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Promising transition metal molybdate (TMM) single phase microstructures for asymmetric supercapacitor and photocatalytic applications

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Abstract

The increasing impact of worldwide energy challenges has sparked significant interest in developing multifunctional nanomaterials for energy and environmental applications. Among semiconductor photocatalysts, stable mixed metal molybdate materials have garnered much interest regarding energy storage and photocatalytic dye degradation. In this context, we have synthesized three different single-phase metal molybdates ($NiMoO_4$, $MnMoO_4$, and $Fe_2(MoO_4)_3$) using the gel matrix method. XRD and Raman were executed to confirm phase formation of the acquired materials. Difference in surface morphology of synthesized transition metal molybdate powders was examined using SEM analysis. The energy-storing properties of synthesized transition metal molybdate powders were analyzed and compared using three and two electrode method. At a 1 Ag^{-1} current density, the as-synthesized $NiMoO_4$, $MnMoO_4$, and $Fe_2(MoO_4)_3$ nanostructures exhibit specific capacitances of about 424.6, 325.5 and 157.8 Fg^{-1}, respectively. Furthermore, the fabricated ASC device with $NiMoO_4$ shows 41.6 $Whkg^{-1}$ and 750 Wkg^{-1} as maximum energy and power density at 1 Ag^{-1}, respectively. Meanwhile, photocatalytic methylene blue degradation was carried out using the as-synthesized materials as photocatalysts. The $Fe_2(MoO_4)_3$ effectively decolourizes the dye with a maximum efficiency of 82.7 %, when compared to other two metal molybdate powders. Thus, the results show that the synthesized metal molybdates such as $NiMoO_4$, and $Fe_2(MoO_4)_3$ can act as potent electrode materials and efficient photocatalysts for energy storage and dye degradation applications when compared to $MnMoO_4$.

Introduction

The extensive use of fossil fuels for energy generation leads to environmental pollution and global warming. It is imperative to establish a sustainable energy storage and conversion system to address the concerns of energy crises and environmental degradation. Supercapacitors are acknowledged as a viable energy storage technology in contrast to conventional storage technologies because of their affordability, sustainability, and friendliness [1]. Supercapacitors are thus employed in increasing applications, including portable electrical vehicles, microdevices, electronics, and power backup. Pseudocapacitors store charge by reversible redox processes at the electrode and electrolyte interface region among all other supercapacitors [2]. Electrodes possess more essential functionality in the architecture of supercapacitors than any other components. The three primary electrode materials are repeatedly used to form supercapacitors, such as carbonaceous, conducting polymeric materials, and metal oxides [3]. Porous carbonaceous-based electrodes lead to low packing density electrodes, significantly restricting their capacitance [4,5]. Furthermore, the conducting polymers employed as pseudocapacitive electrodes offer significantly high capacitance because of their larger surface areas and redox storage capabilities. However, the reduction-oxidation process in conducting polymers limits their stability and increases deterioration over several charge-discharge cycles [6]. This can be overcome by employing TMOs, which show enhanced stability compared to conducting polymers. The poor electrical conductivity of many metal oxides remains a disadvantage of these materials. This signifies that the advancement of supercapacitor technology is primarily concerned with developing electrode materials that can store large amounts of charge with high conductivity for practical applications.

Besides global energy demand, the rise in air and water pollution is wreaking havoc worldwide. A substantial amount of organic dyes discharged by the paper, textile, and plastic industries into the water systems contribute to environmental pollution [7]. If these pollutants are discharged into major water sources, they can disrupt the ecological balance and impact human life by disturbing the food chain [8]. Traditional processes such as chemical precipitation, electrolysis, reverse osmosis, ion exchange, adsorption, and nanofiltration eliminate the dyes in the industrial waste water [9,10]. To remove the dyes from waste water, contemporary oxidation techniques are used these days, including photo Fenton, photolysis, electrochemical oxidation, photocatalysis, sonolysis, and Ozonation [[11], [12], [13], [14]]. Among all, utilizing solar energy through efficient photocatalysts is the most promising sustainable approach for degrading organic contaminants in waste water. Several research studies have been conducted on photocatalysis technology and its eco-friendly uses in the last decade. Moreover, photocatalysis avoids the generation of secondary pollutants, which is still an advantage of the method.

The need for advanced solutions for these energy and environment-related problems results in the quest for multifunctional materials with significant properties. As a family of important functional materials, transition metal oxides (TMOs) have been widely researched recently. TMOs are one of the alternate materials for SC electrodes as they possess a larger specific capacitance, strong conductivity, and lower resistance compared to carbon material [15]. The focus has moved to binary or ternary metal oxides, particularly in supercapacitors and photocatalysts. These compounds prevail over single metal oxides because of their high redox behaviour, which involves numerous oxidation states and various ions, resulting in improved efficiency of the materials [16,17]. The binary metal oxides include cobaltites, ferrites, stannates, manganites, and molybdates [18]. Metal molybdate