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The development supercapacitor from activated carbon by electroless plating—A review

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ABSTRACT

The electrochemical capacitor (EC), also called as supercapacitor, is an energy storage device possessing a unlimited life-cycle and high power density known to store energy in the double-layer or through supercapacitance as a result of an applied potential. Fundamental values in relation to the major chemical and physical qualities of electrode materials are explained in the following review, with carbon-made electrodes, specially activated carbon highlighted in regards to their improvement of the typical power and energy densities of ECs. Supercapacitive materials, remarkably transition metal oxides are revealed by the potential to further develop EC performance through synergistic effects and asymmetric design. Recently, several chemically deposited metal oxide thin film electrodes as well as ruthenium oxide, manganese oxide, cobalt oxide, nickel oxide, iron oxide, ferrites etc., have been evaluated in supercapacitors. This review presents supercapacitor performance data of metal oxide thin film electrodes on activated carbon offered by electroless plating as a suitable, fast and economical technique. The supercapacitors demonstrated the specific capacitance (Sc) principles, which are relatively comparable with bulk electrode values; therefore, it is likely that metal oxide films will continue to play a major role in supercapacitor technology and are expected to significantly develop the capabilities of these devices in the near future.

Contents

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1. Introduction

Supercapacitors have been recognized for over fifty years and are considered as one of the potential energy storage systems. Electrochemical capacitors (ECs), often described electrical double-layer capacitors (EDLCs), supercapacitors, ultracapacitors, pseudocapacitances, gold capacitors, power capacitors or power caches, have involved universal research interest because of their potential applications as energy storage devices in many fields. Electrochemical supercapacitors or capacitors are novel power devices, which lie between batteries and conventional dielectric capacitors in terms of energy and power densities with applications in computer power back-up, electric vehicles and power electronics. The major focus on developing supercapacitor materials has been on utilizing the double layer capacitance formed at the interface of the electrode and the electrolyte. Electric double layer capacitor (EDLC) is very attractive as an energy storage device because of its high energy density, maintenance-free long-life operation, quick charge–discharge rate, and environmentally friendly energy technology. For the application, activated carbons (ACs) are basic materials for EDLC electrode because of their highly porous structure, large surface area, good adsorption property, and high electrical conductivity [1]. The electrochemical performances of EDLCs are related to the pore structure, surface area, and surface chemistry of the ACs. Now, ACs with high surface area, suitable surface chemistry, and suitable pore structure are expected to be applied as excellent electrode materials to enhance EDLC with high performance. Although this capacitance per unit area is low $\sim$10–30 mF cm^{-2}, it can be improved appreciably by the use of materials with high specific surface areas [2]. The value also has major range due to the presence of edge sites and use of surface functional groups to activate the carbon. A variety of carbonaceous materials with their great specific surface areas and superior conductivity provide as ideal candidates for supercapacitor devices. Recently the researches have been also focused on the advance of an alternate class of supercapacitors based on fast reversible Faradaic reactions. Generally, identified as “pseudocapacitors” they consist of various transition oxides [3–16], transition metal nitrides [17], and conducting polymers [18–21]. The surface functional groups changes the electrochemical performance (such as capacitance, electrical conductivity, and self-discharge) of carbon materials in two different ways. On one hand, surface oxygen groups may develop the wettability between the carbon surface and the electrolyte solution. The more the surface oxygen groups content, the easier the interaction between interface and water molecules [8]. However, the surface oxygen groups may occur faradic reactions that can enhance the capacitance and self-discharge. Several chemically deposited metal oxide thin films as well as ruthenium oxide [16,22], iridium oxide, manganese oxide [10,23], cobalt oxide [5,24], nickel oxide [3,21], tin oxide [25], iron oxide [26,27], pervoskites [28], ferrites [29], lead dioxide (plumbic oxide) [30] etc., have been applied in supercapacitors. Classic electrodes can be fabricated by cathodic deposition and co-precipitation with use of polymer binders and additives. The polymer binder fuses active materials and permits the electrode to adhere to a current collector [31,32]. However, the polymeric binder material leads to reduced capacitance and increased resistance in the supercapacitor. Some of the experimental techniques to organize the carbon composites are as follows: wet impregnation [33–36], plasma reduction [24], pulse laser [23], sputtering [37], electrodeposition [32,38] and thermal evaporation [39,40].Wet impregnation is the most generally used, but good control of particle size and morphology are missing. Electrodeposition requires additional electricity and electrodes. Moreover, some of these techniques involve sophisticated equipment, long processing times and may make the demolition of the carbon structure. On the other hand, electroless deposition (ED) is an effective route to deposit metal nanoparticles [4,16,22] and polymers [31]. There are many advantages with the ED technique: low cost; high reproducibility, a simple process and the requirement of very simple equipment [41–47]. This review presents the investigation of supercapacitive performance of chemically deposited metal oxide thin film electrode materials by electroless deposition (ED) technique. The supercapacitors have revealed the specific capacitance (Sc) values, which are moderately comparable with bulk electrode values. Therefore, it is expected that these metal oxide thin films will continue to play a major role in supercapacitor technology.

2. Electrical energy storage mechanisms of electrochemical capacitors (ECs)

The charge-storage mechanism of ECs is predominately due to double-layer (DL) charging effects. But in common, further contributions of supercapacitance may also be part of the observed capacitance due to the functional groups present on the electrode surface. The major advantages of ECs are that they can offer high power excellent reversibility (90–95% or higher), capability (60–120 s is typical), and long cycle life (> 105). Classically they exhibit 20–200 times larger capacitance per unit volume or mass than conventional capacitors [48,49]. Therefore, a number of applications of ECs are used in electric vehicles, electric hybrid vehicles, electric tools, digital communication devices, mobile phones, digital cameras, pulse laser technique, uninterruptible power supplies for computers, and storage of the energy generated by solar cells [50–52].

Capacitors based on the charge-storage mechanisms, can be classified into two types: EDLC and Faradaic supercapacitor, the descriptions of which are explained in the following next section. The EDLC, generally focusing on carbon materials, which arising from the charge separation at the electrode/electrolyte interface, whereas faradic supercapacitor materials, such as cerium oxide [15], titanium oxide [8], vanadium oxide [53], cobalt oxides [5,54–56], nickel oxide [9,54], manganese oxide [10,11,57,58], indium oxide [59], bismuth oxide [60], tin oxide [59] and ruthenium oxide [61–65], which not only store energy like an EDLC, but also display electrochemical faradic reactions between ions and electrode materials in the suitable potential window. To develop ECs performance, especially its specific energy while retaining its basic high specific power, many researchers have focused their efforts mostly on improving the properties of electrode materials. The main classes of materials applied for ECs include different forms of carbon, transition metal oxides, and conductive polymers [10]. Over the last few years, a number of groups have reported capable research on ECs based on polymer electrodes. As stated earlier, these materials are weight, cheap, suitable morphology, fast doping–undoping process, and can be comparatively simply manufactured into ECs. However, the long-term stability during cycling may