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Development of nanomaterials for flexible lithium-ion batteries (LIBs) and supercapacitors (SCs) play role in future electrochemical storage devices (FESDs)

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Abstract
Depletion of fossil fuels and the adverse effects due to their combustion has triggered an energy crisis around the world. The research relating to the energy storing devices has picked up momcatum recently. The effective storage of energy is the utmost necessary from the utilization point of view. Traditionally used materials for energy storage are not efficient and the self-discharging, of the Lithium-ion batteries (LIBs) cannot be restricted. In this regard, the present trend of study comprises the development of a 2D material known as MXenes, its processing methods, various applications, challenges and Play role in failure electrochemical storage devices recommendations. MXenes are considered an efficient energy material for secondary batteries and supercapacitors.

Keywords: Lithium-ion batteries, energy storage, 2D materials, MXenes, supercapacitors, nanomaterials

Introduction

The sustainable development of the energy sector is a matter of concern in the present world due to the large energy demand. The environmental impacts caused by the fossil fuel has been increased at an alarming rate as reported in many scientific journals. This leads to the intervention of renewable sources of energy *viz*. hydro, solar, biogas, H_2, wind, etc. However, the energy derived from these sources is difficult to store for future use. Therefore, scientists and research communities are devoted to the invention of new technologies that can efficiently store energy. Micro grid technology, renewable energy integration, batteries and flywheels, etc. are some of the means of energy-storing devices [1,2]. The development of energy-storing devices is slow but steadily becoming a detachable part of our lives [3]. Rechargeable batteries have shown good electrochemical properties. The cycle of charging/discharging and Coulomb efficiency are exhibited well by Lithium-ion batteries (LIBs).

Lithium-ion Batteries (LIBs) are the main energy-storing device at present. It has various applications like mobile phones, cameras, robots and E-vehicles. Lately, aqueous batteries e.g., Zn, Al, Na, Mg, etc. have gained much attention from researchers because of their commendable qualities like high ionic transfer rate, low cost, environmentally benign, ease of assembly and safety [4]. The genre of two-dimensional transition metal carbides, nitrides and carbonitride materials commonly known as MXene has been demonstrated as an effective functional material for battery applications. MXenes possess great thermal and chemical properties, high conductivity, novel topographical features, fair absorption capacity, and good mechanical properties, MXenes have been used in biomedical applications [5], energy storage devices [6], electronics, water splitting and purification [7], catalysis [8] and gas storage [9]. Traditionally, electrodes are mounted on a metallic foil current collector which fails to support the structure during repeated bending causing poor performances [10, 11]. These drawbacks can be eliminated with the help of nano-materials which provide adequate flexibility, mechanical strength, and resistance to hending fatigue [12, 13]. Recently the author described investigation of transition metal oxides nanomaterials as electrode for sodium ion batteries [14] and role of surface modification in enhancing electrochemical properties for battery applications [15] have already been described.

Materials and Methods

The processing technology of MXenes is broadly divided into two categories: (a) top-down method involving selective etching and (b) bottom-up method which is mainly chemical and physical vapour deposition. Method (a) is normally useful for MXenes synthesis as reported. The first step in synthesizing MXenes includes etching the MAX phase with chemicals such as hydrofluoric acid and an oxidizing agent (H_2O_2). This facilitates the exposure of element and X-element over the surface. The resulting material is exfoliated with various techniques such as ultra sonication, electrochemical delamination, intercalation with organic molecules, etc. In this step, the MXene layer is separated from each other using a 2D structure. After exfoliation, the MXenes layers are washed with water and dried off to remove any residues of the exfoliation agent or etchant.

Energy storage mechanism: MXenes have emerged as promising candidates for negative electrodes (anodes) in various Electrochemical Storage Device (ESD) systems. When MXene, Nano flakes (NFs) are immersed in aqueous solutions, they become enveloped by an electrical double-layer (EDL), preventing cationic atomic orbitals from interacting with those of MXene Nanomaterials (NMs). The introduction of hydrated cations and water molecules leads to the formation of an internal potential difference, thereby creating an EII. Within the interlayer gaps of MXene NFs. The capacitance of this EDL can be calculated using the formula C where $C = \frac{\varepsilon_R \varepsilon_0 A}{(b-a)}$ "ε_r" represents the dielectric constant between MXene and cations, "ε_0" denotes vacuum permittivity, "a" stands for ionic radius, "b" signifies the separation distance between MXene layers and "A" denotes the surface area. This equation underscores the importance of precise MXene NM synthesis to achieve a minimal value of (ba) for optimal design. While the effect on capacitance is minimal (0.05 (e^-) and 0.05 Li^+ per titanium atom in a IM L_2SO_4 electrolyte) exposure of titanium atoms is slightly reduced, impacting electron storage. However, in the case of highly acidic electrolytes, Faradaic interactions occur between protons and metal-oxygen bonds, enhancing Faradaic energy storage contributions. MXene NM-based Supercapacitors (SCs) utilizing sulphuric acid as the electrolyte typically exhibit broad redox peaks, as expected. Due to the potential reactivity between alkali metals and water, non-aqueous electrolytes are usually preferred in batteries. MXene Nanomaterials (NMs) exhibit potential as hosts for redox reaction-based energy storage, leveraging the redox activity of their abundant surface termination groups. By immersing Nanoflakes (NFs) of MXene NMs in molten sulphur or subjecting then to a hydrothermal reaction with suffices, sulphur be readily incorporated into MXene [16]. These straightforward approaches highlight the advantages offered by MXene NMs, including the high electrical conductivity of the MXene core and the effective binding of sulphur species to the surface termination groups. The functionality of MXene NFs as hosts can be further enhanced through chemical modifications For example, the robust interaction between lithium polysulfide's and heteroatoms enables MXene NFs to catalyze the redox processes when doped with heteroatoms (such as nitrogen and metal stems) [17].

Results and Discussion

Secondary Batteries: The rising demand for renewable energy fueled by consumer gadgets and future electric vehicles (EVs), and advancements in Electrochemical Storage Devices (ESDs), particularly their flexibility are crucial for the evolving nanotechnological landscape. Super capacitors (SCs) offer benefits such as high-power densities, rapid recharge times and extended operating periods [18]. They still face challenges related to cost-effectiveness and efficiency. Nickel-metal-hydride (Ni-MII) and Lithium-ion batteries (LIBs) stand out for their affordability, high energy densities, stability, long cycle lifespans and robust electrical conductivity, unlike lead-acid batteries. Despite LIBs impressive theoretical capacity and other favourable attributes [19], concerns regarding safety due to lithium dendrite formation and limited Columbic efficiency hinder their widespread practical application. Graphite has historically been the primary choice for anodic material in Lithium-ion Batteries (LIBs), boasting a specific capacity of 372 $mAhg^{-1}$. However, on-going exploration of novel materials for LIBs is essential, given their significance in various applications such as electric vehicles, aerospace and portable electronics [20]. Lithium-ion batteries (LIBs) serve as hugely adaptable and cost-effective power solutions, offering prolonged lifespan and impressive energy density for flexible printed electronics (PE) systems. The materials utilized for both the anode and cathode in Lithium-ion Batteries (LIBs) need to possess minimal self-discharge rates and substantial capacity, as these characteristics significantly influence their performance. Furthermore, the recyclability of LIBs is being explored as they represent advanced next-generation power sources, distinguished by their exceptional capacity and enhanced safety features.

Supercapacitors: Supercapacitors (SCs) play pivotal zone in Future Electrochemical Storage Devices (FESDs) and are essential for the advancement of nanotechnology. Essentially, SCs represent a category of ESDs positioned between batteries and conventional capacitors, boasting higher power density than batteries and greater energy density than unconditional capacitors, Consequently, SCs have garnered significant interest in recent times due to their high-power density, rapid charging capability, and prolonged lifespan. They have emerged as prominent power sources for smart electronics, especially small devices, thanks to their advantages of elevated power density, extended cycle life and efficient charge/discharge processes [21]. SCs are poised as ideal candidates for EST) applications where electrical double layers are charged through the rapid reversible adsorption of ions on the surface of large Specific Surface Area (SSA) electrode Nanomaterials (NMs) like Carbon Nanotubes (CNTs), Graphene (G), Porous-C (P-C), and MXenes, enabling energy storage. Additionally, SCs offer lower internal resistance, lighter weight, and longer lifespan, operational versatility across a wide range of environmental temperatures, swift transient response, and high-power density.

Challenges and recommendations: Despite significant development and innovative concepts, multifunctional, flexible and integrated secondary batteries (FSCs, FMBs and FMSCs) are still in their early stages of manufacturing and application. Currently, alternative device architectures are prohibitively expensive to implement, requiring flexible current collectors, electrode materials, solid-state electrolytes and encapsulation materials for Flexible Electrochemical Storage Devices (FESDs) While progress has been made in these across, there are still several challenges to address to enhance the performance of fabricated FESDs, including flexible batteries, super capacitors (SCs), micro super capacitors (MSCs) and micro batteries (MBs). For instance, standard organic liquid electrolytes in flexible batteries, especially Lithium-ion batteries (LIBs), pose safety concerns due to thermal stability issues while solid-state electrolytes suffer from poor ionic conductivity. Additionally, achieving the true meaning of solid-state FSCs, often utilizing gel electrolytes, requires further attention. Research should focus on increasing energy and power densities, designing novel 3D and binder-free electrode structures, discovering new electrode materials with high surface area and efficient ion diffusion paths, and exploring unique structural designs for FESDs to meet future demands. Fibre-shaped FESDs, such as fibre-shaped LIBs and FSCs, offer exceptional flexibility and integration potential, particularly for wearable and portable devices

Conclusion

In this manuscript, the synthesis, processing, and applications of MXenes are highlighted. The use of traditional electrode materials fails due the loosely bounded particles. However, the introduction of MXenes can provide better binding capacity of the electrodes and improved mechanical and electrochemical properties of the energy storing devices, for flexible Lithium-ion Batteries (LIBs) and the development of nanomaterials and super capacitors play articles in the failure electrochemical storage devices (FFSDs).

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