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# Electrochemical performance of $RuO_x$/activated carbon black composite for supercapacitors

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ABSTRACT

Hydrous ruthenium oxide/activated carbon black ($RuO_x$/ACB) composite was synthesized for the first time for supercapacitors by a chemical impregnation method. The $RuO_x$/ACB composite is characterized by thermogravimetric analysis (TGA), field emission scanning electron microscope (FE-SEM) and transmission electron microscope (TEM). The results of TGA and TEM characterization showed that the reaction temperature of composite moved to lower temperature due to the catalytic effect of $RuO_x$. XRD characterization of $RuO_x$/AC illustrated that amorphous hydrous $RuO_x$ structure maintained in the composite heated at 150 °C. The equivalent series resistance (ESR) of the composite almost increased with the increase of $RuO_x$ content in the composite. The specific capacitance ($C_{sp}$) of the composite increased with increasing $RuO_x$ content in the composite while the $C_{sp}$ of $RuO_x$ decreased from 1255.8 to 533.7 $F g^{-1}$. The above results showed that the utilization of $RuO_x$ decreased with higher loading $RuO_x$ on ACB.



## 1. Introduction

Supercapacitors have attracted increasing interest in the power sources due to its short charging time, high power density and long cycle life [1]. Supercapacitors included electric double layer capacitor (EDLC) and Faradic capacitor according to the charge storage mechanism. The charge storage in an EDLC is based on the double layer process at the electrode–electrolyte interface while the charge storage in a Faradic capacitor is based on the Faradic redox reactions. Ruthenium oxide ($RuO_x$) is known as the best electrode material of the Faradic capacitor due to its outstanding specific capacitance ($C_{sp}$) and long cycle life [2,3]. However, its practical utilization was limited because of the high cost of ruthenium element. Thus, interest in research has focused on developing a hybrid system that consists of an electrochemical double layer process and a Faradic redox reaction with $RuO_x$/carbon composite materials. Carbon materials used as electrode materials in the hybrid system included activated carbon [4–8], carbon aerogels [9], carbon nanotubes [10–13] and carbon black [14–16]. The $C_{sp}$ of supercapacitor relied on the content and microstructure of $RuO_x$ as well as the specific surface area of the composite. Miller et al. [9] reported that the high annealing temperature of ca. 300 °C initiated a crystalline transition of $RuO_2$ particle on the carbon aerogel and resulted in that the $C_{sp}$ of the composites obtained by chemical vapor impregnation is lower than that of the composites obtained by the sol–gel method. Zheng et al. [17] found that $RuO_2$ performance is highly sensitive to the annealing temperature and that its structure changed from amorphous to crystalline above 175 °C. Zhang et al. [4] reported that $RuO_2$/AC powers had the highest $C_{sp}$ when the powers were annealed at 150 °C.

In this paper, hydrous ruthenium oxide/activated carbon black ($RuO_x$/ACB) composite was synthesized by a chemical impregnation method and the effect of $RuO_x$ content in the composite on the equivalent series resistance (ESR) and the $C_{sp}$ were investigated. The aim of this research is to find the optimal $RuO_x$ content in the composites for the maximum $C_{sp}$ of the electrode material of supercapacitors.

## 2. Experimental

### 2.1. Preparation and characterization of the composite electrodes

Ruthenium precursors were impregnated onto ACB powders with a specific surface area of 1270 $m^2 g^{-1}$ and primary particle size of 34 nm. The $RuCl_3$ precursor solution was injected into a cup that was previously charged with dried ACB powders under stirring by a magnetic bar. The ruthenium complex colloidal solution formed with a slow addition of 1 M ammonium hydrogen carbonate ($NH_4HCO_3$) solution into the aqueous $RuCl_3$/ACB solution. The

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