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Overview on MoS_2 Nanomaterials with Synthesis and Applications

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Abstract

Molybdenum disulfide (MoS_2) is the one which belong to the transition metal dichalcogenide system with analogue structure and was attracted to the world because of its use in a series of applications such as energy conversion, energy storage, environmental restoration and building strong sensors. The functional properties of MoS_2 and graphene include high load transport, strong wear resistance, high mechanical strength and better friction. However, in comparison with graphene, MoS_2's low cost, abundance, adjustable morphology and a tunable band gap are of advantage. In this analysis we concentrated mainly on recent changes to nanostructured MoS_2 materials for the specific energy and its applications. Special emphasis has been placed on their applications in colour sensitized solar cells, super-capacitors, Li-ion cell battery, production of hydrogen with several reactions, photocatalysis of organic degradation, chemical / biological sensors, and gas sensors. Also, energy and environmental applications are important for the development of nanostructured MoS_2.

Keywords: Molybdenum Disulfide (MoS_2), dichalcogenide, Li-ion battery, super capacitors, solar cells, band gap.

1. Introduction

Molybdenum disulfide (MoS_2) is one of the class having layers of transition metal chalcogenide Because of its properties similar to graphene, the researchers have been made considerable attention to several applications including dye sensitized solar cells (DSSCs), supercapacitor fabrication, highly efficient Li-ion battery, hydrogen production, organic pollutant photocatalysis, sensors etc. MoS_2 exhibits physical characteristics identical to the graphene, including high charge transportation, high resistance to wear, etc. [3,4]. MoS_2 nanosheets stand out as a promising alternative 2D material with many excellent physicochemical, biological, and mechanical properties that differ significantly from those of graphene-based nanomaterials, potentially leading to new environmental phenomena and novel applications [77,78]. The latest advances in the use of MoS_2 nanosheets for important water-related environmental applications such as contaminant adsorption, photocatalysis, membrane-based separation, sensing, and disinfection [79,80]. The unique structure and properties of MoS_2 nanosheets enabling exceptional environmental capabilities are compared with those of graphene-based nanomaterials. Yet MoS_2 has higher graphene characteristics, such as cheaper, more abundant and tunable border divide with strong visible light absorption ability [5,6].

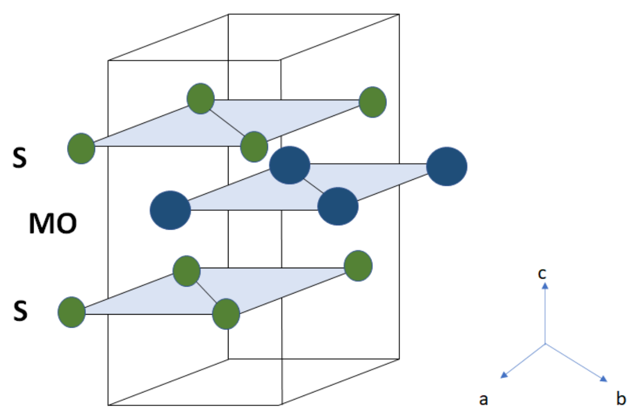

Fig.1. Schematic Structure of MoS_2

Fig.1 shows the structure of MoS_2. The layers for Mo atoms are sandwiched in between two layers of S so called the MoS_2 crystal structures, which are closely packaged and which form a layered structure in the shape of S-Mo-S [7]. The interaction of Mo and the interactions between layers of S is Vander Waals force [10,11], which results from a strong covalent bonding feature. The structure allows for the placing of other ions or molecules within S-Mo-S layers. MoS_2's broad uses rely on its superior physical and chemical properties, which can be adapted to different morphologies, particle sizes, and hetero-structures [8].

However, from many reviews of MoS_2, Zhang et al.,[9] recently addressed synthetic MoS_2-preparation strategies and their electrochemical application efficiency with different nano structuring. Several studies have published in recent years on MoS_2 nanostructures for environmental remediation applications. The current literature incorporates the planning and pertinence of these studies. This study focuses on advances in energy and environmental materials MoS_2nanostructured [13]. Especially important have been their use in desensitized solar cells, supercapacitors, Li-ion batteries, hydrosphere growth, MoS_2 chemical nanostructures/biological sensors and gas sensors. Finally, the energy and environmental benefits of MoS_2 nanostructures are also explored [14]. The review was structured on the basis of applications that discussed different synthetic methods to emphasize the advantages of such syntheticmethods.

2. Literature Overview

Viet Hung Pham et al [15] (2013) have reported a successive method to synthesis composites of MoS_2 and graphene. These composites are fabricated through the MoS_2 liquid phase exfoliation along with nanoplatelet. Converted graphene by chemically in (NMP) N methyl pyrrolidone used in exfoliation done through the help of ultrasonication. The characterization techniques (SEM, XRD & BET) show that the composites from MoS_2- graphene are mesoporous materials. The obtained MoS_2-graphene compositenanosheets which are having a better performance in lithium-ion batteries can be used as anode. This shows good reversible capacity and cycling stability. Richard C.T. Howe et al [16] (2014) synthesized dispersions of Molybdenum Disulphide (MoS_2) nanoflakes in aqueous surfactant solutions. This is done by the liquid phase exfoliation method.

The stabilization and exfoliation of MoS_2 is done by the chemical structures of bile salt surfactants. They have obtained optical absorption from the films, even at wavelengths below the MoS_2band gap. Average flake volume and the exfoliated MoS_2 surface area in a unit volume of dispersion were also calculated. The mechanic of solvent-assisted exfoliations was synthesized by Ali Jawaid et al., [17] (2015). The exfoliation results achieved are best connected to the development in sonolytic circumstances of highly reactive hydroperoxides at NMP. SEM from bulk flakes reveals ultrathin micro sized crystals, TEM showssub-200 nm particles from micron size crystals from MoS_2 powder. HRTEM confirms the presence of single crystalline mono layer MoS_2.Lilitao et al [18] (2014), they have synthesized few-layer MoS_2 nanosheet and their good nonlinear optical response in the poly (methyl methacrylate) (PMMA) matrix. The MoS_2 samples were prepared by exfoliation assisted by sonication method. They have found that the sample has an interesting dependence on layer number because of the interlayer separation. This is due to the weak wander walls force and the interlayer repulsive force. Leila Taran et al., [19] (2017) have used a new method for the exfoliation of MoS_2. They have used a better approach which is based on the thermal shock and refreezing for enhance the exfoliation. By icing MoS_2 powder with ethanol, sample was exfoliated and functionalized. They have obtained exfoliated MoS_2 sheets with less than 2nm. The peaks were obtained from the exfoliated sample by UV-vis and PL spectrums.

The optical band gap of the bulk molybdenum disulphide sample increases (about 1.4 to 1.8) with the increase in thermal shock. The contact angle of the sample decreases when it is treated with high temperature (from 200-400^{o}C). The contact angle of the exfoliated sample decreases and it becomes super hydrophilic. S. Patil et al., [20] have synthesized molybdenum disulphide nanosheets by hydrothermal technique(one-pot) applied by a cationic surfactant and (CTAB) cetyl trimethyl ammonium bromide. The surface modified molybdenum disulphide sample is dispersed in epoxy matrix. The loading level of this matrix is 0.1-0.5 wt%. it is used to investigate the thermal and chemical properties of the sample. It is also used for the reinforcing competence of the sample too. The morphology and microstructure of the sample is understood by the characterisations (XRD and FE-SEM).

To recognize the effect of the molybdenum disulphide sample prepared by the hydrothermal method, the tensile and dynamical properties of the samples were studied. Thermal stability of the sample is studied and by analysing the samples they have realized that the sample is showing a reduction in onset temperature. A. V. Barna et al., [20] (2014) studied about the effect of solvent which is used for increasing the efficiency of liquid phase exfoliation of molybdenum disulphide MoS_2. The concentrations of the reagent and the solvent nature have an effect on efficiency of the sample which is synthesized from the ultrasonic liquid exfoliation. They have realized that the structure is somewhat playing a role affecting the nanoparticles of the semiconductor. Molybdenum disulphide/ gold nanocomposites can synthesize by the reaction of molybdenum disulphide with hydrogen tetrachloroaurate in aqueous ethanol solutions. From the obtained composites, their morphology is a function of preparative conditions. This is due to oxidation reduction reaction. Hechun Lin et al., [21] have reported an exfoliation method, which is efficient and quick to synthesize high yield MoS_2, WS_2 nanosheets. The synergy effect of surface etching was taken place. This is caused due to the rapid exfoliation process. Better quality of MoS_2, WS_2 nanosheets was produced with the controlled concentrations of nitrosyl chloride and chlorine in the solution. This process has enhanced for the large-scale preparation of MoS_2, WS_2 nanosheets. These nanosheets can be used for the purpose of energy conversion and anticorrosion.

These reviews provide an overview of research process and related studies by including substantiate findings in both theoretical and methodological contributions to the exfoliation of molybdenum disulphide. Literature review is necessary to write a research paper. This survey evaluates, encapsulates and compares different scholarly books and other related sources that are openly related with this present research.

3. Applications

Fig.2. Applications of MoS_2

3.1.(DSSCs) Dye-sensitized solar cells

Dye-sensitized solar cells (DSSCs) are revolutionary energy systems that convert solar power into electricity, providing a wide variety of solutions for future-oriented energy issues. DSSC are the largest 3rd generation solar panels, providing a better alternative to regular p-n crossover silicon solar cells in various ways, such as easy production, low-cost production, high durability, strong plasticity, environment-friendly, and so on [22]. The excellent work of O'Regan and Graetzel detailed in 1991[23] was a turning point in DSSC research that generated significant interest in the international research community. Factors such as efficiency, service life and cost must depend on its commercial applications given fairly good results. Figure 3 shows the working of a DSSC.

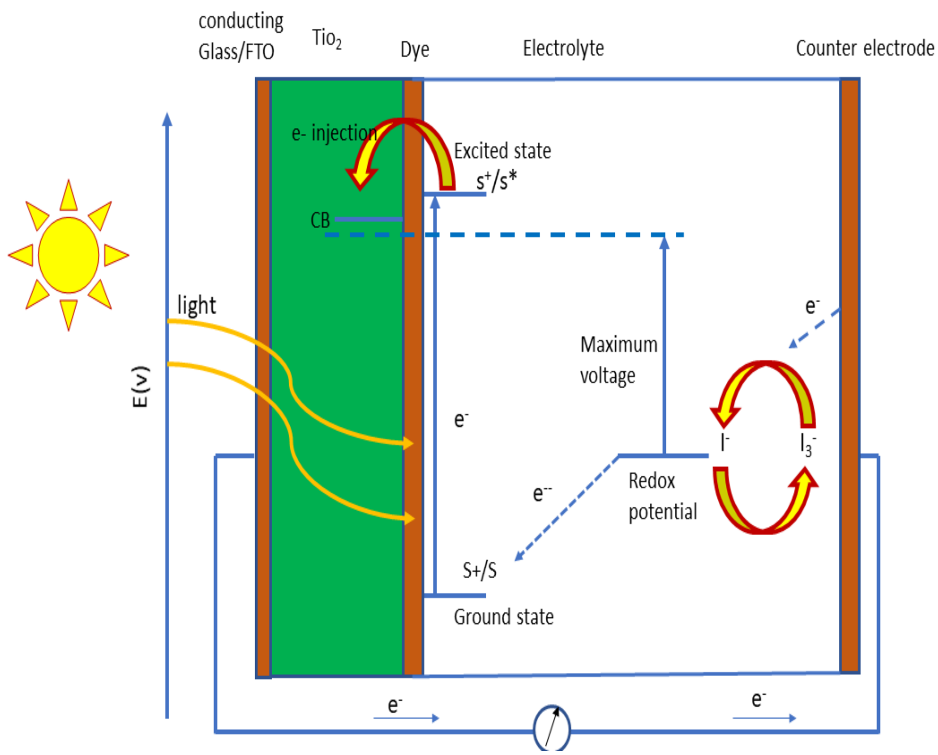

Fig.3. Working of DSSC

A TiO_2, I-/I_3redox and a counter electrode (CE) are the normal DSSCs. Extensive studies have recently been performed in order to reduce production costs and achieve high cell efficiency on individual DSSC components. CE is one of the main components in DSSCs to catalyze the redox electrolyte with triyoid (I_3−) to iodide (I−) therapy, which helps the cell to complete the circuit [24, 25]. The most common use of CE for DSSCs is platinum (Pt), which is the noble metal for its impressive electrocatalytic decreases for I3. In I−/I_3− electrolyte Pt, however, there is very high, low abundance of noble metal and PtI4 and H2PtI6 produce that greatly restrict DSSC's marketing [26-29].

This problem has motivated many researchers to develop new, low-cost, high-electrocatalytic CE reduction materials for I_3. In commercial applications CE material should be cheap and have good electrical conductivity, high chemical stability and high electrical activity. In the case of DSSCs, a number of usable materials were currently used to replace Pt, including carbon [30,31], conduct polymers [32,33], metal oxides [34], sulfides [35-37], selenide [38,39], metal carbides

[40] and nitrides [41]. MoS_2 is one of the most fascinating products, with its high volume, high conductivity, fast manufacturing and high electrocatalytic activity. Kim et al. [42] investigated the effect on electrocatalytic behavior and efficiency of DSSC power conversion of the MoS_2 nanosheet CEs. Installed with thermally treated 100°C MoS_2, DSSC showed a comparable efficiency of conversion of 7.35% to traditional Pt C E (7.53%) while the MoS_2 displayed a substantial reduction in energy conversion output due to its chemical transformation into poorly treated electro-catalytic MoO_3. Patil et al [43] have produced MoS_2 with the low-temperature under the wet-chemical cycle, thus developed DSSC using a better MoS_2 CE with a competitive 7.01 per cent (7.31 per cent) power conversion to Pt.

3.2. Li-ion batteries

Energy in the 21st century is a big issue, with rising demand energy in our daily lives. Conventional fuel prices have also become increasingly global over the last decade, along with growing emissions of carbon, energy and storage [44,45].

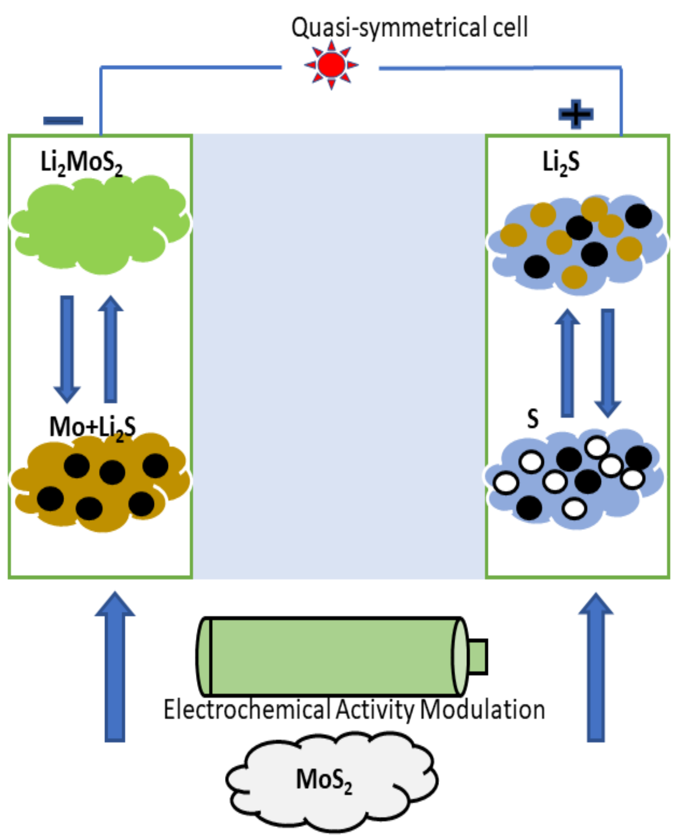

Fig.4. Working of Li-ion batteries

Electrical and rechargeable storage systems (lithium, sodium, magnesium) and fuel cells and supercapacitors are more common and more necessary than ever. The LIBs have been the most common energy storage devices since the first commercialization of LIBs in 1990 by Sony Corporation [46]. Such LIBs have undergone rapid growth and enormous potential in the past two decades in different applications such as mobile phones, notebook computers, hybrid / pure electric vehicles, smart grids, etc. [47]. Nevertheless, short lifespan, poor reliability and operational issues related to material selection continued to lead to sluggish marketing of LIBs for emerging technologies. LIBs will need adequate materials that enhance safety, durability and efficiency to develop commercially viable, promising energy technologies [48]. The working of Li-ion batteries is shown in Figure 4.

Transition metal sulphides are one of the promising materials such as anode and cathode for LIBs because of their high ability [49] among different materials. Many of these sulphide compounds, however cannot reversibly process lithium in higher runs. It will suffer from limit occurrence, which is a significant issue in cycling polysulfide development. After the discovery of transition metal sulfides, scientists have focused on the substitution of sulfur with oxygen by a related group of materials [50].

Metal oxides can be used as potential electrode materials for lithium-ion batteries, but in contrast with metal sulphides they have an unnecessary positive potential. MoS_2-based materials are commonly used in LIBs as anodes and cathodes because of their high capacitance, amongst the metal sulfides[51]. Some of these studies include research on anodic materials based on MoS_2, which is also an emergent and promising field for cathode materials. MoS_2's efficiency was 3.5 times that of the commercial anodes used. The MoS_2-based nanostructured anodes were also extremely firm during cycling [52]. The applications of LIB based electrode materials based on MoS_2 have been outlined here.

3.3.Supercapacitor Application

Electrochemical condensers (SUCs) are used for the high-speed storage devices that store electricity through double layer electrical formation with speedy surface redox reactions [53-56]. The advantages of supercapacitors are high energy densities, quick charges and discharge, high power densities, long life cycles and relatively small costs compared to normal condensers. The two-layered electrical condensers charging mechanisms (EDLCs) and (ii) pseudo capacitors can be divided into two classes. Examples include carbon-based materials for types of EDLC electrodes, such as activated carbon, CNTs and graphene [57]. Pseudocapaciting active materials are metal oxides and conductive polymers [58–61]. Because of rapid and reversible load transferring reactions, the pseudo capacitive material is stronger than the EDLC electrodes [62]. Thanks to their high surface area and strong in-plane conductivity [63, 64], metal sulfides are considered to be electrochemically active materials for supercapacitor applications. VS2 nanosheets for example were used in supercapacitor electrodes. Even after 1000 load / deletion cycles, they show a significant specific electrical capacity of 4,76 mF cm−2 with excellent cycling activity. The CoS_2 ellipsoid-based electrodes show 1040 F g−1 at 0.5 A g-001[66] high capacity. Similarly, Yang et al. [67] showed remarkable hierarchical electrochemical efficiency, like the NiS. The material was highly capable of 857,76 F g−1 at 0,5 A g−1 due to its large surface area.

3.4. Solar water splitting

One of the most promising options for meeting increased energy demands is the photocatalytic hydrogen from water with sunlight. Because of its poor quantum performance, photocatalysis makes it extremely difficult to produce hydrogen. The abundance of available solar energy has given considerable attention to photocatalysts with semi-conductors are included in the hydrogenproduction [68].

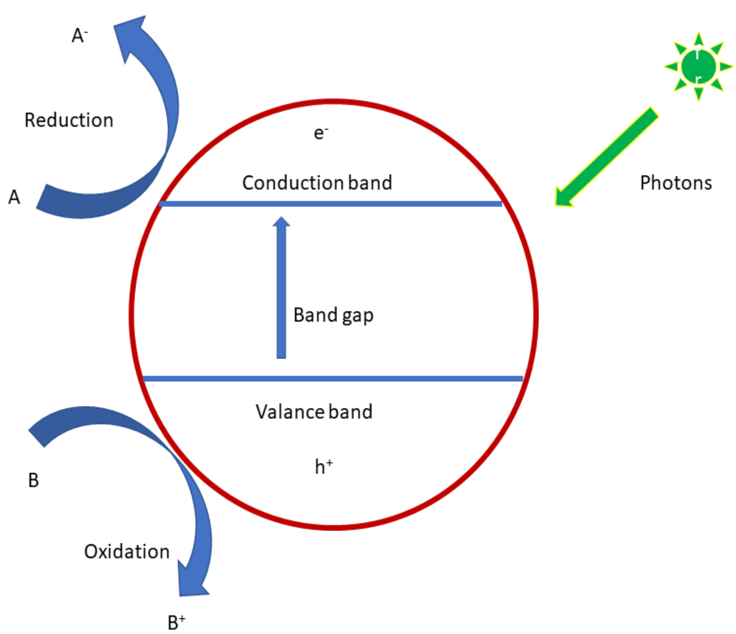

Fig.5. Water splitting

A photocatalyst has to be photostable, economical, and able to produce more solar energy. The main problem of the photocatalyst is the rejoining of pairs of electron-hole pairs made using photographic data [69]. Many active photocatalysts were therefore developed and used in the production of Photocatalytic solar energy H_2 including phosphide, metal oxides, carbon nitrides and sulfides etc. Of these, MoS2 is a common and significant photocatalyst for its specific characteristics, and S-Mo-S crystal grid coordination produces in saturated Mo and S atoms at the end, which results in MoS_2's unique 'edge operation.' As a new photocatalyst with efficient H_2 output by water separation, MoS_2 recently demonstrated great promise. Kadam and others [70] use a solvothermal route that is free of templates and use it as photocatalyst for creating the 2D H_2 synthesized honeycomb as MoS_2 and $CdMoS_4$ Hierarchical 3D marigold nanoflowers. Figure 5 shows water splitting.Photocatalytic H_2 reveals CdS, MoS_2 and $CdMoS_4$, where $CdMoS_4$ and MoS_2 impart H_2 rates of evolution of 25445 and 12555 mole h−1 g−1 respectively. Nanostructures for H_2 development with $CdMoS_4$ and MoS_2 show high yields of 35.34 percent and 17.18 percent respectively. The photocatalytic activity with higher H_2 efficiency was due to the recombination of nanostructured 3D flowers such as $CdMoS_4$ and Honeycomb, such as 2D MoS_2 charger inhibitors. The Ternary $CdMoS_4$ showed enhanced photocatalytic activity H_2 as compared to the pristine CdS and MoS_2 because CdS and MoS_2 combined effect was strong.

3.5. Gas sensor

Environmental monitoring of hazardous gasses is essential and critical thing which could be further seen in the directives of development, agriculture and human health. It is necessary to have a better and choices of gas sensor for toxic gas determination. Half-conductor gas sensors have been highly attracted among several gas sensors by their comfort, efficiency and quick detection [71,72]. More recently, several researchers in the field of gas sensing have studied MoS_2 extensively. The molecules of gas could be rapidly adsorbed to the surface of MoS_2. However, the weak interaction allows for the free penetration of gas atoms and electrons into and transport of MoS_2. Better performance gas sensors like H_2, NH_3, NO and many types of chemical vapor are therefore produced [73,74]. Micro flocks and nanoparticles formed by 2D MoS_2 by Kim et al. [75], respectively, through mechanical and liquid exfoliation. The synthesized MoS_2micro flocks and nanoparticles were studied in their oxygen sensing behavior. The MoS_2 liquid nanoparticles exfoliated at several ends display a wide spectrum of oxygen concentrations

(1–100 percent) with fast and linear reactions due to energy-friendly reversible oxygen absorption.

4. Conclusion

A number of researchers received information on the basic system used for the synthesis, modification and application of layered, nanostructured MoS_2 material. We have also outlined several recent developments in the manufacture of nanostructured MOS_2 materials including DSSC, efficient supercapacitors, Li-ion batteries, photocatalytic degradation of organic pollutants, gas sensors, and chemical / biological sensors. Because of their superior physical and chemical properties, MoS_2 is widely used for nanostructured materials like the uses in high wear resistance, resistance, mechanical rubbing, huge, tunable band size, special area, better visible light absorption properties and better charging transmission efficiency. The latest advances in the use of MoS_2 nanosheets for important water-related environmental applications such as contaminant adsorption, photocatalysis, membrane-based separation, sensing, and disinfection. In many of the studies, the key challenges were to optimize MoS_2-based nanostructures in many applications for superior performance.The environmental implications of MoS_2 nanosheets are emphasized, and research needs for future environmental applications of MoS_2 nanosheets are identified.

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