Applied Energy 153 (2015) 41–47

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Porous carbon made from rice husk as electrode material for electrochemical double layer capacitor ☆

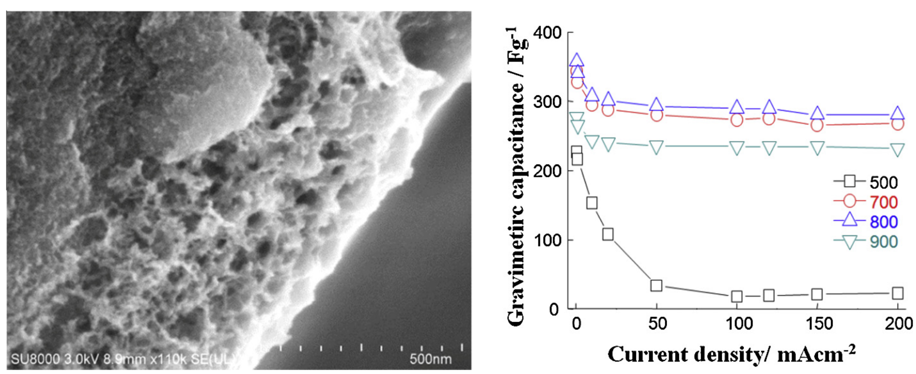
Yu Gao [a], Lei Li [a], Yuming Jin [a], Yu Wang [a], Chuanjun Yuan [b], Yingjin Wei [a], Gang Chen [a], Junjie Ge [c,*], Haiyan Lu [b,*]

[a] Key Laboratory of Physics and Technology for Advanced Batteries, Ministry of Education, College of Physics, Jilin University, Changchun 130012, PR China
[b] College of Chemistry, Jilin University, Changchun 130012, PR China
[c] Hawaii Natural Energy Institute, University of Hawaii – Manoa, Honolulu, HI 96822, United States

HIGHLIGHTS

- Rice husks were converted into activated carbon by KOH activation.
- The highest specific surface area of porous carbon is as high as 3145 $m^2\,g^{-1}$.
- The highest gravimetric capacitance performance is 367 F $g^{-1}$and 174 F g^{-1} in aqueous and organic electrolytes.
- The rice husk supercapacitor shows excellent rate performance and cycling stability.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 27 July 2014
Received in revised form 24 December 2014
Accepted 26 December 2014
Available online 28 January 2015

Keywords:
Porous carbon
Rice husk
KOH-activation
Cycle-life
Supercapacitors

ABSTRACT

Rice husks were converted into activated carbon by KOH activation, at temperatures between 400 and 900 °C and used in a two-electrode supercapacitor. The rice husks contain SiO_2 nano-crystals surrounded by an amorphous carbon matrix. The activated carbons maintained their size and shape after the synthesis process and the ordering degree of carbon increased at elevated temperatures. The highest BET surface area of the activated carbons was around 3145 $m^2\,g^{-1}$. Electrochemical properties of the studied samples were measured using a two electrode cell in 6 M KOH and 1.5 M tetraethylammonium tetrafluoroborate in acetonitrile. The material synthesized at 800 °C showed the highest gravimetric capacitance performance of 367 F $g^{-1}$and 174 F g^{-1} in aqueous and organic electrolytes, respectively. In contrast to the commercial activated carbons, rice husk activated carbon (RHAC), this material showed excellent high-power handling ability and electrochemical cycle performance, after 30000 cycles the capacitive value almost remained unchanged.

1. Introduction

Since electric motors and generators were invented in the 1870s, electrical energy has become the most important secondary energy source and the primary form of consumed energy. Supercapacitor [1] is one kind of typical electrochemical energy

☆ This paper is included in the Special Issue of Electrochemical Supercapacitors for Energy Storage and Conversion, Advanced Materials, Technologies and Applications edited by Dr. Jiujun Zhang, Dr. Lei Zhang, Dr. Radenka Maric, Dr. Zhongwei Chen, Dr. Aiping Yu and Prof. Yan.

* Corresponding authors.
E-mail addresses: gejunjie@hawaii.edu (J. Ge), luhy@jlu.edu.cn (H. Lu).

http://dx.doi.org/10.1016/j.apenergy.2014.12.070
0306-2619/

storage devices, which stores electricity in electrochemical processes. Supercapacitors are drawing much attention because of their long cycle life and high power storage capability [2], which are highly desirable for applications in hybrid electric vehicles, medical devices, consumer devices and power backup systems [3–6]. The performance of supercapacitors is intimately related to the electrode materials used. One material that show promise as the primary material in the production of supercapacitor electrodes is porous carbon materials because of its environmentally benign nature, high conductivity and good physical–chemical stability [7].

Porous carbons can be prepared from cheap agricultural wastes and residues [8–12]. In the rice milling industry rice husks are the main by-product that is formed. With an annual production of 1.2×10^8 tons rice husks worldwide [13], some countries have utilized the product as a cheap energy resource. However the excess that is not used is either burned in the field or discarded. There is great motivation to further utilize the rice husk in other products such as the production of silica or porous carbon materials. This is an efficient way to utilize discarded rice husk resources.

The purpose of this article is to explore the use of porous carbon electrodes derived from rice husks in supercapacitors. The porous carbons are prepared by potassium hydroxide (KOH) activation following procedures reported by Guo et al. [14]. The pore structure, chemical surface and electrochemical property are determined for the rice husk electrodes and compared to other activated carbon materials produced from other agricultural wastes and residues such as firewood, banana fiber, cassava peel and celtuce leaves. It is found that porous carbon made from rice husk exhibit much higher specific capacity and better cycling performance compared with other agricultural wastes.

Table 1
Values of SSA, pore size, and pore volume acquired from N_2 gas sorption for porous carbons and the precursor.

	BET SSA ($m^2\,g^{-1}$)	Total pore (volume/$cm^3\,g^{-1}$)	Average pore size (nm)
Precursor	188	0.13	6.57
500 °C	467	0.21	6.03
600 °C	1720	0.59	6.68
700 °C	2301	0.67	6.82
800 °C	3097	2.08	7.09
900 °C	3145	2.68	7.23

2. Experimental

2.1. Raw materials

The original rice husks, which were provided by a rice mill in Jilin province, China, were washed completely by deionized water to remove any dirt and dust. The husks were dried at 110 °C overnight, then carbonized into porous carbon material under N_2 flow at 450 °C for 0.3–1.0 h. The material was ground to have a particle size between 2 and 3 mm.

2.2. Treatment of porous carbon material

The porous carbon material was chemically activated by KOH activation by preparing a KOH/material mixture with a 4:1 weight ratio. The mixture was placed in a nickel pot and calcined in a muffle furnace at the desired temperature (400–900 °C) for several hours under nitrogen atmosphere. The sample was then washed with deionized water to neutralize the material and then dried at 120 °C overnight.

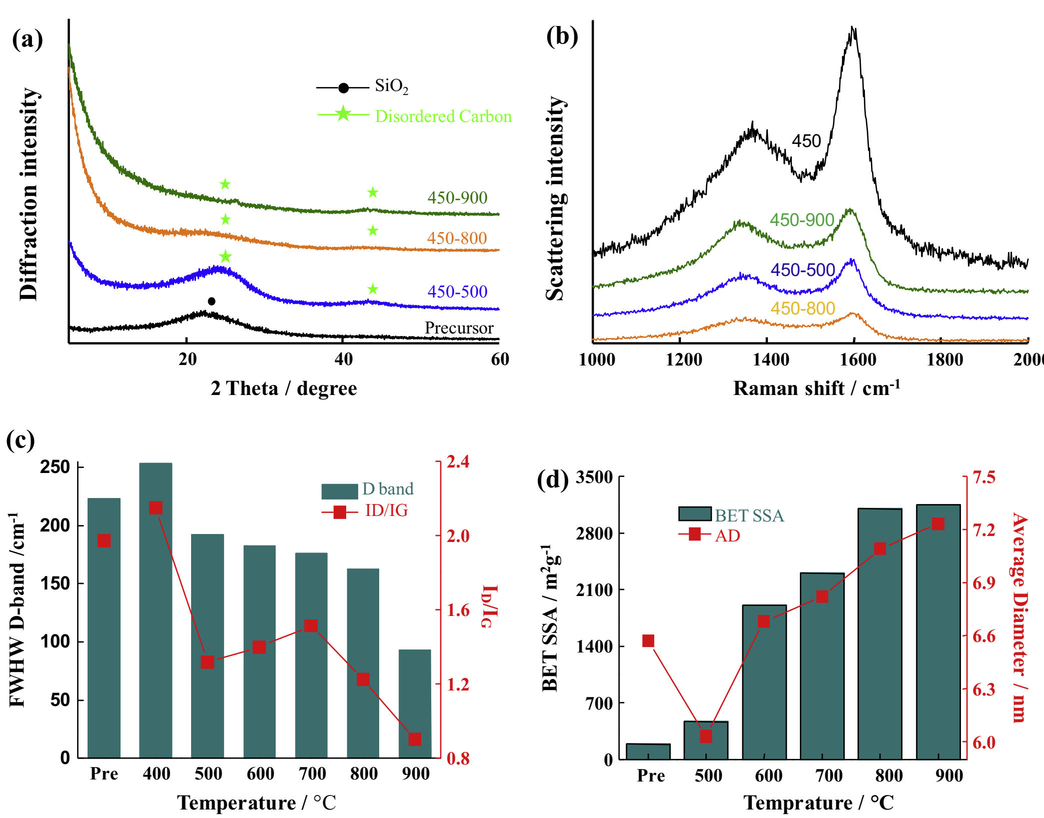


Fig. 1. XRD pattern (a) and Raman spectra (b) of rice husk activated carbons (RHACs) and their precursor. The dependence of FWHM of D-band and ID/IG ration on the synthesis temperature (c). SSA and average pore diameter as a function of activation temperature (d).