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Laser Generated MoS_2 Nanomaterials and Its Applications: A Review

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Abstract

This review study emphasizes the significance of MoS_2 nanomaterials, their manufacture, and their applications. This review examined nanomaterials and their generation processes, concentrating on laser ablation and nanomaterial production. This study advances nanomaterial synthesis and helps discover new applications by explaining the fundamental concepts and aspects affecting synthesis. Future studies should optimize laser settings, explore novel precursor materials, and understand laser-induced MoS_2 synthesis pathways to enable customized nanomaterial design and engineering.

Keywords: Nanomaterials, MoS_2, Laser Ablation.

المواد النانوية MoS_2 المولدة بالليزر وتطبيقاتها: مراجعة

ليال عبدالكريم جاسم ، فاطمة حامد رجب ، احمد الشاعر

الخلاصة:

تؤكد دراسة المراجعة هذه على أهمية المواد النانوية المكونة من MoS2 وتصنيعها وتطبيقاتها. وقد فحصت هذه المراجعة المواد النانوية وعمليات إنتاجها، مع التركيز على الاستئصال بالليزر وإنتاج المواد النانوية. تعمل هذه الدراسة على تعزيز تخليق المواد النانوية وتساعد في اكتشاف تطبيقات جديدة من خلال شرح المفاهيم الأساسية والجوانب التي تؤثر على التخليق. يجب أن تعمل الدراسات المستقبلية على تحسين إعدادات الليزر واستكشاف المواد الأولية الجديدة وفهم مسارات تخليق MoS2 المستحثة بالليزر لتمكين تصميم وهندسة المواد النانوية المخصصة..

1. Introduction

The definition of the nano originated from a Greek word that means dwarf, and it denotes a size decrease by a factor of 10^{-9} meters. The substance may be categorized based on its size into several classes: macro, meso, and macroscopic. Macroscopic, which the naked eye can see; mesoscopic, it has micron-scale dimensions, such as some cells & bacteria, and this scale can be viewed using optical Microscopy. Microscopic matter, on the other hand, refers to such as Atoms, and the majority of molecules have dimensions that are less than 1 nm. Nanoscopic materials are another class of matter that falls between microscopic and mesoscopic within the size between 1 nm – 100 nm [1]. Nanomaterials are also known as nanoscopic materials. Nanoparticles have sizes that vary between 1 and 100 nm. These particles have different physical properties compared to bulk materials due to a higher surface area to volume ratio than bulk materials. Nanomaterials can be available with a single material or multi-material as composite nanomaterials. Depending on the size, the property of nanomaterials differs from one material to another[2]. For example, they are (SPR) in some metallic and paramagnetism in some magnetic metallic NP, whereas they are quantum confinement in semiconductors. Surface Plasmon refers to the collective oscillation of electrons occurring at the interfaces of metals and dielectrics, resulting in the generation of surface Plasmon polaritons upon stimulation by light [3]. These sensations are influenced by the properties of materials and incident light, allowing for manipulation of light at the nanoscale. The oscillating electric fields of incident light interact with the cooperative motions of electrons on metal surfaces, allowing surface plasmons to propagate along metal-dielectric interfaces, resulting in significant field enhancement and localization of electromagnetic energy. If the incoming light corresponds to the wave vectors of the surface plasmons, a reduction in the intensity of reflected or transmitted light, known as surface plasmon resonance (SPR) dip, may be seen [4]. This depression is very sensitive to variations in the refractive indices of adjacent media. Consequently, surface plasmons have given rise to extensive applications in label-free and real-time detection of biomolecular interactions, such as DNA hybridizations and antibody-antigen recognitions, facilitating nanoscale analysis of biological and chemical interactions based on the unique properties of plasmonic materials[5].

Quantum confinement occurs when the size of a semiconductor or metal particle is comparable to or smaller than its exciton Bohr radius, and a material that displays a significant alteration in electrical or optical characteristics due to confinement in at least one dimension (1D) is termed a quantum-confined structure. Effects on Nanomaterials: Tunable Optical Properties, Enhanced Reactivity, Reduced Conductivity[6]

According to their size, nanomaterials can be classified as fine (100-2500) nm and ultra-fine (1-100) nm nanomaterial, whereas according to their morphology, the Aspect ratio distinguishes two classes of nanomaterials: low aspect ratio materials, like nanospheres and nanocubes, and high aspect ratio materials, like nanowires and nanotubes [2], [7].

Nanomaterials may be classified into four dimensions[2].: Zero - Dimensional nanomaterials, often known as 0D materials, are materials of dimensions at a macroscopic level and the movement of the electrons is confined to all three dimensions. nanorings, nanoclusters, and nanospheres are examples of this type of nanomaterials; One - Dimensional nanomaterials (1D) have two dimensions that are inside the nano-scale range, while the 3rd dimension is in the macro-scale region. This indicates that when confined, the electrons are in their movement in two dimensions and can only easily move in the remaining dimension. These items include nanoneedles, nanowires, and nanotubes; Two - Dimensional nanomaterials (2D): 2D materials possess two dimensions within the macro-scale range, while the remaining dimension falls within the nano-scale range. Consequently, the electrons are confined to a single dimension yet have the freedom to travel in two dimensions. Materials that have a single dimension at the nanometer scale are often referred to as thin films and layers. [8], [9]; Three - Dimensional materials (3D) do not have any dimensions that are in the nanoscale range, while all dimensions of this material are in the macro-scale range. This implies that the electrons are not restricted to the nanoscale in any direction and can move freely in all three dimensions [7], [10].

2. Nanomaterials production techniques

There are two basic approaches for creating nanomaterials: The bottom-up technique incorporates the collection of produced molecules from smaller particles to generate nanostructures. On the other hand, the top-down technique involves eliminating material from the bulk material; only the required nanostructures remain[11]. These two methodologies give materials with nanoscale as shown in Figure 1 [12].

From Figure 1, it can be seen that Various techniques have been developed not only to synthesize nanoparticles but also to regulate their dimensions. Typically, the techniques used to generate nanoparticles may be categorized into three distinct types: Various methods, including Chemical Vapor Deposition (CVD), sol-gel, wet chemistry, Physical Vapor Deposition (PVD), pyrolysis, ion sputtering [13], Laser ablation is a process of removing solid target in a liquid environment. [14], and the utilization of curry leaf extract can be employed for chemical, physical, and biological purposes. In recent years, there has been an increasing fascination with utilizing Laser ablation was remove a solid target in a fluid environment as a method for creating NPs [14]-[15].

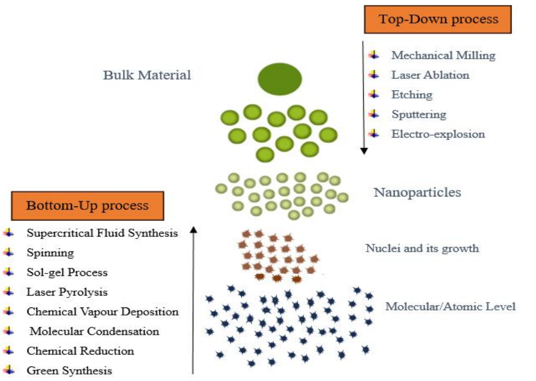

Figure (1): Synthesis techniques of nanomaterials [10].

This method has been applied to generate porous nanoparticles [16] and nanoparticles of metal oxide [17] and to alter the morphology of existing nanoparticles [18]. Some researchers choose laser ablation in a liquid-filled setting for synthesizing NPs over other traditional techniques, such as chemical approaches, since it produces colloidal nanoparticles that are free from contaminants [19] and chemical reagents [20]. Moreover, this technique is a very uncomplicated approach for synthesizing nanoparticles [21]-[22]. Even though several research scientific papers have also been published on using sodium dodecyl sulphate (SDS) as a surfactant in a colloidal solution [13]- [23] and a Polyvinylpyrrolidone (PVP) solution for producing noble NPs [15]-[24], Phuoc et al. [21] reported that the preparation of nanoparticles using the chemical methods constantly involves reduction reactions. Furthermore, these particles tend to form clusters, resulting in a reduction of the NPs' high – surface-area potential. However, this might be eliminated using the laser ablation method in fluid media, which may be because of the purity of the NPs' substance, such as free from irrelevant ions or chemicals. One more disadvantage of chemical techniques is the need for an additional purification procedure after synthesizing the nanoparticles to eliminate unintended chemical byproducts [25] This is an important process for applications like biomedical, photocatalysis, and sensing devices due to their need for highly purified nanoparticles [26]. Hahn et al. [27] also emphasized that chemical techniques are constrained by factors such as the limited availability of materials, the tendency of nanoparticles to clump together, the presence of contaminants, and the uneven distribution of particle sizes. The laser ablation technique in a water-based solution, on the other hand, can produce a wide range of metal nanoparticles without any limitations. This approach can be carried out using various liquids, which adds to its convenience. Additionally, the ease of the procedure is a clear benefit over conventional methods.

3. The Mechanism of generating nanomaterials using laser ablation in liquid

The introduction of lasers initiated a new field of study about the interaction between radiation and matter. The main observable impact of laser activity on a solid target is the elimination of a certain amount of material from the surface of the target within the area illuminated by the laser. The method was referred to as "laser ablation," derived from the Latin term "ablatio," meaning eradication. Researchers have shown significant interest in the methodology of laser ablation of targets in fluids throughout the last decade. The primary reason for this is the straightforward nature of the experimental configuration [28].

The laser ablation methodology involves directing a laser beam onto the workpiece's surface. This is often achieved by utilizing suitable optics to concentrate the laser beam into a certain spot size. Therefore, focusing the laser beam onto the surface of the material will cause the material to be exposed to radiation. This continuous exposure to the laser beam will result in a series of sequential reactions, including heating, melting, boiling, and the creation of plasma[29], [30]. When the photons interact with the target material, the force of the laser's electric field leads to the atoms' oscillation. Consequently, the heating process occurs, causing the transfer of heat to occur inside the substance. Through further laser irradiation, enough energy is absorbed by the target material to intensify molecular vibrations, leading to a reduction in the intermolecular binding energy and causing the substance to melt. Continuing to irradiate the target material with the laser after it has melted increases the vibration of the molecules, causing the molecular bonding to weaken. During this phase, the substance will undergo evaporation. The vapour retains its ability to absorb the laser light, and when there is enough absorption, the electrons become highly agitated, resulting in the transformation of the gas into a plasma state. Figure 2 illustrates the phenomenon of absorption that occurs in materials because of high power[29].

The primary distinction between laser ablation procedures conducted in liquids and those performed in a vacuum or gas is the growth of the plume. When the plasma plume grows in a liquid environment, it undergoes a more considerable compression, leading to a more noticeable expansion of the plume. Furthermore, shock waves are generated at the boundary between the plume and the liquid, causing oscillations inside the plume. The expansion of plasma plumes shows higher levels of temperature, pressure, and density compared to the confinement of air or gas, resulting in the vaporization of the liquid at the interface between the plasma and the liquid and the creation of liquid plasma [31],[32]. Ultimately, two plasmas will be combined, which may lead to chemical reactions between the liquid plasma and the plume species [32], [33].

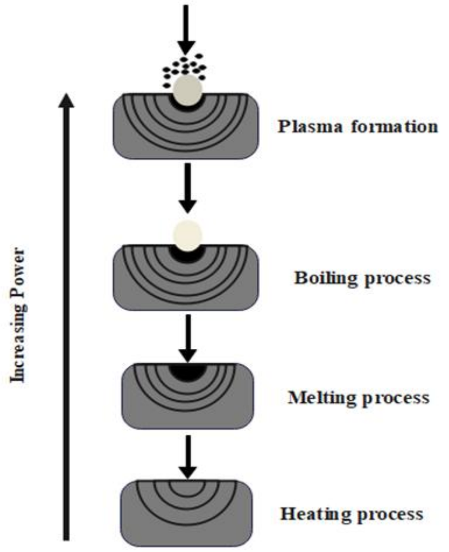

Figure (2): The phenomenon of absorption occurs in materials because of high power [29].

Nanoparticles may be generated in two ways: The nucleation and growth of plume species or the direct expulsion of liquid droplets from the target. Ultimately, the expanding plasma plume will be extinguished as a result of the cooling effect caused by the liquid. The quick colling duration leads to decreased average sizes of nanoparticles compared to those produced by vacuum or gas techniques [31]. During the early phases, the liquid plasma expands around the plasma plume of the material, creating a cavitation bubble that envelops the ablated substances. As the bubble enlarges, its temperature and internal pressure fall. The bubble will attain its maximum dimensions when the gas enclosed inside the bubble achieves a state of equilibrium with the encompassing liquid. When the internal pressure of the bubble decreases below the pressure of the surrounding liquid, the bubble bursts and releases a 2nd shock wave [34]. Nanoparticles are formed inside the cavitation bubble as it expands, occurring within a time range of (10^{-6}) to (10^{-4}) seconds. Gas generally exhibits lower heat conductivity than liquid. Consequently, the temperature of the NPs within the cavitation remains higher than the temperature of the surrounding liquid. As a result, the temperature differential between the two sides of the liquid-bubble interface causes the condensation and creation of nanoparticles after the cavitation bubble collapses [35]- [36]. Figure ٣ shows the synthesizing procedure of NPs using laser ablation in a fluid solution [31].

The process of nanoparticles occurs via a single-step process, leading to the instantaneous synthesis of nanoparticles in the liquid where the target is submerged. The primary characteristic of the procedure is that, in an ideal scenario, the liquid only consists of nanoparticles composed of the desired substance and the liquid itself. The solution is devoid of counterions and any remnants of reducing agents. Laser ablation of objects in liquids might be regarded as a technique for synthesizing NPs, serving as an alternative approach to chemical methods [28].

Commercially available lasers are characterized by several parameters, such as average and peak powers, pulse repetition rate, and wavelength of emission. These processing parameters are important for generating nanoparticles with desired properties, such as NPs size, distribution, concentration, and chemical composition. Additionally, the characteristics of the liquid have a substantial impact on the ultimate properties of nanoparticles produced during laser ablation[28].

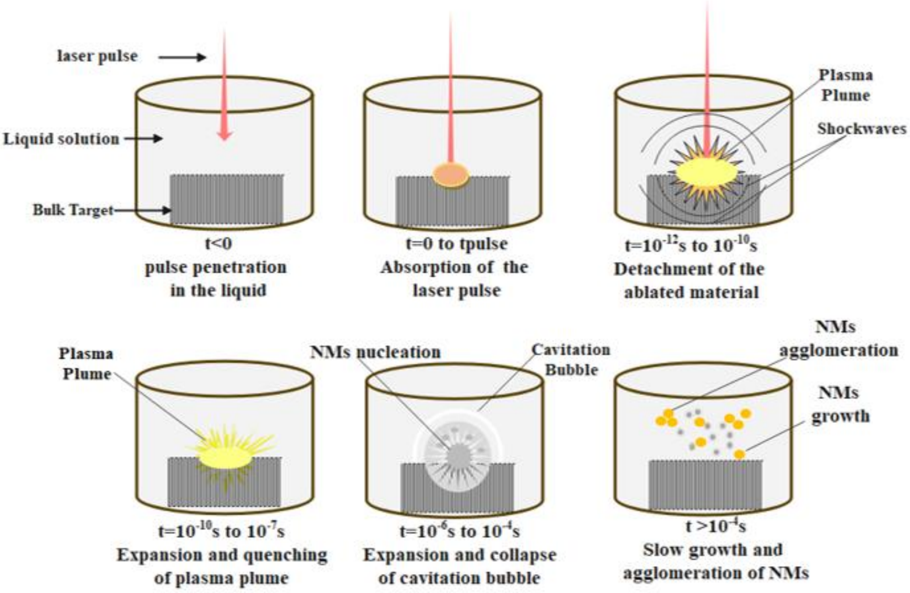

Figure (3): Synthesis of NPs using laser ablation in a fluid solution [31].

4. Factors affecting nanomaterials' characteristics

Researchers have shown significant interest in the distinctive characteristics of NPs, distinguishing them from bulk substances. These unique qualities have found applications in several fields, including catalysis, magnetism, medicine, electronics, and medicine. The shape and dimensions of NPs determine the distinct characteristics of nanoparticles [37]. Phuoc et al. [21] favored working with suspended NPs instead of micro-particles because of the benefits provided by their smaller dimensions. For instance, nanoparticles exhibit a larger variety of size- and shape-dependent properties compared to micro-particles. These features include magnetic, thermal, electrical, mechanical, and optical characteristics. Figure 4 provides a comprehensive overview of the many elements that influence the synthesis and manufacturing of NPs by the laser ablation technique [38].

A variety of laser processing parameters has different effects on the efficiency of the synthesis of nanoparticles. When considering laser ablation of materials, any laser wavelength is suitable since the optical properties of materials are identical throughout the emission range of the most used lasers. Nevertheless, laser light may be absorbed by nanoparticles formed during the target's ablation. Many nanoparticles absorb in the "UV- region," which imposes a certain disadvantage on using "excimer UV-lasers" to generate NPs [28]. It was demonstrated that it is possible to control the size of the nano colloids by the photon energy of the laser (wavelength); increased wavelength will lead to larger particle size [38].

According to the effect of "laser repetition rate" " nanoparticles (NPs) are expelled from the solid target during each pulse as long as the absorbed laser energy is enough to melt the target in a solution. Consequently, when the frequency of laser pulses increases, the concentration of the nanoparticle formation also increases. However, the target might be screened from the laser due to residual gas bubbles from previous pulses using a high laser frequency or repetition rate. To prevent this, one may use either a flow cell or high scanning velocity "rotation" of the object [28].

According to the effect of the laser energy, power intensity, or fluence, the amount of material extracted from a target is directly proportional to the amount of energy applied to the target. Nevertheless, ablation is limited by energy. The quantity of hot electrons generated by rapid ablation in a liquid is directly proportional to the number of electrons separated from the target, resulting in the formation of molten material. Electron-phonon collisions, influenced by laser pulse energy, are what the latter alludes to. Research findings indicate that the pace of ablation is dependent on the pulse energy, and there is a direct linear relationship between nanoparticle formation and pulse energy. As kinetic energy increases, the volume of melt and the quantities of nanomaterials also increase, but specific restrictions limit these changes. Laser fluence is another factor to consider when a laser beam accurately focuses on the object's surface. This activity leads to the creation of nanoparticles and nanostructures. Moreover, increasing the laser fluence will result in a greater quantity of nanoparticles compared to decreasing fluence. At a low laser energy level, nanoparticles' distribution is quite good with a small average size. Nanoparticles of varying sizes will be produced at the intermediate fluence [39].

Reports have indicated that the interaction time affects the size of NPs as found utilizing a collection of experiments. Extended ablation duration resulted in a proportional rise in the density of nanoparticles (concentration) and a decrease in size [38]. It has been discovered that the width of the Surface Plasmon Resonance (SPR) line decreases as the particle size increases because of the inherent size effects. As the duration of ablation increases, the creation of nanoparticles initially promoted. However, this increase gradually approaches a state of condition. The accumulation of nanoparticles forms a protective barrier around the laser, preventing the generation of additional nanoparticles once they have reached their critical period [40].

The duration of the pulse is an essential component in the nanoparticles' production. Changing the interaction time from nanoseconds to pico- and femtoseconds leads to a shift in the ablation process. Specifically, the change from nanoseconds to picoseconds or femtoseconds results in a shift from melting as well as thermal evaporation to phase explosion. Decreased pulse length leads to a more effective ablation, causing immediate vaporization and a smaller heat-affected area [38]. Laser pulses are a crucial factor that significantly affects the amount of material removed by ablation. Tsuji et al. [15] examined the impact of laser pulsewidth on NPs' production using pulses of different durations: microsecond, nanosecond, picosecond, and femtosecond. They found that the diameter of the holes reached their maximum size when using microsecond pulses with 1000 pulses and nanosecond pulses with 250 pulses. On the other hand, the smallest hole size was observed with picosecond pulses (500 thousand pulses) and femtosecond pulses (5000 pulses). Therefore, it can be concluded that increasing the pulse duration leads to increasing the size of nanomaterials [21].

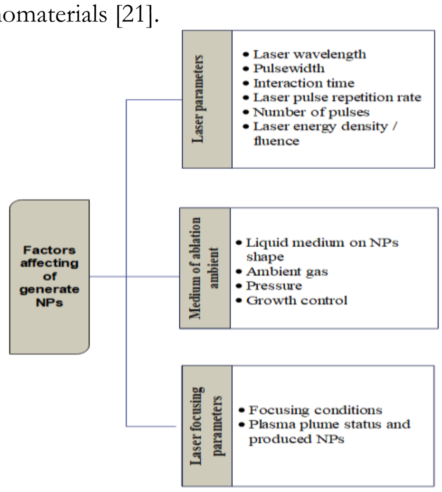

Figure (4): Factors and processing parameters affecting the synthesis process of nanoparticles using the laser ablation technique [38].

5. MoS_2 Nanomaterial

Molybdenum disulphide (MoS_2) is an inorganic compound belonging to the class of transition metal dichalcogenides (TMDs), consisting of one molybdenum atom and two sulphur atoms [41]. Molybdenum disulfide (MoS_2) is of great interest due to its photochemical reactivity, mechanical stability, and tunable electrical characteristics. These materials have the potential for several applications, such as medicine [42], [43], biology[44], catalysis [45], [46], Hydrogen Evolution Reaction (HER) [47]and sensing [48] . Furthermore, these materials are very cost-effective and may be easily produced employing several technologies, including simple water-solution-based processes [49] and more intricate but adaptable plasma and discharge - based methods [50]. The MoS_2 nano-structures can exhibit either semiconducting or metallic properties based on the specific synthesis process used, such as exfoliation, laser ablation, CVD, etc. These nanostructures possess the ability to exhibit both p-type and n-type conductivity, enabling their use in a wide range of applications, such as biosensors, solar cells, improved batteries, nanoelectronics, and other related fields. Due to their elevated surface activity and distinctive characteristics, nano-structured MoS_2 materials show great potential for many biological uses, such as anti-cancer treatment and diagnostics.

The two main methods used in synthesizing TMD nano-structures are the bottom-up and top-down approaches [37],[51]. The top-down method relies on the process of selectively removing particles from a substrate that is overlaid with the crystals. Conversely, the second method involves arranging the Crystals stacked on the substrate. Exfoliation is a very efficient technique for generating MoS_2 nanomaterials [52]. Mechanical exfoliation entails the utilization of adhesive tape to remove and transfer MoS_2 flakes off a substrate. The approach yields a small quantity and is suitable for laboratory applications. Exfoliation may be achieved in the liquid phase by adding a chemical agent flowed by subsequent agitation, such as stirring, bubbling or grinding. This approach is characterized by its simplicity and affordability but is also associated with poor quality [53] [54]. Generally, top-down approaches are characterized by limited controllability, scalability, and high expense [37].

Physical Vapor Deposition (PVD) Ion implantation is a bottom-up method, like molecular beam epitaxy (MBE) [55]. This approach only applies to thin layers of Molybdenum disulfide, and the resultant Particle sizes exhibit variability [56]. Chemical Vapor Deposition (CVD) is used to deposition thick and thin layers. In this process, a layer of Mo is deposited onto a substrate and then exposed to Sulphur vapour. This approach exhibits high quality but has a very modest output. The Atomic Layer Deposition (ALD) technique produces thin and thick films. The process is deemed efficient, resulting in layers with reduced contaminants that may be used in many applications, such as sensors and electronics. MoS_2 layers may be synthesized using chemical solutions by hydrothermal and solvothermal processes. In hydrothermal reactions, both S and Mo react in an aqueous solution beyond its boiling point, while in solvothermal reactions, high temperatures cause them to react non-aqueously. This method allows for precise control over the dimension and structure of the layers, enabling the production of both powdered and thin film forms of MoS_2. It is regarded as cost-effective and easily expandable. Molybdenum disulphide (MoS_2) is produced by the chemical vapor deposition (CVD) method, where the Liquid organic precursor is used over an insulating substrate. The procedure is highly repeatable and yields greater surface areas of MoS_2 layers compared to techniques using powdered Molybdenum oxide and sulfur[57]. The approach of sonication and exfoliation methods involves incorporating quaternary ammonium molecules into 2D crystals. The approach yields MoS_2 nanosheets with a remarkable performance. Atomic Layer Deposition (ALD) and thermal evaporation are two different methods of depositing thin films onto a substrate where the conductivity and carrier density of MoS_2 varies in response to the thickness of the layer [58].

Molybdenum disulphide (MoS_2) optical, chemical, and electrical properties allowed this metal dichalcogenide to have various applications in various fields. Its electrical characteristics facilitated its integration into the fields of nanoelectronics and sensor applications, which subsequently extended to the medical area. These materials' unique electrical characteristics and biocompatibility provide opportunities for further medicinal and therapeutic uses. The expansion of its application range was facilitated by the photoluminescence and chemical characteristics [59]. Regarding medical treatment, specifically in the context of cancer, Employing MoS_2/GO nanocomposites for the treatment of lung cancer in mice and the identification of cancer, specifically the detection of breast cancer, by leveraging the photoluminescence property of Molybdenum disulphide (MoS_2). MiRNA21c, a cancer biomarker, undergoes a redshift of 16 nm [60]. For materials with antibacterial properties, the use of nanohole-enhanced MoS_2 to eradicate microorganisms has been shown [61] . Solar cells are devices used to convert sunlight into electricity. The efficiency of organometallic-halide perovskite solar cells may be improved by utilizing MoS_2 as a buffer [62]. In several applications, such as those using terahertz (THz) frequencies, wave reflectors and switchable consisted of layers of MoS_2, SiO_2, and gold, where the reflection phase varies between 0 and 2π, with a linear phase shift depending on the geometric dimension [63]. A nanocomposite of MoS_2-PVP (Polyvinyl pyridine) with ZnO is used to detect hydrogen, where the sensor of five mg/mL of nanocomposite concentration exhibits eight times more sensing capability than pure ZnO [64]. Figure 5 shows the techniques to generate MoS_2 nanoparticles and applications.

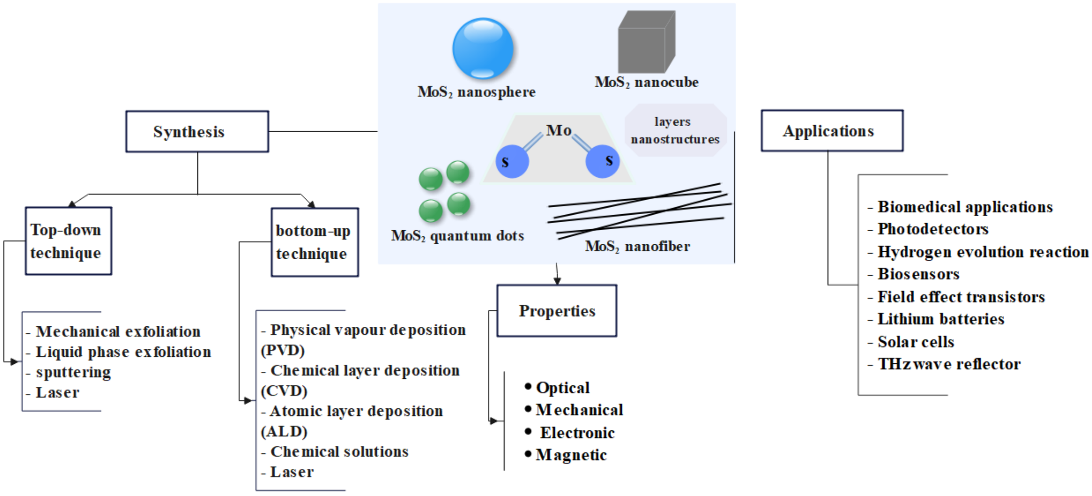

Figure (5): The techniques to generate MoS_2 nanoparticles and applications.

6. Review of laser-generated MoS_2 nanomaterials:

The following review will focus on the several methods of generating MoS_2 nanostructures:

Tugba Oztas et al. (2014) [65] synthesized different shapes and sizes (µm-nm) of MoS_2 structures using laser ablation of crystalline 2H-MoS_2 powder. The used laser was Nd:YLF of 527 nm wavelength, 100 ns pulse duration, 16 W average power and 15 minutes ablation time. They suggested that one step ablation is a promising method for generating 2D-3D layered materials spherical fullerene-like morphology MoS_2 structures.

Shu-Tao Song et al. (2015) [66] synthesized MoS_2-Fl NPs with an average size of around 20 nanometers from Mo target in DMTs reactive and argon gas by a 1064 nm Nd: YAG ablation Laser with (25 and 45 J/pulse, 1 Hz prr, 20 ms pulse duration, time 15 min). They recommended that the generated NPs could be effectively used as heat-resistant photoelectrical and photodetector switches.

Heng Deng et al. (2016) [67] used a direct laser writing technique to synthesize and pattern the MoS_2/carbon hybrids with size 20-40 nm nanoparticles for HER electrocatalysts. Firstly, they prepared MoS_2/carbon hybrids from chemical reactions then they patterned the surface of MoS_2/carbon hybrids using a CO_2 laser. They reported that the DLW method to produce the MoS_2/carbon hybrids was better than the conventional hydrothermal method and could be used for fabricating micro-catalytic reactors and micro fuel cells.

Le zhou et al. (2017) [68] fabricated spherical MoS_2 NPs with 10-100nm in diameter by laser ablation of (1064nm in wavelength, 5Hz in frequency, 10nm in

Duration of a pulse, 50 mJ laser power, and 1 hour in exposure time) in water. They concluded that the surface of MoS_2 NPs showed onion-like structures that exhibited a much higher Surface-Enhanced Raman Scattering (SERS) effect than the MoS_2 nano-plates produced using a traditional technique.

Bo Li et al. (2017) [69] synthesized high-purity, small-sized, and uniform (ranging from 1 to 5 nm) monolayer MoS_2 Quantum Dots (QDs) using femtosecond (fs) laser ablation process of MoS_2 bulk target in water with (single or multipulse of 0.77J/cm^2). They reported that nanosheet MoS_2 exhibited a significant enhancement in their catalytic activity for the Hydrogen Evolution Reaction (HER).

Makoto Kanazawa et al. (2019) [70] synthesized MoS_2 nanoparticles using Neodymium-doped yttrium aluminum garnet (Nd:YAG) laser (532 nm wavelength, repetition frequency 10 Hz, ten ns fwhm/pulse, 55 mJ pulse^{-1}) for 120 minutes on samples immersed in various solvents (ethanol, methanol, and NMP of 40 ml) and they studied the effect of solvents on the NP characteristics. The researchers discovered that the shape and dimensions of the MoS_2 NPs were influenced by the kind of solvent used in the laser ablation process.

Brian Ko et al. (2020) [71] synthesized MoS_2 nanosheets with an average size of (300 to 400 nm) and a specific thickness of multilayer (~10nm) using the exfoliation/lithium–intercalation method with used fs laser (800 nm wavelength, 100 fs, and 30 nm FWHM). They reported that This process could be an alternative to coinage metals like gold and silver.

Changj Pan et al. (2020) [72] used ultrashort laser to irradiation micro size MoS_2 and analyzed the effect of pulse duration (1-100 ps) and laser fluence (0.4,0.15 J / cm^2) on transient reflectivity of MoS_2 material both experimentally and theoretically, and they achieved two kinds of structure for MoS_2. They simulated the electron, lattice and reflectivity of laser interaction of MoS_2 depending on the used laser fluence. Two kinds of laser ablation were detected. They reported that their result could be useful for understanding the mechanism of ultrafast laser interaction with material.

Mitra Mahdavi et al. (2020) [73] MoS_2 nanosheets have been successfully generated with a high level of uniformity, purity, and a few layers with nanometer lateral dimension and wide band gap 4.7ev by using the hydrothermal method, followed by the reduction method using Nd: YAG pulsed laser irradiation (7mm beam diameter, 5ns pulse duration and 15 min) with various energies between 40 and 80 mJ. The result displayed that the widest band gap (4.7ev) was for the sample irradiated under 80 mJ energy of the laser.

Fan Ye et al. (2021) [74] used fs laser irradiation (800nm, 35fs, and 1 kHz) to prepare MoS_2 nanosheets with an average size of 30 nm by suspending MoS_2 powder in an ethanol/water mixture and investigated the impact of ultrafine Laser radiation time and ethanol in water concentration on oxidation of prepared nanomaterial and compared their results with conventional hydrothermal process. They found that fs laser could break the chemical bonds of MoS_2 efficiently. They conculcated that 80 and 90% ethanol concentration was the optimum one for synthesized plasmonic MoO3-x at 30 min radiation time, which could be used for photothermal cancer therapy.

Anton S. Chernikov et al. (2023) [75] Synthesized molybdenum disulfide (MoS_2) NPs via a femtosecond Yb:KGW laser ablation process in a liquid (Deionized water and ethanol) with (1030 nm wavelength, 150 mJ energy, 280 fs pulse duration, and 10 kHz PRR. and through laser fragmentation, which causes a transformation of MoS_2 into its oxide MoO3x, the obtained NPs can be used in medical diagnostics as nano catalysts for chemical reactions.

Samira Moniri et al. (2021)[76] prepared MoS_2 NPs by (ns laser ablation process in ethylene glycol) using a Nd: YAG Laser (Q-switched) at various wavelengths (1064 and 532 nm). They reported that the MoS_2 NPs synthesized at 1064 nm showed a 3.95-fold increase in absorption peak intensity compared to those prepared at a wavelength of 532 nm. When the laser wavelength was increased, the mean particle size dropped 22 - 13 nm because of a photo fragmentation phenomenon.

ZUO Pei et al. (2023) [77] Produced MoS_2 core-shell nanoparticles using femtosecond laser pulses which had the following specifications: a laser pulse energy of 250 μJ, a scanning speed of 400 μm/s, a scan spacing of 20 μm, and a scan duration of one hour. The MoS_2 bulk target was exposed to varying amounts of sodium chloride solution by irradiation. The mean diameter of MoS_2 nanoparticles was 28 nm. The MoS_2 core-shell nanoparticles were used as a reducing agent and Surface-Enhanced Raman Scattering (SERS) substrates for biological sensing and chemical applications.

Tingwei Xu et al (2024) [78] prepared MoS_2 nanostructured via ultraviolet krypton fluoride (KrF) excimer pulse of 7 Hz frequency, 31–33 mJ energy per pulse with the laser spot size of 4 mm × 10 mm, and total pulse numbers were 2000–2500 pulses. was demonstrated a photodetector by integrating PbS CQDs with laser-assisted synthesized MoS_2. The photodetector exhibited a competitive photo-response performance across various wavelengths (365–1550 nm).

Table 1 Listed all previous work related to laser generation MoS_2 NP and the Figure 6 shows the laser systems used for the synthesis of MoS_2 nanomaterial over the past ten years.

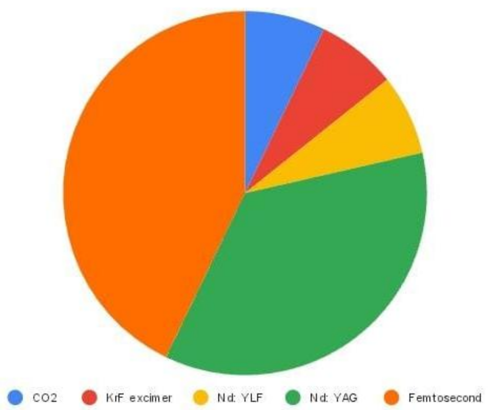

Figure (6): The laser systems used for the synthesis of MoS_2 nanomaterials over the past ten years.

As we mentioned above, the generation of MoS_2 nanoparticles by laser ablation has emerged as a cornerstone in nanomaterial synthesis. It is renowned for the remarkable properties of the nanoparticles it produces. We noticed the fs laser ablation in water was synthesizes nanoparticles with a small size of about (1-5nm).

Table (1): Review of Laser generated MoS_2 nanomaterials

Author	Year	Laser	Process	Size of NP	Application	Ref.
Tugba Oztas	2014	Nd:YLF ablation laser	laser ablation of crystalline 2H-MoS_2 powder	μm-nm	-	[65]
Shu-Tao	2015	Nd: YAG ablation laser	from Mo target in DMTs reactive and argon gas	20 nm	used as heat-resistant photoelectrical and photodetector switches	[79]
Heng Deng	2016	CO_2 laser	used a direct laser writing method	20-40 nm	fabricating micro catalytic reactors and micro fuel cells	[67]
Le zhou	2017	Nd: YAG ablation laser	by laser ablation	10-100nm in diameter	enhanced Raman scattering (SERS) effect	[68]
Bo Li	2017	fs laser	laser ablation process of MoS_2 bulk target in the water	1-5 nm	enhancement in their catalytic activity for the HER.	[69]
Makoto Kanazawa	2019	Nd: YAG laser	Laser ablation in different solvents	-	-	[70]
Brian Ko	2020	Fs laser	using the lithium–intercalation/ exfoliation method	300-400nm	used as an alternative to coinage metals for use with sensitive samples	[71]
Changj pan	2020	Ultrashort laser	irradiation micro size MoS_2	-	-	[72]
Mitra Mahdavi	2020	Nd: YAG pulsed laser	hydrothermal method, followed using laser irradiation	-	-	[73]
Fan Ye	2021	Fs laser	suspending MoS_2 powder in ethanol/water mixture	30 nm	photothermal cancer therapy	[74]
Anton S. Chernikov	2023	Yb:KGW Fs laser	laser ablation process	range from 30 to 340 nm	medical diagnostics as nanocatalysts for chemical reactions	[80]
Samira Moniri	2023	Q-switched Nd: YAG laser	nanosecond laser ablation process in ethylene glycol	13-22 nm	increase in absorption peak intensity	[76]
Zuo Pei	2023	Fs laser pulse Ti: sapphire laser system	irradiated MoS_2 bulk target in different concentrations of sodium chloride solution	28 nm	used as SERS substrates for biological and chemical sensing	[77]
Tingwei Xu	2024	krypton fluoride (KrF) excimer pulse laser	ultraviolet laser-assisted synthesis technology	5 nm	photodetector	[78]

7. Conclusions

In conclusion, this review paper highlights the importance of MoS_2 nanomaterials and its synthesis methods and applications. This review focused on reviewing the importance of nanomaterials and generation methods by focusing on the laser generation of nanomaterials technique and mechanism of ablation. the technique's versatility allows the fabrication of nanoparticles with diverse compositions and applications. By elucidating the underlying principles and key factors influencing the synthesis process, this work contributes to the advancement of nanomaterial synthesis and facilitates the development of innovative applications. Future research efforts should focus on further optimizing laser parameters, exploring novel precursor materials, and elucidating the mechanisms governing laser-induced MoS_2 synthesis to unlock new opportunities for tailored nanomaterial design and engineering. Based on the review the most used lasers for MoS_2 Nano materials generation are the fs and Nd:YAG.

8. References

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