Flexible Fiber-Shaped Supercapacitor for Wearable Electronics

Abstract

The depleting natural resources and ever-increasing needs of energy led to environmental issues which attract immense attention of the researchers for future technology advancement in the field of energy conversion and storage. The electrochemical supercapacitors (SCs), also known as "ultra-supercapacitors" being a part of the electrochemical energy storage devices, attracted great attention owing to it high power delivery > 100 time higher than battery, long cyclic life $>10^5$ and high efficiency. In recent year some flexible wearable electronics have evolved in leaps and bounds and emerged as new market of portable and wearable electronics. To meet the requirement of this new market, fiber shaped SCs have been considered among flexible and stretchable solutions. This dissertation presents the fabrication, electrochemical performance testing and performance optimization of different flexible substrates for fiber shaped SCs. Nanoscale materials offer advanced and exciting fabrication techniques of SC electrodes for high-performance electrochemical energy storage devices. In material science, major challenge is to synthesize the nanomaterials with desirable chemical properties and to engineer the nanostructures in an appropriate way.

This thesis exhibits the successful fabrication and applications of very promising materials in electrochemical SCs for energy storage, including ZnO/Graphite composite, manganese dioxide deposition on carbon fibers (CFs), Fe_2O_3 composite with rGO aerogel and MoS_2. The prime objective is to understand their synthesis processes and electrochemical performance in supercapacitor devices. First of all, two parallel electrode configuration devices were assembled in gel-polymer electrolyte using ZnO/graphite as active material dip-coated on copper wire. The assembled device exhibits excellent performance as compared to bared graphite powder-based electrode in term of specific capacitance, energy and power density. The cyclic and bending stability has also been evaluated. Moving towards flexibility, other flexible substrates, transition metal oxides and their composites are investigated as electrode material for SCs. Here, I have selected CFs as flexible substrate and MnO_2 as active material. MnO_2 is electrodeposited (ED) on CFs using both potentiostatic and galvanostatic techniques. After comparing electrochemical performance, best performing deposition technique (galvanostatic deposition) was optimized by tuning deposition parameters such as, time and current density. The morphology of the

nanostructures and their electrochemical performance (specific capacitance, cycling effects and bending stability) which contribute to the understanding of the energy storage mechanism of MnO_2 based SCs is thoroughly investigated. In addition to single step deposition, the performance of MnO_2 on CFs (MnO_2/CF) electrode is further improved using 2-step ED of MnO_x by achieving the full coverage of the substrate and connectivity of the nanostructured material. The performance of the material was also improved by introducing oxygen vacancies on the MnO_x surface by hydrogenation process (obtaining Mn_3O_4) and subsequently optimized by electrochemical conversion of this spinel structure into Sodium Birnessite. Electrochemical performance and energy density of the supercapacitor is also enhanced by exploiting asymmetric configuration of the device in PVA based gel-polymer electrolytes. In this dissertation two asymmetric devices are assembled: i) MnO_x/CF and Fe_2O_3/rGO, ii) H-MnO_x and MoS_2 with former as cathodes and later as anodes material respectively. Both the devices have shown excellent electrochemical performance along with wide voltage windows 1.2 V and 1.8 V respectively which is fundamental for high energy density devices. The synthesis of electrodes described in this thesis exploiting electrodeposition technique is simple, cost effective, and environmental friendly approach. It possesses great potential to fabricate low-cost and high specific energy density SCs.