Preparation Methods and Classification Study of Nanomaterial: A Review

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Abstract. The world today stands on the brink of an important industrial revolution that is causing important progress in our lives in many industrial, medical electronics, biology, and electronics fields, etc. Nanotechnology is one of the most important sciences at this time. Nanoparticles possess very different chemical and physical properties comparative with macroscale particles. The laser ablation technique is one of the most used and important techniques used for the synthesis of nanoparticles. The laser ablation technique provides the most appropriate nanoparticles with high purity. This paper reported a review of nanoparticles and its properties also the methods used to synthesis it.

1. Introduction
In recent years, considerable attention was given to nanomaterials due to their applications in different fields [1]. The expression “Nanoparticles” called on the particles between (1-100 nm). They show attractive physicochemical properties such as ultra-small sizes (many essential properties are size dependent), high surface area to volume ratios, enhanced mechanical properties, tuneable optical emissions, their ability to be active, and concentration i.e., to have to change properties as a function of time or some other variables, and superparamagnetic features [2]. NPs possess very different chemical and physical properties comparative with macroscale particles. [3]. Opaque matter (such as copper) turned transparent to the visible light, insulators transform into conductors, inert materials (like platinum or gold) behave as catalysts, fusion temperature of material changes significantly, etc.[4]. They are found in nature and can make in the laboratory [5].Synthesis of nanomaterials with specific control over size, shape, and crystalline structure very important for nanotechnology applications as thin film-based solar cell technology, medicine, photo-catalysis, [6], biology [7], and electronics. Laser ablation technique is the one of the most efficient and reliable methods for nanoparticles synthesis. Nanoparticles produced by laser ablation is high purity and smallest size (in nano). One thing in this technique may led to use the other techniques which is economic reason. Many papers are reported about nanoparticle and the synthesis method. In this paper, we reported a review that discuss different techniques are used to
synthesis NPs as chemical and physical methods and the difference between them also the important of laser ablation technique in this field.

2. Nanoparticles Induced by Lasers
In the beginning, we should explain why we focus on using the laser to produce NPs? To answer that question, we should know how the laser interacts with the material that contains the desirable nanoparticle and what is the features of using the laser in NPs manufacturing. To ablate the atoms from the material the energy of the laser should exceed the bonding between the atoms [4]. A high energy power laser is utilized to remove desirable nanoparticles out of the target material. High energy pulsed laser beam hits the target material and breaks the bonding between the atoms. The particles will be vaporized then the vaporized particles will be carried out by the inert gas into coolant collecting material. The produced nanoparticles will be in the range of nano also laser will not affect the purity of the particles. So, we can say that the laser ablation technique is the most effective technique for the synthesis of NPs [4].

3. General properties of nanoparticles
a. Size: The properties of nanoparticles are changing with size. The remarkable changes in the electronic structure lead to the prominent dependence of numerous properties of Nano sized objects on their size [8]. It has been expounded that many essential properties are size dependent on the nanoscale. For example, the most stable crystalline phase and electronic properties of the material are size-dependent [5].

b. Shape: It’s found that the NPs shape plays a serious turn in its properties (e.g., shape reliance on the absorption spectrum of spherical noble metal NPs) [8]. Different properties (mechanical properties, biological, catalytic activity, thermal and electrical conductivity, optical absorption, and melting point) of nanoparticles due to the difference in their shape and size [9].

c. Surface properties: Surface properties include surface reactivity, charge, composition, and functionalization for nanoparticles [5].

d. Aggregation of nanoparticles: NPs tend to form aggregates in an aqueous environment. Aggregation is larger than the original size of nanoparticles. This tendency to form aggregate depends on pH, surface nanoparticle, functionalization, concentration, and ionic strength [5].

3. Concentration: Because of the small mass of single nanoparticles, an important observance is how to calibrate nanoparticle concentrations [5].

4. Classification of nanoparticles
   Nanoparticles are divided into organic and inorganic depending on the size, shape and, morphology.

4.1. Organic nanoparticles
   The organic nanoparticles are also known as polymeric nanoparticles. Also, it is known by the name of Nano capsules which are light and heat sensitive. The organic nanoparticles contain dendrimers, micelles, ferritin, and liposomes. The organic NPs are not toxic, biodegradable and some of them have a hollow sphere like Liposomes and micelles [10]. Organic NPs are a perfect choice for drug delivery due to their characteristics [10]. Then nanoparticles are also widely utilized in target drug delivery. The matrix particles are the previous overall mass which is the solid and outer boundary of the spherical surface adsorb other molecules. In the latter case, particles encapsulated the solid mass.

4.2. Inorganic nanoparticles
   In this type, Carbon is not existing. It is not toxic, biocompatible hydrophilic, and more stable than organic. The inorganic nanoparticles are separated into metal and metal oxide nanoparticles. Metal nanoparticles are employed to produce metallic nanoparticles by utilized destructive or constructive methods. The metal precursors are utilized to produce the pure metal nanoparticles. Because of plasma resonance characteristics, metal nanoparticles have distinctive optoelectrical properties. The synthesis of metal nanoparticles is controlled by facet, shape, and size. Aluminium, cadmium, iron, gold, silver, lead, zinc, cobalt, and copper nanoparticles are examples of metal
nanoparticles. The objective of the manufacturing of metal oxide nanoparticles is modifying the property of the metals nanoparticles such as iron nanoparticles are oxidized to iron oxide nanoparticles. The reactivity of iron oxides nanoparticles is increased as compared to the iron nanoparticles. Due to an increase in reactivity and efficiency of metal oxide, the nanoparticles of metal oxides are synthesized. The example of metal oxide nanoparticles is silicon dioxide, zinc oxide, aluminium oxide, iron oxide, titanium oxide, and cerium.

Figure 1. Different morphologies of nanoparticles [11].

5. Methods to synthesize the nanomaterials
There are two methods for nanoparticle manufacturing relying on the experimental status and protocols which are: “Top-down” and “Bottom-up”. The manufacturing of NPs occurs by physical, chemical, and biological techniques. The top-down method includes the decomposition of the larger molecules into smaller and suitable particles while keeping the original integrity [3]. The defect in structure also major crystallization damage to the processed patterns are the cost, imperfections, slow, and are not suitable for large-scale productions.[12] Despite that, this method typically provides better control over the NPs [5]. Bottom-up or (building-up) is performed by building the structure from the bottom as an atom, molecules, and even NPs up to form complex NPs. This method is less expensive than up-bottom, scalability, and in general better uniformity of the product [5].

Figure 2. Top-down and bottom-down methods [5].

6. Nanomaterial method of synthesis
Due to its applications, there are a lot of fabrication techniques have been developed for synthesizing various metallic and alloy micro/nanoparticles, which could be mainly classified into physical and chemical processes. In addition to the physical and chemical production of noble metal nanoparticles using biological materials has emerged as a potential research area [13]. Biological materials as Using Bacteria, Fungi, Plants, Yeast or Enzymes [14][11].
6.1. **Physical method**

In physical methods, metal nanoparticles are usually prepared by evaporation–reduction, which could be executed by a tube heater at the atmospheric pressure [14]. The benefits of the physical methods are fast, radiation utilized as reducing factors, and no dangerous chemicals involved but, the drawbacks are high energy exhaustion, solvent pollution, and lack of uniform pattern [15]. Although the size of the nanoparticles cannot be controlled exactly, even in physical techniques, it is possible to cramp the size distribution by controlling the vaporization rate, system pressure, or by changing the system geometry [16].

6.1.1. **Inert gas condensation**

In this technique, the NPs are produced by evaporation of metallic sources with the help of inert gas (helium or argon). The NPs depend on the inert gas pressure, ablation rate, temperature, gas composition, and sputtering technique [5].

6.1.2. **Plasma arc discharge**

This technique is employed for producing low-dimensional carbon materials (Nano diamonds, graphite) between the graphite electrodes in a low-pressure inert gas environment in the presence of a catalyst [5].

6.1.3. **Ion sputtering**

Also called ion beam deposition (IBD). It include an ion source which is used for sputtering the targeted material (metal or dielectric) to generate free ions or clusters which evaporate and deposit,[5]

6.1.4. **Laser pyrolysis**

The laser beam effect with a flow of reactants feed through a nozzle to the reactor. Excites particular vibrations of the reactant molecules and increases the internal energy to induce dissociation”. This method supplies a direct output of the wanted products upon decomposition [5].

6.1.5. **Chemical vapour deposition (CVD)**

This technique involves exposing high-temperature material to the volatile precursor. The reactant divided into different products, which spread on the surface, suffer a chemical reaction, nucleate, and grow to compose the chosen material [5].

6.1.6. **Laser ablation (LA)**

The pulsed laser beam is focused on the substrate to ablate NPs from the irradiated part. The characteristics of the produced particles depend on the laser parameters (wavelength, pulse duration, flounce, and repetition rate), material properties, and interaction properties [17]. The ablation rate of the laser can be increased with increasing laser energy. PLA has many features over the other techniques as, do not need a chemical solution, simple, safe, less porosity, the ability to manufacture materials with complicated stoichiometry, narrower particle size distribution, and high purity [7]. Laser ablation supplies a segmentation of a broad range of target materials at room temperature [16] also the purity of nanoparticles reaches about 90%. Due to these advantages, laser ablation techniques are the most important and used technique for nanoparticles producing and film deposition. The only problem with it, is the cost.

6.1.6.1 **Laser ablation in vacuum**

Robert Eason, in his book, explained the ablation in a vacuum which has different condition from ablation in the air [18]. It was found that the ablation rate for all metals in a vacuum is larger than in air that’s belongs to increasing the accumulation temperature in the air which means enhanced the ablation temperature in air. While the difference in the ablation rate between air and vacuum for silicon is small. S Amoruso et al. used a femtosecond laser in a vacuum to produce films of individual nanocrystals. They explain the advantages of using this method which are, the laser does not interact with the ejected gases, the initial laser-heating happens almost at a solid density, which is leading to the excessive pressure and temperature, and producing novel material states which cannot be produced by using longer
pulses of comparable fluency, all the complication produced by gases are avoided since the plume occurs in a vacuum, and it can be applied on different material [19].

6.1.6.2. Pulsed laser ablation in liquid (PLAL)

Pulsed laser ablation also occurred in liquid which is called pulsed laser ablation in liquid (PLAL) which may be involved in some other particular processes. In this case, another process will occur which should be taken into account between substrate/liquid and plasma/liquid bubble formation, stronger shock waves (in comparison with a gas environment), are the main issues [20]. The liquid may have fundamental physical and chemical effects, such as oxidizing, reducing, cooling, and forming a plasma, which can share in to improve the efficiency of ablation. It was mentioned that the ablated material during the PLAL in the liquid process is significantly higher than that in PLAL in gases due to high acoustic pressure and long duration shock wave in liquids concerning gas ambient. It has been found that the PLAL process strongly depends on the laser parameters (such as fluence, spot size, repetition rate) and the thermo-optical properties of the target and liquid ambient from which the ablation rate can be defined as a nonlinear function of these parameters. PLAL is inexpensive, simple also no need for a lot of chemical materials, and flexibility so it is a good choice to get high purity metal-oxide NPs because only water and target are need [21]. Due to these strength PLAL consider the efficient approach for NPs producing [20]. The researchers summarize the PLAL method as the following: laser interaction with the material in liquid, laser-induced plasma (LIP) which is the formation of plasma, expansion and cooling process, the formation of shock waves, the formation of bubbles, expansion, and collapse, producing of NPs in the liquid medium [22].

![Figure 3. Pulsed laser ablation in liquid technique [7].](image)

A.A. Menazea used the LA technique for the synthesis of titanium dioxide doped zinc oxide nanocomposite to increase the antibacterial activity of zinc oxide NPs at room temperature. Nd:YAG nanosecond laser was utilized as the laser source in the laser ablation technique. The measurement proved enhanced in the crystallinity, optical transmittance, and increase in the cell viability after doped by TiO$_2$ [20]. Eshita Mal et al., used Nd: YAG nanosecond pulsed laser to ablate the tungsten target. The laser-induced plasma (LIP) of tungsten is generated by focusing the second harmonic Nd: YAG laser and the LIP is studied using the time-resolved LIBS technique [23]. H. Moza and M. H. Mahdieh., produced aluminium NPs by Q-switched Nd: YAG laser (1064 nm). PLAL was used in the presence of an external electric field (EEF) and was studied as effective techniques for enhancing laser absorption, the material removal rate, and production efficiency of NPs [17]. Abdullan Ceylan combined resistive evaporation and laser ablation techniques (which are considered a modified version of inert gas condensation IGC technique) to produce Magnetic core/shell nanoparticles. A 246 nm KrF Excimer laser is used to ablate target material. It was found an improvement in the magnetic properties of the particles than the original material.
6.1.7. Plasma jet

It's also called thermal plasma torches or arc plasma torch. In this technique, first: an electric arc is produced at a high voltage between the electrodes, also hot gases are transported around the column to preserve a temperature of (800016,000 K) through the heat exchange, conductive, and convective operations. This high temperature is used to vaporize and decomposition the electrode [24]. Two kinds of arc plasma torches are usually relied on to form the (DC arc plasma) for nanoparticle synthesis: transferred and non-transferred. Both of the torches have a nozzle for the gas flow and a cathode in the torch. This nozzle is cooled with the cool water inside [25]. A nozzle is placed at the end of the torch to expand the heated gas and form a plasma jet. The jet conditions (temperature, velocity, etc.) are governed by nozzle design and can be customized for the fabrication of nanomaterials. This high temperature and gas velocity will be helpful to produce nanoparticles. The difference between transfer and non-transfer arc plasma is that in transfer the anode (target material) placed out the torch while its placed in the torch in non-transferred arc plasma. Transfer arc used electrically conductive material as an anode and the contrary in non-transferred arc plasma, also the material evaporated by non-transferred is less efficiency. The electrode is less erosion in non-transferred arc. Nanoparticles produced in this method have spherical shape [25]. This technique can be used widely for the production of nanomaterials [2]. This technique used currently is known and recognized in medicine, waste treatment, technology, and microbiology [26].

![Figure 4](image)

**Figure 4.** Illustrate carbon nanotubes synthesis system by arc discharge where: 1.anode, 2.cathode, 3.vapour jet, 4.cathode deposit [26].

L. Sarma et al. used a plasma jet to synthesis super paramagnetic carbon encapsulated iron NPs. They found that controlling plasma heating during synthesis led to the burning down of extra carbon that resulted in further enhancement of the magnetization of the product. Graphitization of the encapsulating layers and the saturation magnetization of the CEMN (carbon encapsulated magnetic NPs) also enhanced, which could successfully protect the metallic core from oxidation, as well as improved its cytocompatibility [27]. Grzegorz Raniszewski et al., studied the effect of metal components (they used carbon) on the plasma jet containing carbon nanotubes cathode deposit. It was found that the metal in the plasma determines the essential properties of the plasma. They also found that the addition of catalysts changed the plasma composition”, electrons density, conductance, and effective temperature of the plasma [28]. Hitoshi Furusho et al., used the plasma jet method to fabricate Water-dispersible gold nanoparticles. They found that old nanoparticles prepared in this manner has remarkable stability under physiological conditions” because of the immobilization of PEG (polyethylene glycol) derived materials on the gold surfaces. Such gold nanoparticles may therefore be considered excellent candidates for high-performance bio nanoparticles [1].

6.2. Chemical methods

The advantages of these methods are cost-effective, ease of production, and high production [15]. On the other hand, using the chemical methods are harmful to the living organisms, most of the chemical methods are the precise reduction control of the particle size distribution. Agents like the reaction time, the concentration of component, and temperature exhibit some control of the particle shape and size. In some states, the growth conditions are very sensitive to the process variables and let a little flexibility for the process changes [16].
6.2.1. **Hydrothermal synthesis**

This technique involves direct crystallization from solution in two steps: nucleation followed by crystal growth. Hydrothermal technique is carried out in a pressure container or autoclave with a Teflon or alloy lining. The autoclave temperature can be increased cumulatively over the boiling temperature by increasing the vapour pressure of the closet [5][29].

6.2.2. **Solvothermal synthesis**

It involves the boiling of organic liquid and surfactant over the boiling degree of the dissolvent to produce supersaturated solutions, then nucleation of the crystals with crystal growth at a faster rate.

6.2.3. **Cryochemical synthesis**

This method includes crystallization of different solutions at very low temperature (cryogenic), then removing the dissolvent by freezing, drying, or spraying [5].

6.2.4. **Aerosol-based process**

This technique consists of three parts: an atomization chamber where high energy affects the carrier gas with the liquid produces fine aerosol, a tubular reactor where the produced aerosol transferred into and keep at (800_1000 C), and a particle collector [5].

| Table 1. Methods of nanoparticles synthesis. |  |
|---------------------------------------------|---------------------------------------------|
| Technique                      | Information                      | Limitation                      | Strength                                      |
| Inert gas condensation          | Physical method, bottom-up approach. | Agglomeration                   | Ultrafine-grained materials and excellent resistance to grain growth |
| Plasma arc discharge            | Physical method Bottom-up approach   | Required suitable space and temperatures. The results of the technique are also influenced by many variables like current buffer gas, etc. | cost-effective |
| Ion sputtering                  | Physical method Up-down approach.    | In a molten metal, the temperature distribution is often non-uniform, therefore exact reproducibility is difficult.[23] | Widely used in thin film technology [23]. |
| Laser pyrolysis                 | Physical method Bottom-up approach.  | The desired elements must be present in vapor phase | cost-effective, short reaction time, simple equipment, and high purity products [23]. |
| Chemical vapor deposition (CVD) | Chemical approach Bottom-up approach | Required high process temperatures, complicated, toxic, and producing corrosive gasses | Cost-effect, used for coating organic and inorganic material, deposited the materials which are hard to evaporate Good control over shape, size distribution, and crystallinity. |
| Hydrothermal synthesis          | Chemical Up-down approach           | The morphology and size of the particles crystallized are affected by temperature, pH, reactant concentration, etc. | Good control over crystallinity, size, shape better than the hydrothermal technique |
Conclusion

In this review, we introduce details about nanoparticles, its properties, its types, and the technique used to produce nanoparticles. We focused on the laser ablation technique and mention some researches on this technique. Laser ablation is one of the most important nanoparticles synthesis methods. Its importance owing to several benefits over the other techniques, including less porosity, its ability to manufacture the materials with complex stoichiometry, narrower particle size distribution, and control of the amount of the impurities and imperfections. Also, we tried to focus on the plasma jet technique which is suffering from the lack of information. The importance of the nanoparticle forms in its multiple applications in many areas of life, such as medicine, industry, and others. Finally, this work will help the researchers by providing the necessary information to recognize and study the nanoparticles.

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