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Review

Molybdenum Disulfide for Different Applications –A Review

Tahir Iqbal[a]*, Memoona Kousar[b], Aqsa Tehseen[c] and Almas Bashir[d]
Department of Physics, University of Gujrat, Hafiz Hayat Campus, Gujrat, 50700, Pakistan

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Abstract. MoS_2 is a layered evolution metal having similar structure to graphene. It has got universal consideration due to its different applications as sensors, energy storage devices, energy adaptation and environmental remediation. The properties of MoS_2 and graphene are almost comparable but MoS_2 has higher tendency than graphene because it has a low cost, tunable band gap and good visibility for light absorption properties. So, our main focus is to elaborate the up-to-date advances of MoS_2 with respect to applications of energy and environment at broad area, for example, applications in HER, Li-ion battery, dye sensitized soar cells and super capacitors. At last the submission of energy and environmental for challenges to design MoS_2 are painted. But MoS_2 also has some limitations as a good photo catalyst which are discussed in this review article. In this study, we systematically explore the recent researches on transition metal doped MoS_2 as photo catalyst for hydrogen evolution by splitting the water.

Keywords: hydrogen evolution reaction, super capacitor, photo catalysis, graphene, Li-ion battery, sensors, molybdenum disulfide, fossil fuels, dye-sensitized solar cells

Introduction

In universal economy, the quick progress of industrialization and human civilization has created severe problems (Ge *et al*., 2016; Xiong, 2016; Zhang *et al*., 2016; Wang *et al*., 2015; Zhu *et al*., 2012). Now a days, the most serious challenges of space are the safety of utilization of energy and environment. Many other materials like TiO_2 and Cd S are also used for these procedures but there is a need of other material for their replacement because these materials are costly and not earth abundant. The best option to replace these materials is MoS_2. The physical properties of MoS_2 are like graphene but MoS_2 it is superior to graphene due to low cost, tunable bandgap and its more abundance. MoS_2 is a unique combination of properties as structural, optical, chemical, thermal and mechanical properties that make it attractive for specific applications (Chhowalla *et al*., 2013; Zeng *et al*., 2011). Bulk MoS_2 with unintended band gap of 1.2 eV is semiconducting. MoS_2 belongs to the class of transition metal dichalcogenide (TMDs) (Butler *et al*., 2013; Novoselov *et al*., 2004).

It appears in the Earth's crust naturally as mineral. It is not different from other elements such as graphite or leads. By the ancient Greek, it was called molybdos means beadlike. Molaybdenum is snack between two sulfur layers. The representative of 2D materials is graphene that has zero energy gap which results in stimulating applications and stimulating properties. Usually, major energy sources such as oil, coal and usual gas are non renewable. Our 80% current sources of energy production are fossil fuels. But this source of energy is main cause of global warming and climate change (Kim *et al*., 2014; Snyder *et al*., 2013). Because of fossil fuel, the amount of CO_2 increased in environment. To solve the significant problems of atmosphere and energy, we must develop highly active catalytic materials. Four polytypic of MoS_2 are discovered after many year's research, *viz* 1T MoS_2, 1H MoS_2, 2H MoS_2 and 3R MoS_2 (Imanishi and Takehara, 1992). After the successful research in graphene, other single layer 2D materials such as Boron nitride (BN) and TMDs are also established great potential due to their unique electronic and structural properties. MoS_2 is also one of the most studied 2D materials which attracted much attention. MoS_2 is a closest competitor of graphene and used as its substitute, because of its reasonable energy gap, mechanical flexibility, absence of dangling bonds, chemical and thermal stability. We shall focus on MoS_2 advances nan ostructured materials in the field of environment and energy in this review. There are most useful technologies to overcome the

*Author for correspondence;
E-mail: almasbashir001@gmail.com

energy and environment related problems; such as Solar cell, Super capacitor, Li-ion-battery and hydrogen evolution reaction (Zhang *et al*., 2016).

Structure and preparation of MoS_2. In 1923, Pauling and Dickson introduced the positions of Mo and S in hexagonal structure of MoS_2 by using theory of space groups and photographs. They also investigated that Mo and S were stacked along c-axis in S-MO-S layered structure. In 1966, Frindt *et al*. determined that thin sheets of MoS_2 with thickness 1.2-1.5 nm will be obtained by micromechanical peeling technique. In 1986, by using lithium intercalation followed by exfoliation in water to obtain the MoS_2. In 1986, Yoshimura *et al*. using the Vander Waals epitaxial to obtained single layer MoS_2 (Koma and Yoshimura, 1986). In 1991, Frindt *et al*. investigated the structure of MoS_2 by using exfoliation of lithium intercalated MoS_2 powder. The MoS_2 belonged to class transition metal dichalcogenide (TMDs). The TMD was generally characterized by the formula: MX_2, where M was transition metal element from groups IV, V and VI of periodic table and X was chalcogen species S, Se and Te. The electronic characteristics could be metallic, semiconducting or superconducting TMDs of family material. MoS_2 had hexagonal layered crystal structure. Mo layer is sandwiched between two sulfur layers. The unique structure of MoS_2 has many promising properties, such as anisotropy antiproton corrosion and chemical stability.

Crystalline phases. After many years research, the researchers determined that there were four polytypes of MoS_2 which were 1H, 1T, 2H and 3R where T, H, R stands for tetragonal, hexagonal and rhombohedra respectively. Here numbers determined the S-Mo-S layers per unit cell as shown in Fig. 1. Among them 1H and 2H were most stable and 1T and 3R were metastable polytypes. The cohesive energy of 15.55eV per cell was found to optimize the 1H MoS_2. 1H MoS_2 had low confrontation to bending and strain is exposed ~10% without failure. 2H MoS_2 had trigonal prismatic coordination around the Mo atom with two layers per unit cell with lattice constants of a=3.16A° and c=12.29A° that belonged to the space group of P63/mmc. 2H MoS_2 had non-bonding d orbitals that were fully occupied and this led to semiconducting behaviour. The 2H-MoS_2 was most common polymorph phase which could be transformed from semiconductor into the metallic 1T phase by using phase engineering. 3R MoS_2 was similar to 2H MoS_2 but it had three layers per unit

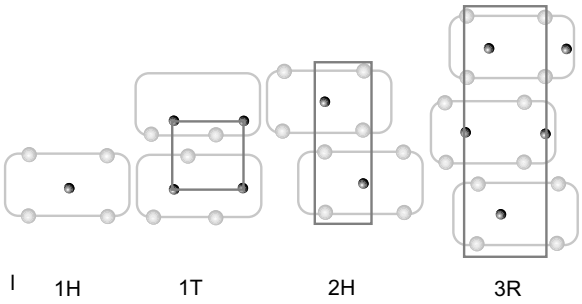

Fig. 1. Systematic diagram of common polytypes of MoS_2 (Benavente *et al*., 2002).

cell with lattice constants of a=3.17A° and c=18.38A° that belong to the space group R3m (Goloveshkin *et al*., 2013). To form a unit cell, molybdenum atoms octahedrally coordinated by the sulfur and molybdenum atoms in 1T MoS_2. In 1T MoS_2 the non-bonding d orbitals were partially occupied and this contribute to metallic conductivity.

Applications of MoS_2. For the financial improvement of state and ecological dominance, energy is significant input. Fossil fuel provides over 80% current energy tradition. However, amount of CO_2 liberates from flaming of fossil fuels which is a main cause of climate change and global warming. Therefore, it is essential to introduce extremely active catalyst to resolve serious problems associated to energy and environment. By using these applications of MoS_2 as renewable energy sources, energy can be produced and stored without effecting the environment as the other sources of energy, solar system is a best option to produce energy but it has also its side effects. (Santhosh and Madhavan, 2019) The two-dimensional graphene like MoS_2 had almost same functional properties such as high transportation of charge carrier, good mechanical friction, excellent electronic and optical properties. All these extraordinary properties of MoS_2 are valuable in different applications including energy conversion and storage, lubricants, catalysts, environment remediation, water degradation to remove heavy metal and purify drinking water under visible light. MoS_2 had low cost, tunable bandgap and good visible light assimilation capacity and these properties are better than graphene. If energy is produced by using solar system, there will be rise in the amount of CO_2 which cause environment pollution. So, it is an urgent necessity of materials or sources which can replace the previous sources. MoS_2 provided that to be a adaptable material for an extensive variety of

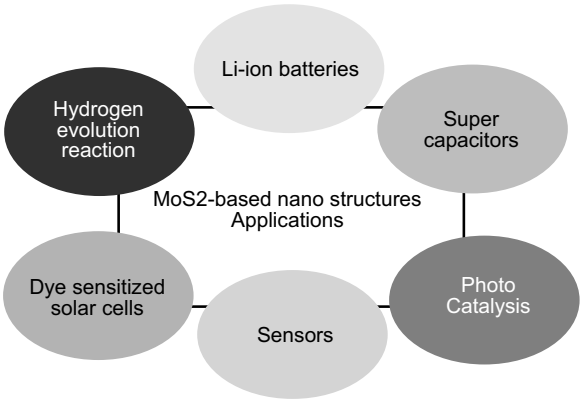

Fig. 2. Applications of MoS_2-based nano structures.

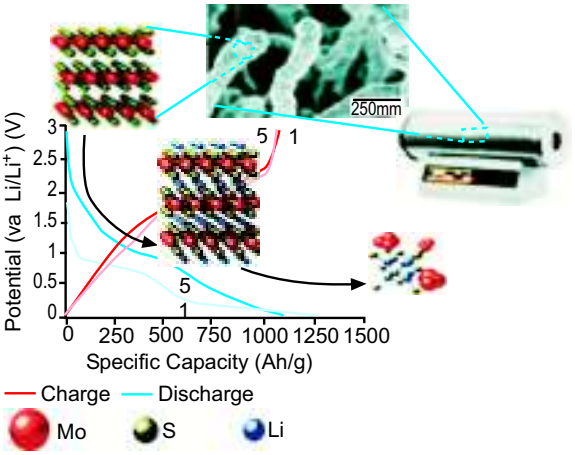

Fig. 3. Lithiated 1T–MoS_2 showing lithium ions occupying octahedral interstices (Stephenson *et al*., 2014).

applications such as lithium ion batteries, dye synthesized solar cell, super capacitor and hydrogen evolution reaction (Arshad *et al*., 2019; Lou *et al*., 2008) as shown in Fig. 2.

Lithium ion batteries (LIB's). One of the most important concern in our daily life is energy due to its increasing demand in 21st century, since in 1990 by Sony corporation the first commercialization of LIBs (Long *et al*., 2016). Li-ion batteries (LIBs) have become the mostly effective energy storage devices, among all rechargeable batteries. From last two eras, there is sudden enlargement and immense potential in many applications, but the commercialization of LIB's is immobile slow for modern technologies due to their short life period and poor dependability. These things are associated to partiality of the materials (Long *et al*., 2016). LIB's will need appropriate material for commercialization. In this way, its protection and lifetime can be recovered. Many transition materials are accomplished for behaving as LIB anode materials, transition materials are following: Co_3O_4 (Lou *et al*., 2008) TiO_2, NiO_2 (Zhu *et al*., 2012) and Mn_3O_4. But MoO_2 is special candidate with theoretical precise capability of 838 mAh/g as LIB anode material. Recently, many information is published on LIB anode materials that are MoS_2 based. MoS_2 based materials are as anode and cathode in LIB's because of their high capacitance (Qu *et al*., 2017; Yu *et al*., 2014; Zhang *et al*., 2014; Shi *et al*., 2013). CLET MoS_2 showed very good result with much better cyclic solidity than commercial MoS_2 as shown in Fig 3. Ding *et al*. introduced a simple and wellorganized technique to organize more efficient MoS_2 materials. They arranged accurate MoS_2 superstructure made up of nanosheets of MoS_2. Good electrochemical presentation than the commercial MoS_2 is achieved when as an anode material CLET MoS_2 was functional in LIB's (Ding *et al*., 2016).

Super capacitors. Super capacitors are energy storage devices which are used to store electrical energy by fast surface redox reactions (Wang and Zhang, 2012; Zhang, and Zhang, 2012; Pandolfo and Hollenkamp, 2006; Kötz and Carlen, 2000). They have relative low cost and high-power density. They are of two types.

(i) Pseudo capacitors
(ii) Electrical double layer capacitors (EDLCs) Examples of EDLCs type of electrode is CNTs and graphene(Zhang and Zhao, 2009). Capacitance of pseudo capacitive materials is high than EDLCs type of electrodes because of reversible and fast transfer reactions. Very first work on MoS_2 films for super capacitors as an electrode material was reported by Loh and Soon.

In MoS_2 slight films charge storage can occur potentially in three modes principally as:
(i) Inner sheet double layer charge storage on individual atomic layer of MoS_2 by diffusion.
(ii) Charge storage inner sheet double layer.
(iii) On Mo transition metal centre faradaic charge transfer process (Soon and Loh, 2007).

Composites of MoS_2 conducting polymer has shown enhanced performance of good cycling stability and high capacitance as reported by many researchers. In the field of super capacitors 2D-layered materials, MoS_2

was consider important due to its corresponding structure of graphite. By chemical vapour authentication super capacitor performances of MoS_2 films set and parallel to carbon nanotube arrays. Super capacitors have high energy compactness as compare to traditional capacitors, fast charge and discharge, high power density long cycle life and low cost. (Ratha and Rout, 2013; Soon and Loh, 2007) The MoS_2 material was reported for fabrication of dye-sensitized solar cell. The MoS_2 preparation with metal, non-metal and rare earth elements make a positive influence on the performance of DSSCs. For example, when dye-sensitized solar cell was assembling with MoS_2 TiO_2 nanoparticles, the efficiency of solar cell was enhanced as compare to pure material. Broad applications including other electrochemical devices and beyond might be covered by the excellent performance of the hierarchical MoS_2 super structure. Due to conductivity merge with intercalation of ion pseudo capacitance 1T-MoS_2 phase can proceed as vastly competent super capacitor electrode objects.

Dye sensitized solar cells (DSSCs). One of the hopeful renewable energy devices is dye sensitized solar cells (DSSCs). DSSCs convert the solar energy into electrical energy and are the solution of energy problems in future. The advantages of solar cells are low cost, simple fabrication process, good plasticity and high flexibility (Grätzel, 2003). The excellent work of two scientists Graetzel and O'Regan reported in 1991. In international research community, work of Zhang *et al*. (2008), becomes a great attention. MoS_2 using a method of solid-state sulfurization and used for DSSCs as CEs. MoS_2 was prepared by Ho *et al*. (2004) (Jhang and Lin, 2015) by mixing purchase MoS_2 with TiO_2 nanoparticles for DSSCs. The efficiency of power restoration of fabricated DSSCs enriched from 2.54% to 5.08% by mixture of TiO_2 and MoS_2.

As contradict electrode patterned MoS_2 and un-patterned MoS_2 were assembled on the catalytic activity of atomic layers of MoS_2 to examine the effect of active edge sites as shown in Fig 4. Comparison can be performed by using platinum electrode. The curves that are formed between photocurrent and voltage of solar cell devices are shown in Fig. 4 (Roy-Mayhew *et al*., 2012). Un-patterned MoS_2 based devices have low current density as measure from platinum. The outcome of those devices which are based on ornate MoS_2 is at a standstill lower than platinum.

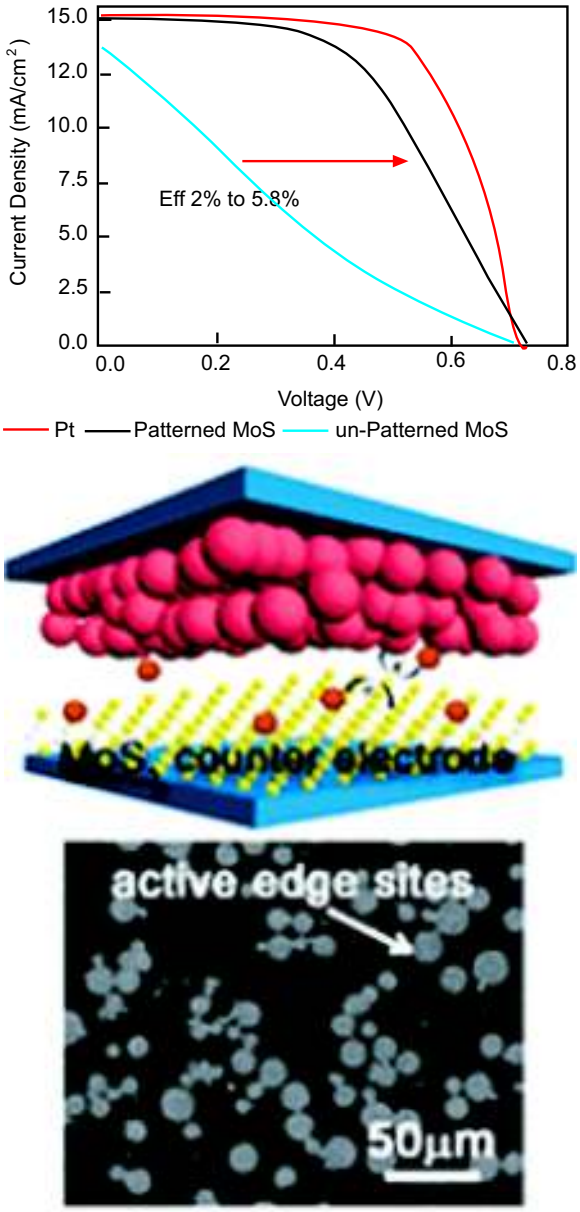

Fig. 4. A schematic diagram of a DSSC with MoS_2 as counter electrode and voltage–density characteristic curves (Roy-Mayhew *et al*., 2012).

DSSC is a current tool which is used to change solar energy into electrical energy. For the energy related problems in future, it provides explanation at wide ranges. The typical DSSCs consists of dye synthesized TiO_2 photo anode, I^-/I^{-3} redox electrolytes counter electrode (CE) (Kwon *et al*., 2013; Chen *et al*., 2005) The splendid metal platinum (Pt) is generally used as

CE in DSSCs because it has surprising electro catalytic characteristic for I^{-3} decrease. MoS_2 is one of the interesting materials due to its large quantity, prominent conductivity, easy production and extraordinary electrocatalytic activity. Kim *et al*. 2014 and 2015 reported that DSSCs accumulated with thermally preserved MoS_2 at 100 show analogous power modification competence of 7.35%. However, MoS_2 over 300 showed considerable diminish in power adaptation success owing to its substance renovation (Kim *et al*., 2015).

Hydrogen evolution reaction (HER). For future energy needs, hydrogen is considered one of the best options as a clean fuel. MoS_2 in which hydrogen will be produced that participates in the field of energy storage and it will be proved a good replacement of fusel fuels. In the atmosphere, the content of carbon dioxide will be more than double if only fossil fuels were exploited to meet the energy requirements, thereby increasing global warming. Research on renewable fuels is required to get rid from fossil fuels as energy source. In the recent years, hydrogen attained much attention for energy storage and conversion of solar to chemical energy. Production of hydrogen from renewable source, especially from water was a great challenge.

Generally, there are two ways for production of H_2 as from steam reforming of methane and coal gasification. But these methods cause environmental pollution and costly. So, by splitting of water which is naturally abundant has forced the researchers to focus on

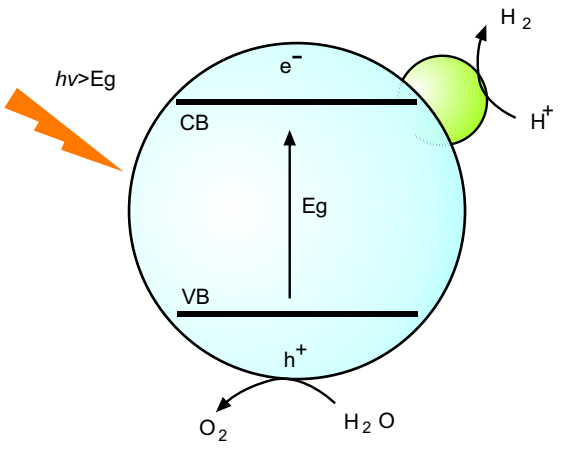

Fig. 5. Principle of photo electro-catalytic water splitting on a photo catalyst (Yuan *et al*., 2015).

renewable and green resources of energy (Guo *et al*., 2016; Bose *et al*., 2015; Ma *et al*., 2015; Rowley-Neale *et al*., 2015; Yu *et al*., 2015; Zhang *et al*., 2015; Zhang *et al*., 2014). Protons in the electrolyte are absorbed and then reduced into H_2 on the electrode; during the hydrogen evolution reaction process whenever potential is applied as shown in Fig. 5. A catalyst is required for the efficient production of H_2. It was hypothesized that to activate the "inert" in plane MoS_2, the in-plane doping of MoS_2 is not ideal due to limited electron transport and limited active sites.

In addition, doping of MoS_2 with atoms or materials can enlarge the inter layer spacing of MoS_2 and alter the Basel planes and thus modify their d-band electronic properties. MoS_2 was discovered in 1977 for HER but it was ignored due to its bulk form (Tributsch, 1977). In 2005, MoS_2 was reported as gifted HER catalyst. Tributsch and co-workers worked on natural catalyst of MoS_2 for electrochemical hydrogen evolution. Very little studies have reported foremost restriction on the straight use of MoS_2 as a photo catalyst for HER is the low action. For photo induce water splitting, ordinary semiconductor equipment as CdS (Zong *et al*., 2008), TiO_2, and Cu_2O (Tran *et al*., 2012) can be used. There are a lot of dis advantages of these materials. The band gap of TiO_2 is very minute, so it sucks up only small partition of sun light. Much work is needed to triumph over these troubles by amendment of photo catalysis. For HER under visible light, Frame and Osterloh premeditated the property of photo catalytic CdS. The first exclusive right was published in 1980 (Haering *et al*., 1980) of MoS_2 based LIB. Searching this apparatus by Bonde *et al*. (2009) and they found the rim of MoS_2 coating and vacancy fashioned by S atoms on edge sites, contributed to the electrocatalytic activity of MoS_2. They also suggested that by the morphology convenient synthesis course of action, the active edge of MoS_2 are increasing and this procedure may get better the electrocatalytic exploit of MoS_2 in electrochemical HER (Bonde *et al*., 2009).

MoS_2 for solar water splitting. One of the gifted solutions is photo catalytic H_2 evolution from water using sunlight to address the increasing energy needs. Because of low quantum effectiveness, production of H_2 is quite challenging. In the field of H_2 production by water splitting, semiconductor have received much attention. Water splitting derived by sunlight was one

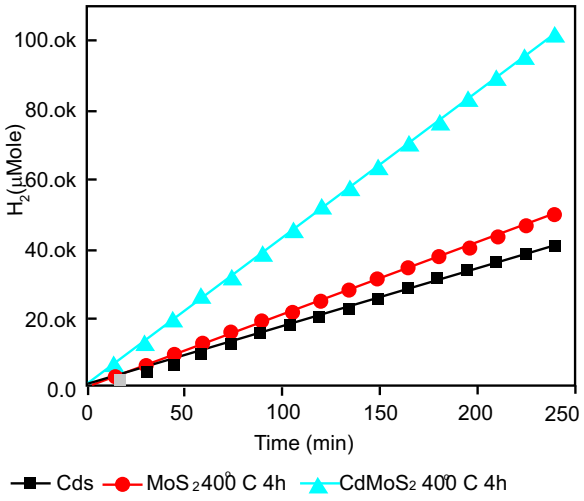

Fig. 6. Photocatalytic H_2 generation activity plot H_2S over MoS_2 and CdS (Kadam *et al*., 2015).

of the most attractive methods to produce hydrogen for energy storage. Enhancing the energy requirements without infusing the environmental pollution will be a great challenge. The reaction of water splitting was expressed as:

$$H_2O \rightarrow H_2 + 12O_2 \; \Delta G^0_{298k} = 2.37 \text{ kJ/mol}$$

Water splitting requires energy of 2.37 kJ/ mol for HER that will be lowered with the help of appropriate catalyst. Thermodynamic voltage requirement of 1.23V was corresponding by the input energy of that reaction. The

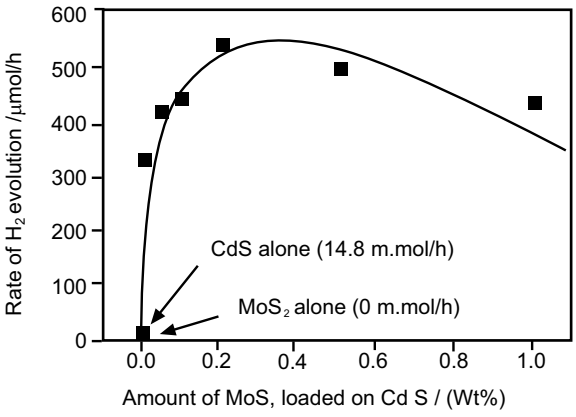

Fig. 7. The rate of H_2 evolution on MoS_2/Cd S photo catalysts loaded with different amount of MoS_2 under visible light (Sobczynski, 1991).

needs of photo catalyst are following: low cost, must be photostable, capable of storing more solar energy. MoS_2 is an important photo catalyst due to its exceptional properties. MoS_2 has shown great development as a photo catalyst with H_2 production by water splitting as revealed in Fig. 6 (Kadam *et al*., 2015). Jia *et al*., (2015) Esin Y (EY) modified MoS_2 photo catalytic H_2 evolution by water splitting.

The attractive and exigent topic is production of photo catalytic H_2 using semiconductor (Zong *et al*., 2008). Photo catalysts consist of co-catalysts and semiconductor materials. In the production of H_2 and O_2, there is important role of co-catalysts. The activities of photo catalysts can greatly enhance by loading of paper co-catalysts. By loading MoS_2 as a catalyst, it is found that role of CdS can be extend, under the same reaction condition, it is shown that activity of Pt/CdS is even lower than that of MoS_2/CdS as shown in Fig. 5. It is recommended that MoS_2 is not active for photo catalytic H_2 evolution because when alone MoS_2 is used as catalyst, no H_2 was detected. The activity of H_2 evolution increased up to 22 times, when only 0.01% of MoS_2 on CdS is added.

After loading Cd S by MoS_2 of 0.2 wt.% commotion is 36 times enlarged. The activity also appears maximum by using other photo catalysts as Pd, Pt, Ru and RuO_2. The double peaks in MoS2/CdS indicate the formation of MoS_2 (Ho *et al*., 2004) as shown in Fig. 7.

The photo catalyst in trellis acid solution are shown under visible light (lambda>420nm). For H_2 or O_2 evolution, co-catalysts offer low activation potentials and obtainable for H_2 or O_2 generation as active sites. Consequently the behavior of photo catalysts are improved by loading of proper co-catalysts (Zong *et al*., 2008).

Cd MoS_2 conferred at rates of 25445 mol/g/ H_2 fruition and MoS_2 as at rate of 12555 mol/g. Cd MoS_2 and MoS_2 nanostructures were used for H_2 production with quantum yields of 35.34% and 17.18% respectively. For H_2 production, a well-organized photo catalyst was used by method of chemical vapour deposition on Au@Ag nano rattles deposited on MoS_2 (Kang *et al*., 2015). An enhanced photo catalytic activity is exhibited by ternary Cd MoS_4 than MoS_2 and Cd S untouched, due to combining positive effect of MoS_2 and Cd S. By impregnating Cd S with an aqueous solution of (NH_4) MoS_4 with highly detached MoS_2 on Cd S, MoS_3/CdS

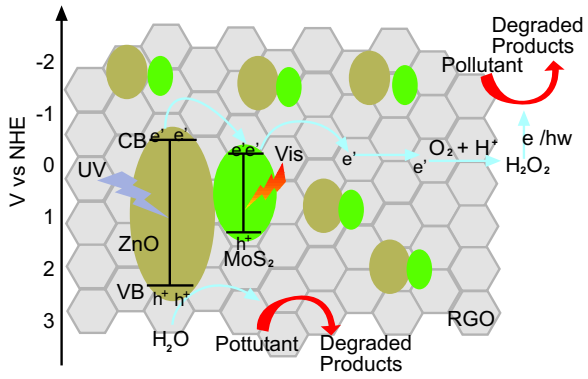

Fig. 8. Mechanisms of possible retardation for MB over MoS_2-ZnO-RGO hetero structure under irradiation of sunlight (Kumar *et al.*, 2016).

catalysts prepared by using method of H_2S flow at high temperatures for 2h. Both cubic and hexagonal phases of Cd S after treatment at 573K are present in Cd S and MoS_2/Cd S samples 1wt% MoS_2/Cd S was investigated by HRTEM, to visualize the junction structure of MoS_2 and Cd S.

Degradation of photo catalytic organic pollutants. In the area of ecological redress and energy storage space, the advancement of nanostructured solar energy provoked photo catalysis of semiconductor has established much concentration. Oxygen levels that conduct to many problems in ecosystem can be changed by organic impurity that in attendance in wastewater. One of the efficient ways to get rid of the organic pollutant from wastewater is photo catalytic deprivation. Although, TiO_2 is consider more efficient which manage its practical application only under UV light (Han *et al.*, 2014; He *et al.*, 2014). MoS_2 has shown great attention in this field due to its environmentally gracious, its nontoxicity and its absorption matching to solar spectrum and due to its stability against photo catalyst. Jeo et al supported TiO_2/g-C_3N_4 MoS_2 photo catalysts by scheme of wet impregnation and for degradation of methylene blue in employ it as obvious light active photo catalytic. For the elimination of organic pollutants in wastewater driven semiconductor photo catalysts that are based on solar light synthesized ZnO-MoS_2-RGO. MoS_2 decorated by two steps progression with SnO_2 mesoporous nanoparticles prepared by Vattikuti *et al.*, 2015.

The intensification of photo catalytic activity was because of developed electron hole-pair partition at TiO_2/g-C_3N_4. Interface imparted through z-scheme electron transfer presented by Kumar et al (Kumar *et al.*, 2016) as shown in Fig. 7.

By using method of hydrothermal composite catalysts were prepared and are used to find out the optimum levels of ZnO nanoparticles doping in heterostructures of ZnO-MoS_2-RGO. When ZnO nanoparticles are doped with 1wt% MoS_2-RGO there is most favourable and superior photo catalytic performance to eliminate the organic pollutants. By using simple method as hydrothermal. Wang *et al.* (Wang and Zhang, 2015) synthesized flower like MoS_2/CdS heterostructures. Li *et al.*, proposed that, MoS_2 and Ag_3VO_2 are used by using two-step hydrothermal route and by explore photo catalytic performances for degradation of MB under visible light irradiation. MoS_2/CuO heterogeneous nano flower structure synthesized. Due to vigorous edge sites of porous MoS_2 towards the dreadful conditions of MB, porous MoS_2 showed attractive photo catalytic activity without any outline, porous MoS_2 is synthesized, and explained by Zhou *et al.* (2014). By procedure of hydrothermal without any pattern, porous MoS_2 was synthesized. Owed to energetic boundary sites of absorbent MoS_2 the porous MoS_2 exhibited eye-catching photo catalytic activity towards poverty of MB. Jeo *et al.* (2016) prepared MoS_2 nanosheets loaded composites ZnO-g-C_3N_4 and ZnO-g-C_3N_4 nanocomposites for photo catalytic dreadful conditions of atropine and MB in aqueous solution.

Conclusion

By numerous researchers, the application and alternation of coated MoS_2 nanostructured supplies has been found. (Akbari *et al.*, 2018; Kukkar *et al.*, 2018) In this appraisal, we have calculated about modern progress in the field of MoS_2. Applications of MoS_2 at a wide range start from their chemical properties as enormous surface area, mechanical discovery and excellent charge reposition property. HER recital principally depends upon the inclination of catalyst with having strong necessary energy for absorbed H^+. Due to gapless band structure graphene was not suitable electronic material. MoS_2 was a closest competitor of graphene and used as its substitute, because of its reasonable energy gap, mechanical flexibility, absence of dangling bonds and chemical and thermal stability. Due to positive synthetic strategies, MoS_2 composites show high energetic boundary sites. It has different compensating ways over other catalysts as no toxicity, ability to assemble electron hole-pair for photo catalysis and low cost.

Pt is used at a wide range in DSSCs which gives best presentation for electrocatalytic decrease of $\bar{I}$ to $\bar{I}_3$ ions. But Pt is very costly and due to this reason in liquid state $\bar{I}$ to $\bar{I}_3$ redox electrolyte has imperfect its applications in DSSCs. These properties of Pt have forced the researchers to find the alternative of Pt. So, researchers have paying attention on MoS_2. MoS_2 has excellent properties and incredible potential. Composites of MoS_2 have set up to illustrate superior energy storage properties with porous structures. Characteristic layered MoS_2 are measured comprehensively well-organized applicant for sensor applications. MoS_2 has large surface area and its benefit is assimilation of molecules on surface of MoS_2. Weak Van Dar Waals interface in MoS_2 structure permits the atoms carry liberally in MoS_2. MoS_2 materials are exceptional substrates for applications of energy and surroundings. However, more work is needed on MoS_2.

Conflict of Interest. The authors declare no conflict of interest.

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