Synopsis of Thesis

Index No.: D-7/ISLM/31/2017

We are searching for green renewable energy sources like solar and wind energy to support sustainable growth because of the world's ongoing use of fossil fuels and rising environmental degradation. In the current period of civilisation, innovative, affordable, and environmentally friendly alternative energy storage solutions are required; supercapacitors fall into this category. In the race against rechargeable batteries, supercapacitors still face significant challenges in maintaining high power with high energy density and long cyclic stability. Because of their reversible faradic processes for charge storage, transition metal oxides (TMOs) can meet the aforementioned requirements with high capacitance. Mixed transition metal oxides (MTMOs) and their hybrid with nanocarbons as electrode material should improve TMOs' sluggish redox reaction rate and poor inherent electrical conductivity. Rich redox reactions and enhanced electronic conductivity are provided by MTMOs, which are advantageous for electrochemical energy storage applications. High surface area and porosities can be achieved by carbonization. One of the most exciting new materials, perovskite, has a big impact on energy applications. In this dissertation, the synthesis of TMOs, MTMOs and their hybrid with nanocarbon material like amorphous carbon nanotubes (aCNTs) along with perovskite material is discussed in detail, since their well-controlled shape aided electron transmission and therefore increased electrochemical energy storage.

The main idea of supercapacitors is introduced in this dissertation, along with the ways that TMOs, MTMOs, and their hybrids with nanocarbons and perovskites are constantly developing as supercapacitive electrode materials. After then, a detailed discussion of the issues raised throughout the research period and its successful resolution has taken place. An easy method for synthesising TMOs and its hybrid with nanocarbon material has been developed here in the first experimental attempt. In this study, amorphous carbon nanotubes ($MnWO_4$-aCNT) and manganese tungstate hybrids are realised and used as solid-state asymmetric supercapacitor electrodes. The budgetary solid-state reaction was used to synthesise aCNTs on a large scale at low temperature. $MnWO_4$ nanorods were then added to the walls of these nanotubes by an in situ hydrothermal approach that did not require surfactants. High specific capacitance of 542.18 Fg^{-1} at a scan rate of 2 mVs^{-1} was delivered by the produced electrode based on this hybrid over nickel foam, which is significantly better than the same of other structural units separately. Even after 15,000 cycles of operation, this $MnWO_4$-aCNT based electrode demonstrated a high-rate capacity with around 100% capacitance retention and almost 100% coulombic efficiency. On this combination, the solid-state asymmetric supercapacitor achieved a power density of 893.6 W kg^{-1} and an energy density of 5.6 Wh kg^{-1}. The hybrid sample's significantly improved electrochemical behaviour is explained by its increased surface area, which results in a higher number of redox reaction sites, as well as the beneficial synergistic effect of the building blocks.

In second experimental work my findings describe the synthesis of $MnWO_4$ nanostructures with varying aspect ratios achieved by careful adjustment of reaction temperature and reaction duration. One direct application of size control nanostructures is as supercapacitor electrode material. X-ray diffraction, field emission scanning electron microscopy, and Raman spectroscopy were among the characterisation techniques used to examine the effects of reaction parameters, specifically growth time and processing temperature, on the size of $MnWO_4$ nanorods. The results indicate that all of the samples have very good charge storage characteristics, with the greatest specific capacitance values recorded at 2 mVs^{-1} and 1 Ag^{-1}, respectively, being 455.07 Fg^{-1} and 239.07 Fg^{-1}. Additionally, even after 10,000 charge-discharge cycles, the matching sample exhibits a notable capacitance retention of approximately 94%, demonstrating the electrode's great electrochemical stability. Density functional theory study conducted theoretically indicates that the remarkable charge storage potential of the synthesised $MnWO_4$ is mostly due to the higher quantum capacitance and the existence of electronic states close to the Fermi level.

In third experimental work I present the use of $CsPb_2Br_5$ as a material for supercapacitor electrodes. A specific capacitance of 886 Fg^{-1} is displayed by the $CsPb_2Br_5$-based manufactured electrode at a scan rate of 2 mVs^{-1}. It showed a Columbic efficiency of around 99% after 5000 operating cycles, and it kept 76% of its initial specific capacitance. The observed capacitive behaviour is explained in detail and the charge transfer mechanism is investigated using Mott-Schottky analysis based on real $C'(\omega)$ and imaginary $C''(\omega)$ capacitances as a function of frequency. This important perspective from the dissertation may encourage future scholars to work on some creative ideas that could advance emerging alternative energy technology.

Kausik Sardar 12.09.2024

Kausik Sardar

(Signature of the candidate with date)

(Ex) Professor
Dept. of Mechanical Engineering
Jadavpur University, Kolkata 32

G. Majumdar 12.09.2024

Prof. Gautam Majumdar

(Signature of the Supervisor, date with office seal)