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Metal Oxide Nanoparticles for Energy Storage and Photocatalytic Applications Towards Environment Benignity

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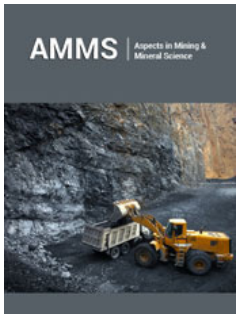

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Abstract

The source of energy is the source of human survival and development. The most promising natural source of energy is sunlight. Currently new Metal oxide nanoparticles, which are green, renewable, and alternative to the fossil fuels are exploring due to their wide applications and also key anode materials to replace the graphite in battery technology. Lithium-Ion Batteries (LIBs) have developed rapidly and controlled the market. Besides, Metal oxide semiconductor photo catalysis is a vital process utilizes the solar energy aids for tackling the industrial waste management. This process has been proven to be an efficient technique for the elimination of pollutants from aqueous and gaseous media.

Keywords: Nanoparticles; Anode; Lithium-ion batteries; Photocatalysis

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Introduction

With a rapid decline and exhaustion of non-renewable energy sources and unreliable renewable energy sources such as wind, solar, biomass, tide, geothermal. Our challenge is to develop large energy storage materials in order to overcome from the surge of fuels and environmental issues. Therefore, it is essential for modifying recurring renewable resources though incorporating them safely and without problems on the network [1]. Environment pollution can be mitigated by finding battery materials for energy harnessing; besides these materials also acts as good photolytic materials. Photo catalysis is a pollution and residual dyes degradation process in the fields such as medicine, cosmetics, agricultural, electronics, coatings, plastics, textiles, etc. which are not readily biodegradable. Various physical, chemical and biological techniques including ozonization, chlorination and filtration have limitations in energy sources. Therefore, photo catalytic method has developed for alleviating the negative environmental impact of toxic water and pollutants [2]. Metal Oxides (MO) are capable of forming large diversity of compounds by simple synthesis mechanism than carbon, alloy, sulphides, titanium and other organic composites materials. These can be implemented with a large number of structural geometries with electronic structure that displays the role of metallic, semiconductor or insulator nature. In technological aspects, oxides are used in the wide variety of applications [3]. Oxides in nano scale exhibit unique and distinct physical and chemical properties due to their particle size, surface area and density. Particle size will influence in the modification of lattice symmetry and cell parameters. Thermodynamic stability is associated with the low surface free energy; it is achieved by the nano sized metal oxides [4]. Various MO Nanoparticles (NPs) have been investigated extensively as hosts for ion insertion (Lithium, Sodium) for energy storage applications and photocatalytic applications. Structural and electronic properties also drive to modify the band gap of metal oxides to increase the chemical reactivity. Lithium and sodium are in same main group, similar chemical features. Sodium is beneficial in terms of abundance and cost. Due to commercialization perspective

Lithium-Ion Batteries (LIBs) are more promising for achieving large scale sustainable portable electrical devices because of its high storage capacity, power density. Negative electrode (anode) is very essential part of LIB's. Here in this review, we discussed few metal oxide nanoparticles for the negative electrode for LIB's and for photocatalytic degradation.

Lithium-Ion Batteries (LIBs)

Lithium-Ion Batteries (LIBs) have developed rapidly and controlled the market of battery industry. To explore and improve the power capability and life span of LIBs for storage medium, transition metal oxides (MO, M is Sn, Mo, Ta, Ti and Cu) are very promising anodes and have been extensively studied for electrochemical performance because of high theoretic capacity and improved rate capability [5]. Metal oxides are chosen based on electrochemically active and passive metal in an oxide. Batteries work according to the de-intercalation /intercalation of lithium ions during discharge/charge from cathode and migrate across electrolyte, without altering the crystal structure. Figure 1 explains the schematic representation of LIBs during discharge and charge process. Set up consists of cathode (Li metal), an anode (MO) and electrolyte (1M $LiPF_6$) was dissolved in ethylene carbonate, dimethyl carbonate and diethyl carbonate as conductor in order to get rid of electrolyte diffusion. Electrochemical interface between electrodes and electrolytes takes place during redox mechanism.

$$M_aO_b + (b.n)Li^+ + ae^- \leftrightarrow aM + bLi_nO$$

Where M=Transition metal, n=Oxidation state of oxide

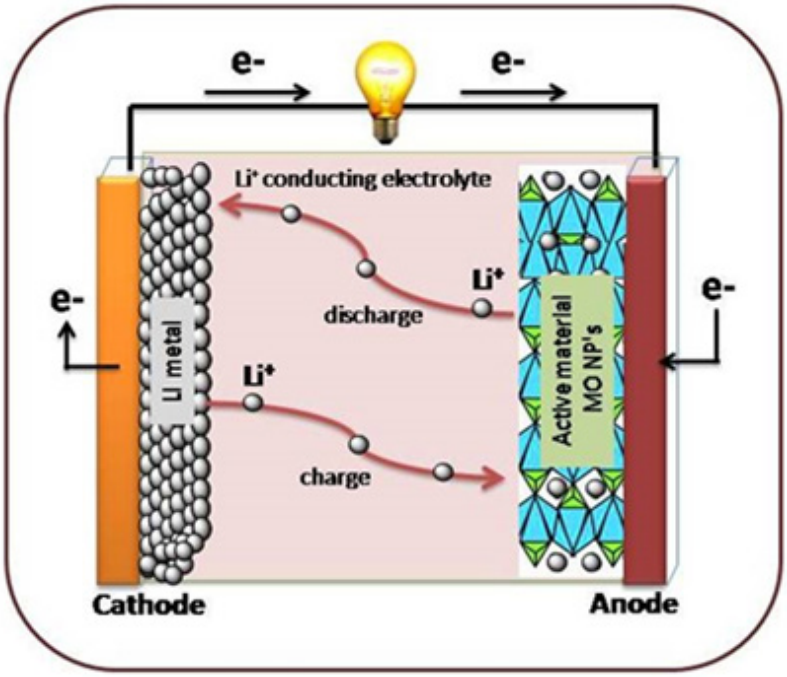

Figure 1: Schematic representation of LIBs during discharge and charge process.

MOs are superior battery material exhibits extraordinary electrochemical behaviour such as high discharge irreversible capacity. Abrupt initial irreversible capacity induced by Li_2O (solid electrolyte interface) can be effectively reduced; this intends to decrease the volume expansion. Moreover, helps to accommodate more lithium ions. Crucial issues such as capacity retention and stability can be minimized by tuning the size of NPs, different shapes (flowers, rods, wires, and dumbbells) and dimensions (3D, 2D and 1D) of structures. Synthesis method also helps for mass production as well as to eliminate the impurities/defects. We focus on SnO_2, MoO_3, Ta_2O_5, TiO_2 and CuO metal oxides; these forms attractive anode materials with high energy density and stable capacity retention [6,7]. Park MS et al. [8] fabricated the self-catalyzed grown one-dimensional SnO_2 nanowires by thermal evaporation method for electrochemical applications. The 1D nanowire structure provided more reaction sites on the surface and enhanced the charge transfer process in the electrochemical reaction. Higher reversible specific capacity of over 300mAhg^{-1} was obtained up to 50th cycle. In addition, tin particles at the tips of nanowires contributed to Li+ storage and avoided capacity fading that is induced by existing metal catalysts. [8]. Zhou J et al. reported hexagonal MoO_3 nanorods for the high-performance lithium-ion batteries. Hexagonal MoO_3 anodes exhibited capacity of 780mAhg^{-1} after 150 cycles at 150mAg^{-1} current density. The h-MoO_3 nanorods exhibited high capacity, cycling stability, good rate capability and less electrochemical impedance due to 1D nanorod morphological structure [9].

Manukumar KN, et al. [10] synthesized mesoporous high surface area Ta_2O_5 nanoparticles via hydrothermal method as an anode material for lithium-ion battery. Significant reversible capacity of 150mAhg^{-1} is obtained at C/10 current rate after 50 cycles and also

exhibited remarkable hydrogen generation of 563.5μmolg^{-1}h^{-1} [10]. Ren Y et al. discussed TiO_2 (B) nanoparticulate electrodes were prepared via hydrothermal route to obtain the highest capacity for the viable commute between lithium ions and the electrodes. Nanoparticulate titanates exhibited superior volumetric capacity at all rates compared with the 6 nm anatase material and reported best high rate (>1000 mAg^{-1}) volumetric capacity [11]. Xiang JY et al. [12] synthesized the self-assembled CuO hierarchical nanostructures such as leaf, flower, shuttle, caddice clew and dandelion for LIBs. In this, they tailored the morphology by adjusting the pH value. Compared to other structures dandelion and caddice clew like CuO morphologies exhibited 385mAhg^{-1} and 400mAhg^{-1} at 0.1C and these were maintained stable discharge capacity of about 340 and 374mhg^{-1} 0.5 C after 50 cycles respectively. Excellent discharge capacities and cyclic performances were due to large surface area, porosity and lower diffusion length between electrolyte and lithium ions [12].

Photocatalytic Dye Degradation

Photocatalytic degradation process uses the nanoscale semiconductor as photocatalyst materials. These catalysts use the lighting power (UV/visible) to produce electron/hole pair are capable of carrying out the oxidation and reduction process on the surface of photocatalyst. It produces reactive oxygen species (hydroxyl and superoxide oxygen radicals). Oxygen species are evolved by the redox process for decomposition of contaminants. Photocatalytic efficiency is strongly depending on the wavelength and power of the light source. The physical properties such as defect density, electronic structure, size, surface area, and surface to volume ratio and chemical nature of photocatalytic species also affects for its efficiency. Figure 2 explains the complete dye degradation procedure under the irradiation of UV/Vis light. Herein, we have discussed few metals oxide photocatalytic nanoparticles which are also energy storage materials for the degradation commonly used dyes such as Methylene Blue and Rhodamine B. Metal oxides are very important photo catalysts due to its rich chemistry with multiple valence states and high thermal and chemicals stability. Metal oxides are semi-conducting materials with band gap of 2-4.0eV, we can enhance the photocatalytic activities by tuning the bandgap [13].

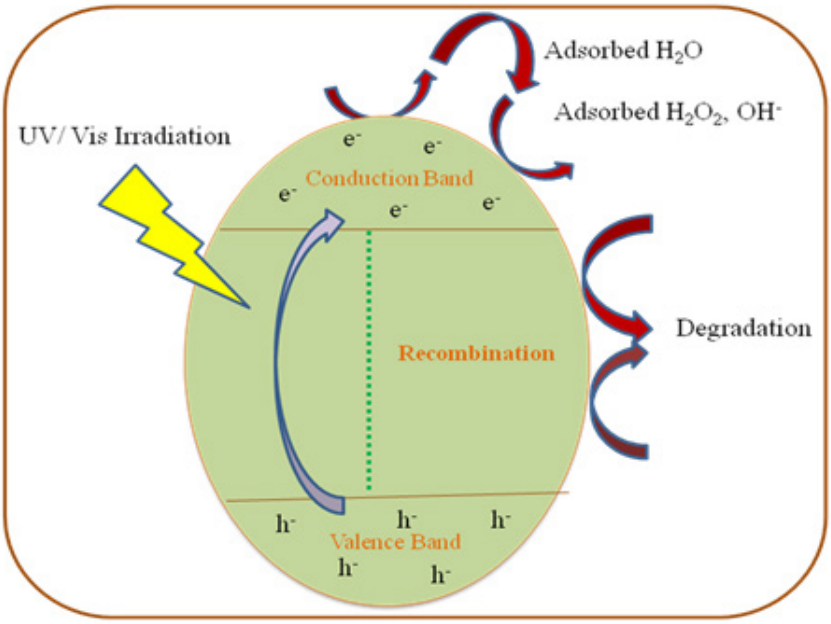

Figure 2: Photocatalytic dye degradation mechanism of dyes.

Elango G et al. [14] were synthesized using C. betacea methanolic extract without introduction of more toxic elements to the environment. SnO_2 NPs provided the promising results towards organic applications such as methylene blue dye degradation at 365nm. About 1ml of Methylene Blue was mixed with 0.25mg of SnO_2 NP and placed in a UV chamber at 365nm. The degradation spectra were recorded from 400 to 800nm in visible UV spectroscopy. The Surface Plasmon Resonance (SPR) band for the blue methylene dye was degraded at 660nm at 70min [14]. Hu C et al. [15] demonstrated the recyclability of MoO_3 nanobelts synthesized thru hydrothermal technique for photocatalytic degradation of Rhodamine B under infrared irradiation. Enhanced results have shown for small concentration of dye at 7.5mg/L catalyst degraded upto 90% after 60 minute [15]. Zhu Y et al. [16] reported the nanosized-Ta_2O_5 powder photocatalyst using the sol-gel method. Better photocatalytic performance has been achieved for the decline of gas formaldehyde. Calcination's temperature and time were played vital role on crystal structure and photocatalytic activities Ta_2O_5 powder. Nanosyzid-Ta_2O_5 powder has shown good photovoltaics activity under UV light radiation [16]. Liao DL et al. [17] reported the optimized TiO_2 nanoparticles for photocatalytic degradation by different surfactants. Photocatalysts were

synthesized by sol-gel method. Various shapes and sizes such as spherical, ellipse, cubic nanoparticles and nanorods were obtained by calibrating with surfactants. Cubic NPs prepared with the use of sodium dodecyl sulfactant had a higher photocatalytic activity than other TiO_2 nanoparticles [17]. Li J, et al. [18] prepared spindle CuO particles for photocatalytic degradation under halogen tungsten lamp. CuO particles were very good sensitizer photocatalyst so CuO NP's degraded the Rhodamine B dye in the presence 0.01M H_2O_2 under the irradiation of 100W halogen sources. They were very stable and could be recycled without considerable loss of activity. Organic pollutants such as Methyl Orange, Methylene Mlue, Erosin B, and P-Nitrophenol can be photo decomposed in similar conditions. These properties showed practical applications in environmental remediation [18].

Conclusion

Battery technology and photocatalysis are considered as the pure technologies in environment perspective in the present worldwide increasing demand for energy. LIBs are hoping to apply in large quantities energy for storage system in the worldwide usage. The photocatalytic activity is also appreciated tool for many hazardous dyes.

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