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Perovskite Materials: Future Prospects for Energy Storage Applications

N. Alam^{1*}, S. Tripathi¹, M. A. Siddiqui¹, V. S. Chandel¹, T. Khatoon¹, A. Azam²

¹Department of Physics, Integral University, Lucknow, (U.P.), India-226026

²Department of Applied Physics, Aligarh Muslim University, Aligarh, (U.P.), India-202002

*corresponding author: navshadkhan@gmail.com

Abstract

Energy production and energy storage is an extremely challenging research area now a days. The present paper reviews different materials for energy storage applications and also discusses different approaches, technologies to manage the energy storage. Within different forms of energy viz. mechanical energy, electrochemical energy, electrical energy, chemical energy, thermal energy etc. only electrochemical energy from renewable energy sources is focused. The current status of materials used for electrochemical energy such as lithium-ion batteries and supercapacitors have been discussed in this paper.

Keywords: Electrochemical, Mechanical, Thermal, Chemical energy, Lithium ion batteries, supercapacitors.

1. Introduction

Titanates having chemical formula $M_2O_n TiO_2$ (where $M = Li, Na, K$ etc. and $n = 2-8$) have been a subject of intensive research during the 19th century due to their various technological applications. These titanates have tunnel or layered crystal structures constructed of TiO_6 octahedra sharing edges with interlaying cations [1, 2]. Especially alkali metal hexatitanates, $M_2Ti_6O_{13}$ ($M = Li, Na, K, Rb, Cs$), have unique properties. These materials have excellent thermal durability, chemical resistivity, mechanical performance, ion-exchange properties and photocatalytic activity [3–13].

Renewable energy is a source key for an environmentally safe and sustainable future. Photovoltaic solar cells, wind turbines are the examples of renewable energy, but they are not able to provide a continuous flow of energy unless they are not connected with an energy storage device. This requirement of energy storage techniques will cause the innovation and advance energy storage materials.

Storage of energy and conversion of energy are closely related to the properties of energy storage materials [14]. Electrochemical energy storage device shows advantages of high efficiency, versatility, and flexibility. Typically there are two type of electrochemical energy devices i.e. batteries and supercapacitor. Storage of energy can be classified in different types of rechargeable batteries. Each battery cell has a negative electrode, a positive electrode and an electrolyte. The two electrodes are compounded by materials having different electrochemical potentials that spontaneously induce a redox reaction which generates an external electrical current when the circuit is closed for discharge cycle. Since these electrochemical reactions are reversible, secondary batteries can be recharged by applying, an external voltage, across the electrodes [15]. Current flows in the batteries or electricity goes in and out in the batteries because of the reversible electrochemical reactions [16]. Depth of discharge, discharge and charge rates, and ambient operating temperature, these are three main factors which evaluates the cycle life of batteries. Depth of discharge shows how much of the stored energy in a device has been used. Discharge and charge rates are denoted by $I = MC/n$, where I is the discharge (or charge) current in amperes (A), C is the numerical value of rated capacity of the battery in ampere-hours (Ah), n is the time, in hours, for which rated capacity is reported and M is a multiple or fraction of C [17–20].

2. Discussion

Supercapacitors exhibit a higher energy density. They can be charged and discharged faster than the batteries. Supercapacitors have high dielectric materials; therefore, they can be used as high energy storage devices. In order to increase power rating and storage capacity, supercapacitors can be arranged in modular systems by parallelizing and/or serializing [21-25].

The equation for maximum stored energy density per unit volume (U) of a dielectric can be written as

$$U = k\epsilon_0 E^2/2 \quad (1)$$

Where, E =Applied field, k =dielectric constant, and ϵ_0 =vacuum permittivity (8.854×10^{-12} F/m) [26]. Capacitance of a parallel plate capacitor is given by

$$C = k\epsilon_0 A/d \quad (2)$$

Where, C =capacitance of a parallel plate capacitor, A =area of the plates, and d =space between the plates respectively. Hence, the larger the value of k (dielectric constant), will store more charge and leading to trimness of energy storage devices. Solid $\text{CaCu}_3\text{Ti}_4\text{O}_{12}$ (CCTO) has a dielectric constant ($k=10^4$ - 10^5 at room temperature), hence this material can be

used in supercapacitors [27, 28]. $\text{CaCu}_3\text{Ti}_4\text{O}_{12}$ is stable over a wide range of temperature 100–600°K [29, 30]. An internal barrier layer capacitor model (IBLC) has been used to explain the origin of an abnormally high dielectric constant in CCTO [31-41].

R. K. Pandey et al. [42] prepared CCTO ceramic powder using ball mill to get particle size in nm. The phase confirmation of CCTO was done by X-ray diffraction. Seebeck coefficient was determined within 150 to 650°C to understand the semiconductor nature of CCTO. The high temperature gives the information of intrinsic nature of CCTO as well as it reveals that CCTO is good materials for high temperature electronics.

CCTO has also been synthesized by solid state route reaction method by many researchers [43, 44]. In this method constituents are heated above 1000°C for desired time period. Due to higher temperature the volatile impurities are removed from the fine powder. Shao et al. [45] prepared CCTO by conventional solid state route reaction method and they reported that dielectric constant increases with increasing temperature.

Mayank Pandey et al. [46] prepared polymer composite comprising polyvinylidene fluoride (PVDF) and potassium hexatitanate ($\text{K}_2\text{Ti}_6\text{O}_{13}$) and synthesized it by solution casting. They changed the surface properties of polymer composite and found that it can be used in application of energy storage devices.

Strontium titanate (SrTiO_3 , STO) is a prototypical perovskite oxide. It has wide application, from catalysis to energy conversion devices. Perovskite oxides (POs) are the most employed electrode materials for solid oxide fuel cells (SOFCs) [47, 48]. Potassium and sodium doped STO have very interesting properties for application as cathode components in oxide-conducting solid oxide fuel cells [49].

3. Conclusion

Demand of portable electronic devices is increasing day by day. In this regard electrochemical energy storage materials, batteries and supercapacitors play very important role. Renewable energy such as solar cell and wind energy are successful only in specifies natural conditions and they are not continuous. Therefore, the need of energy storage devices with high performance energy to generate and produce continuous electricity are required. Electrochemical energy storage promises to store this type of high performance energy.

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