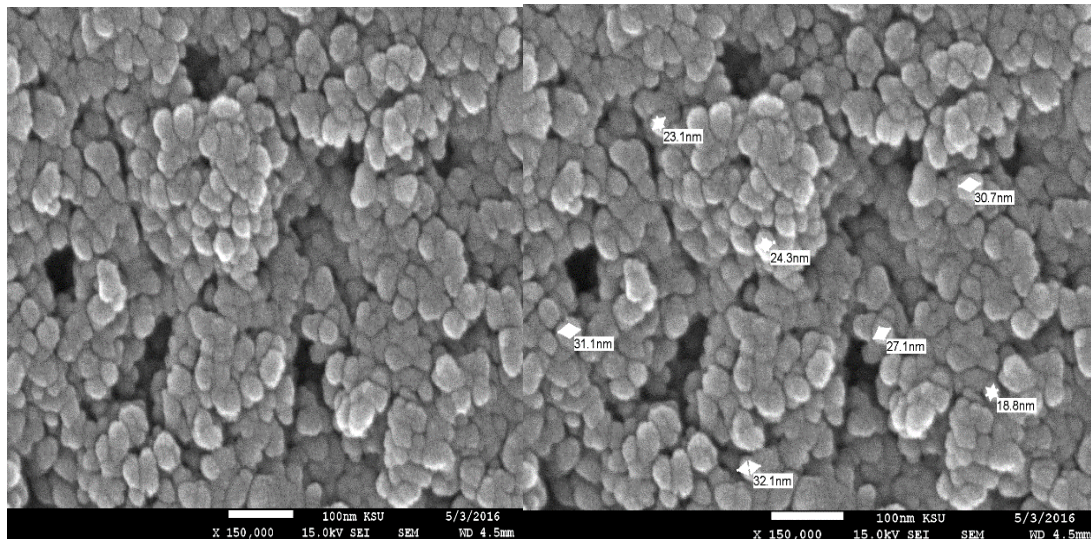


Figure 7. SEM images of titanium nanoparticles with different sizes

The morphology (size and shape) of the titanium NPs samples which were obtained from the laser ablation of titanium pellet submerged in distilled water was investigated using the scanning electron microscopy (SEM). Figure 7 shows the SEM image of titanium NPs powder. Figure 8 shows that the titanium NPs were non-spherical in shape with the size in range between 15-35 nm which can be applied in various field as mentioned the classification part.

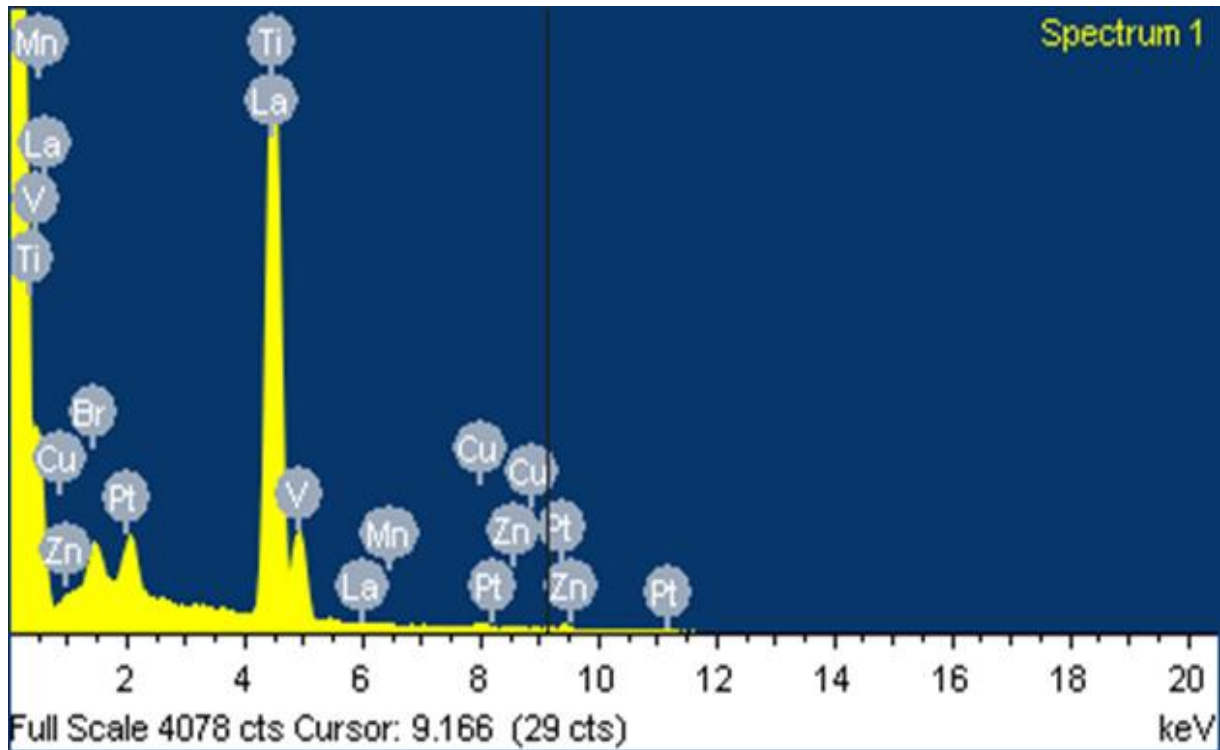


Figure 8. EDAX elements and oxidation of Titanium NPs target

Figure 8 shows the energy-dispersive X-ray spectroscopy (EDAX) analysis that was done to reveal the composition of resulting particles. Spectroscopy shows the evidence of oxidation and also provides the percentage of each elements of the NPs which could particularly challenging due to the types of elements contains of material / particles. The principal transition in the (EDAX) mappings of samples synthesized from titanium targets observed in SEM images as containing titanium as the highest percentage. Contributions from v, Cu, La and Pt which could not be resolved due to the very low detection efficiency of the system for these elements.

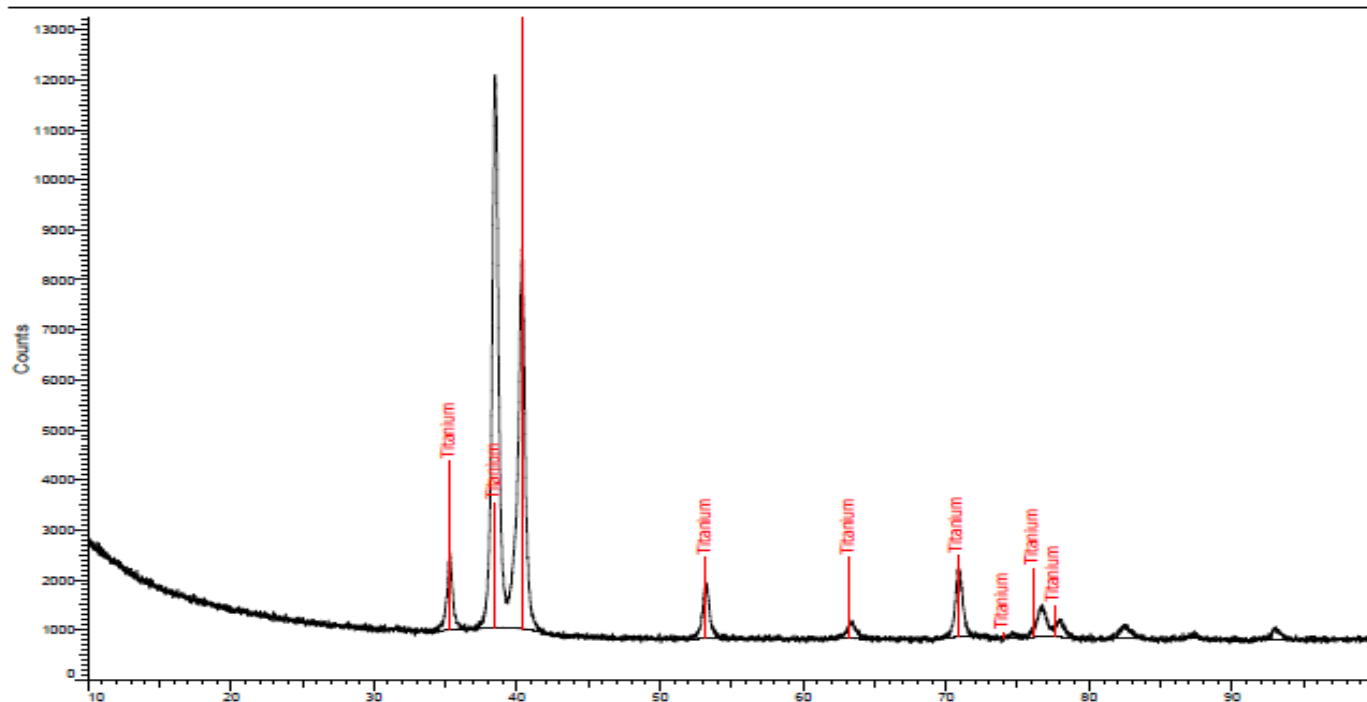


Figure 9. XRD 2Theta (Coupled Two Theta/Theta) of dried titanium NPs.

XRD presented the phase composition of the dried NPs which display the peaks of titanium. Figure 9 shows that, the titanium has some peaks which can be seen clearly. Several peaks of some elements are visible such as titanium oxide. The dried NPs can also have some portion of amorphous of titanium oxide, which is not visible in the XRD in the figure above.

6 Conclusions and Recommendations

The paper summarizes and highlights the different sizes, shapes and application field of nanoparticles prepared by laser ablation with various materials under different liquids. It can be concluded that, the Laser ablation is an efficient and appropriate technique that has the ability to produce NPs with different required sizes. The collected papers on NPs have been classified in into five categories: the size less than 50 nm, between 50-100 nm, between 100-200 nm, greater than 200 nm and others. Moreover, this research provides a case study for preparing a titanium NPs by laser ablation submerged in distilled water. The Size of NPs is an important parameter especially for their applications. The size and shape has been analyzed by SEM, and EDAX was applied to evaluate the oxidation and elements of titanium NPs. XRD was used to evaluate the phase composition of the titanium NPs. SEM technique showed that the synthesized NPs size ranges were between 15-35 nm which can be applied in various field.

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BIOGRAPHY

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