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SCIENCE DIRECT®
Journal of Power Sources 140 (2005) 162–167
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Short communication

Novel electrode substrates for rechargeable lithium/polypyrrole batteries

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Received 16 May 2004; received in revised form 18 July 2004; accepted 9 August 2004
Available online 28 October 2004

Abstract

A lightweight and inexpensive stainless steel mesh has been investigated as an electrode substrate material for Li/polypyrrole rechargeable battery. The effects of substrate materials on surface morphology of films, charge–discharge capacity and coulombic efficiency are discussed in detail. The results show that the capacity of the cell with stainless steel mesh is about 10% lower than the cell using platinum mesh, but it is much lighter and cheaper than that of platinum mesh, therefore, it is a promising substrate material for Li/polymer batteries.

Keywords: Conducting polymer; Battery; Charge/discharge; Capacity; Stainless steel

1. Introduction

In recent years, many different types of electroactive conducting polymers have been synthesized [1]. Among these polymers, conducting polypyrroles have drawn the most attention due to their superior electroactivity, good electrical conductivity and chemical stability. Owing to their physical, chemical and electrochemical properties, polypyrroles have been applied in many different fields including sensors [2], cable shielding [3], ion-selective membranes [4] and electrocatalysis [5–7]. Very recently, the application of polypyrrole as cathode material for rechargeable batteries has also been reported [8–10].

Fabrication of conducting polymer electrodes involves the use of a conductive substrate. To date, platinum foil is almost exclusively used as the electrode substrate for polymer based batteries [11–13]. Despite good performance, the use of a platinum substrate may never become a practical choice due to cost. In order to select a commercially available substrate material for commercial polymer batteries, lightweight and inexpensive stainless steel mesh was chosen and investigated as substrate material in this work. To the best of our knowledge, there has been no report on the use of stainless steel mesh as the substrate for fabrication of polymer based battery. In this work, the performance characteristics of the polypyrrole-based batteries using stainless steel mesh as the substrate electrode were evaluated by comparison with batteries constructed using platinum mesh.

2. Experimental

2.1. Reagents and materials

Propylene carbonate (Aldrich) and $LiClO_4$ (Aldrich) used for preparing polypyrrole electrodes were both of RG grade and used as received. The $LiClO_4$ used for electrolyte of cell testing was vacuum-dried at about 100 °C for 24 h. Pyrrole monomer from Merck was distilled and stored below −18 °C before use. Silver nitrate (BAS), tetrabutylammonium perchlorate (TBAP, Fluka) and acetonitrile (APS) were used as-received.

Two types of materials, platinum mesh (Engelhard-Clal Australia Pty Ltd.) and stainless steel mesh (Metal Mesh Pty Ltd., Australia), were used as electrode substrates for fabrication of polymer electrodes.

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doi:10.1016/j.jpowsour.2004.08.040

2.2. Preparation of polypyrrole electrodes

All experiments were carried out using a three-electrode electrochemical cell. The potential required for polymerization and chronoamperometry was applied using an EG&G Princeton Applied Research (PAR) Model 363 potentiostat/galvanostat. A BAS CV-27 voltammograph was employed for cyclic voltammetry. The data was processed and recorded by a MacLab/4e (ADInstruments) interfaced with a computer. The reference electrode was Ag/Ag^+ (in 0.01 M $AgNO_3$, 0.1 M TBAP/CH_3CN).

2.2.1. Cyclic voltammetry and chronoamperometry

Using platinum mesh or stainless steel mesh, cyclic voltammetry was performed by scanning the potential between 0 and 0.8 V at a rate of 100 mV s^{-1}. The electropolymerization solution contained 0.16 M pyrrole and 0.75 M $LiClO_4$ in propylene carbonate (PC).

Chronoamperometry was then performed for 2 min at applied potentials of +0.5, +0.6, +0.7, +0.8 and 0.9 V. From these data, the conditions for preparing the polypyrrole electrode for batteries were selected.

2.2.2. Electropolymerization

The conducting polypyrrole electrodes were fabricated by a single-step electropolymerization of polypyrrole onto platinum mesh (30 mm × 70 mm × 1.5 mm) or stainless steel mesh (30 mm × 70 mm × 1.5 mm). Polymer samples were grown by electropolymerization from a solution of 0.16 M pyrrole, 0.75 M $LiClO_4$ in propylene carbonate (PC) at 0.75 V (versus Ag/Ag^+ in 0.01 M $AgNO_3$, 0.1 M TBAP/CH_3CN) to a total deposition charge density of 12.5 C cm^{-2}. Following electropolymerization, these electrodes were dried in a vacuum oven for 24 h at room temperature, then cut to a small size of 1 cm^2 and transferred to an argon-filled glove box. The weight of polymer was about 6 mg. The dried electrodes were assembled into cells and were tested.

2.3. Conductivity measurement

The resistance measurements of the substrates and polypyrrole electrodes were performed on long strips using the ASTM four-probe technique. A DC current of 0.5 mA was applied across the two electrodes using an EG&G PAR 363 and the voltage drop across the two inner electrodes was measured using a HP multimeter (Model 34401A).

2.4. Cell assembly and testing

A polypropylene microporous separator was used in the cells. The separator was sandwiched between the two electrodes. The electrolyte used was 0.5 M $LiCO_4$ dissolved in PC. The electrolyte solution was dried several weeks over molecular sieves to reach less than 20 ppm of water content. Lithium foil of 300 μm thickness and area of 0.78 cm^2 was used as the negative electrode. Cells were assembled in an argon-filled glove box (Unilab, Mbraun, USA) with both water and oxygen concentrations less than 5 ppm.

Charge/discharge tests were carried out by using a battery testing device (Neware, Electronic Co., China) interfaced to a computer with software. The system is capable of switching between charge and discharge automatically according to the pre-set cut-off potentials. The cells were cycled between 2.5 and 4.3 V with a constant current of 0.1 mA cm^{-2}.

2.5. Electrochemical AC impedance analysis

Impedance analysis was conducted using a conventional three-electrode configuration. Polypyrrole electrodes were used as the working electrode. Lithium foils were used as both counter and reference electrodes. The impedance was measured with an EG&G Model 6310 Electrochemical Impedance Analyzer (Princeton Applied Research) run by Model 398 software within a frequency sweep range of 10 000 kHz–0.01 Hz.

2.6. Scanning electron microscopy (SEM)

Morphologies of the electrodes were examined using a Leica Model Stereoscan 440 scanning electron microscope manufactured in the UK. SEM examinations were carried out at room temperature under an accelerating voltage of 20 kV.

3. Results and discussion

3.1. Physical properties of substrates

Since a major function of the substrate is to be a collector for current during charge and discharge reactions in a battery, the conductivity of the substrate is one of the most important parameters in selecting electrode substrates. The conductivity of the test substrates investigated here was measured (Table 1). The platinum mesh and the stainless steel mesh all show good conductivity with the conductivity of the platinum mesh more than double that of the stainless steel mesh.

Non-reactive components add to the weight and volume of the battery [14]. Therefore, reducing the weight of the non-capacity contributing components, such as substrate, can improve the specific energy of the batteries [15,16]. The weights of the tested substrates in this work are listed in Table 1. The weight of the stainless steel mesh is just about one quarter of the weight of the platinum mesh. So using lightweight

Table 1
Physical properties of tested substrates

Substrate	Conductivity (S cm^{-1})	Weight (mg cm^{-2})
Platinum mesh	6.8×10^3	62.3
Stainless steel mesh	3.1×10^3	16.8