



Novel microporous carbon prepared from discarded clothes as host materials for high performance lithium-sulfur battery

Xu Sun^a, Ying Huang^{a,*}, Menghua Chen^a, Yanli Wang^a, Xiaogang Gao^a, Lihao Wang^b

^aThe MOE Key Laboratory of Material Physics and Chemistry under Extraordinary Conditions, Ministry of Education, School of Science, Northwestern Polytechnical University, Xi'an 710129, China

^bNO. 203 Research Institute of China Ordnance Industries, Xi'an 710065, China



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ABSTRACT

Novel microporous carbon materials (DCMC) with excellent electron conductivity and ultrahigh surface area ($1896.9 \text{ m}^2 \text{ g}^{-1}$) are successfully prepared from discarded clothes. The porous carbon-encapsulated sulfur composites were synthesized by a feasible melting process and used as host materials for lithium sulfur batteries. Because of the unique microporous, ultrahigh surface area and irregular wrinkled surface coexisting structure, the resulting microporous carbon/sulfur (DCMC/S) composite cathode possesses a good rate capability and long-term cycling performance. The initial discharge capacity of the DCMC2/S composite electrode with 74.3 wt% sulfur content is $1082.6 \text{ mAh g}^{-1}$ at a current rate of 0.2 C. At a higher current rate of 1 C, it possesses excellent cyclic performance and retained a capacity of 422.8 mAh g^{-1} after 500 cycles with a low capacity fading rate of 0.11% per cycle. The coulombic efficiency remains over 98% during cycling.

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1. Introduction

With an increasing demand for high energy density storage system, more and more attention has been paid to the research of rechargeable Li-ion batteries. Nevertheless, the current Li-ion batteries are limited by the low capacity, high cost, and unsafety [1–3]. Rechargeable lithium-sulfur battery has aroused researchers' attention because of the high theoretical specific capacity (1675 mAh g^{-1}) and theoretical energy density (2600 Wh kg^{-1}) [4–6]. Sulfur as a suitable cathode material also has other advantages such as natural abundance, nontoxicity and environmental benignity. However, the commercialization of Li-S battery is still hindered by some chronic issues: (1) the sulfur and reduction products (Li_2S_2 and Li_2S) are electronically insulating at room temperature resulting in the low utilization of sulfur and low practical capacity. (2) The highly dissolved polysulfide intermediates spontaneously shuttle between the sulfur cathode and metal lithium anode leading to low coulombic efficiency and capacity decay. (3) The obvious volumetric expansion ($\sim 80\%$) of sulfur cathode during charging and discharging process, which causes insufficient cycle life [7–10]. To solve these problems, considerable approaches have been proposed to improve the electrical conductivity of the cathode and retard diffusion of polysulfide in organic electrolytes.

One of the most effective means is to encapsulate sulfur with host matrixes to construct composite materials, particularly porous carbon [11]. Porous carbon materials have excellent conductivity, high pore volume and large surface area. They provide excellent conductivity for sulfur and discharging products, improving the utilization rate of active materials. Moreover, the porous structure, large surface area and strong adsorption can alleviate the diffusion of polysulfides.

Discarded clothes are abundant in our daily life. In this work, we first report a novel and simple way to prepare microporous carbon from discarded clothes (DCMC) by a carbonization and KOH activation process. The optimized microporous carbon DCMC2 with ultrahigh surface area ($1896.9 \text{ m}^2 \text{ g}^{-1}$) can encapsulate high sulfur content. The microporous carbon/sulfur composites (DCMC/S) were synthesized by simple melting diffusion treatments. As expected, the electrochemical properties of DCMC/S composite cathode delivered a high specific capacity, excellent cycling stability and good rate capability.

2. Experiment

2.1. Preparation of DCMC/S composites

The discarded clothes made of pure cotton were collected, and then cleaned using deionized water. After being dried in the oven at $80 \text{ }^\circ\text{C}$ for 24 h, they were cut into pieces. The dried discarded

* Corresponding author.

E-mail address: yingh@nwpu.edu.cn (Y. Huang).

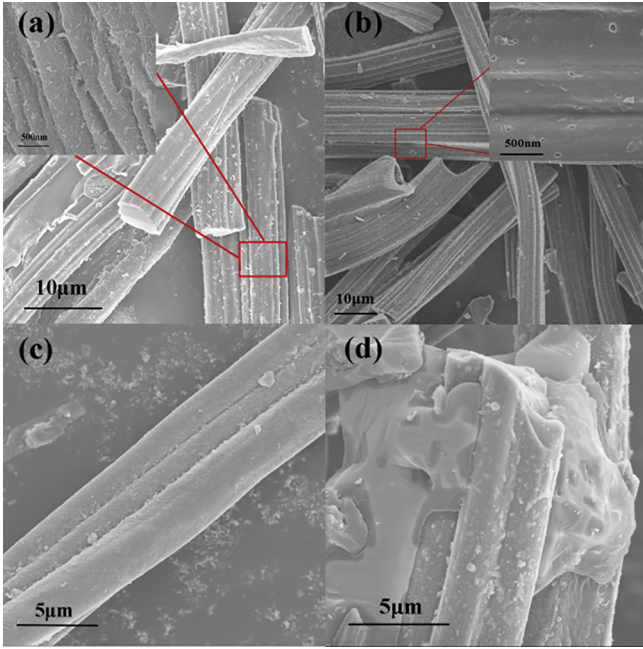


Fig. 1. SEM images of (a) DCMC, (b) DCMC2, (c–d) DCMC2/S composite.

clothes were carbonized in a tube furnace under Ar atmosphere at 500 °C for 2 h with a heating rate of 2 °C min⁻¹. The obtained carbonized discarded clothes after milling were mixed with KOH (w/w = 1:2, 1:4) in ethanol. The mixture was stirred thoroughly for 3 h at room temperature, and then dried at 80 °C in an oven. Then the mixture was activated in a tube furnace at 900 °C for 3 h under an argon atmosphere. The obtained carbon materials were washed with 1 M HCl three times, washed several times with deionized water, and then dried at 80 °C in the oven over night to obtain the DCMC1 and DCMC2. The as-prepared DCMC and sublimed sulfur with the weight ratio of 1:4 were ground together, and subsequently heated at 155 °C for 12 h in a sealed glass tube, the resultant denoted as DCMC1/S or DCMC2/S.

2.2. Materials characterization

The surface morphologies of samples were characterized through field-emission scanning electron microscopy (FE-SEM, Carl Zeiss SIGMA). The crystal structure was tested with X-ray diffraction ((XRD, CuKα radiation, PANalytical, Holland). The sulfur content in the DCMC/S composites was determined by the thermo gravimetric/differential thermal analysis (TG/DTA) measurement (Netzsch STA 449C thermal analyzer). The N₂ adsorption–desorption isotherm and pore size distribution was obtained using a Brunauer Emmett-Teller (BET, BEL LAPAN, INC. Belsorp2).

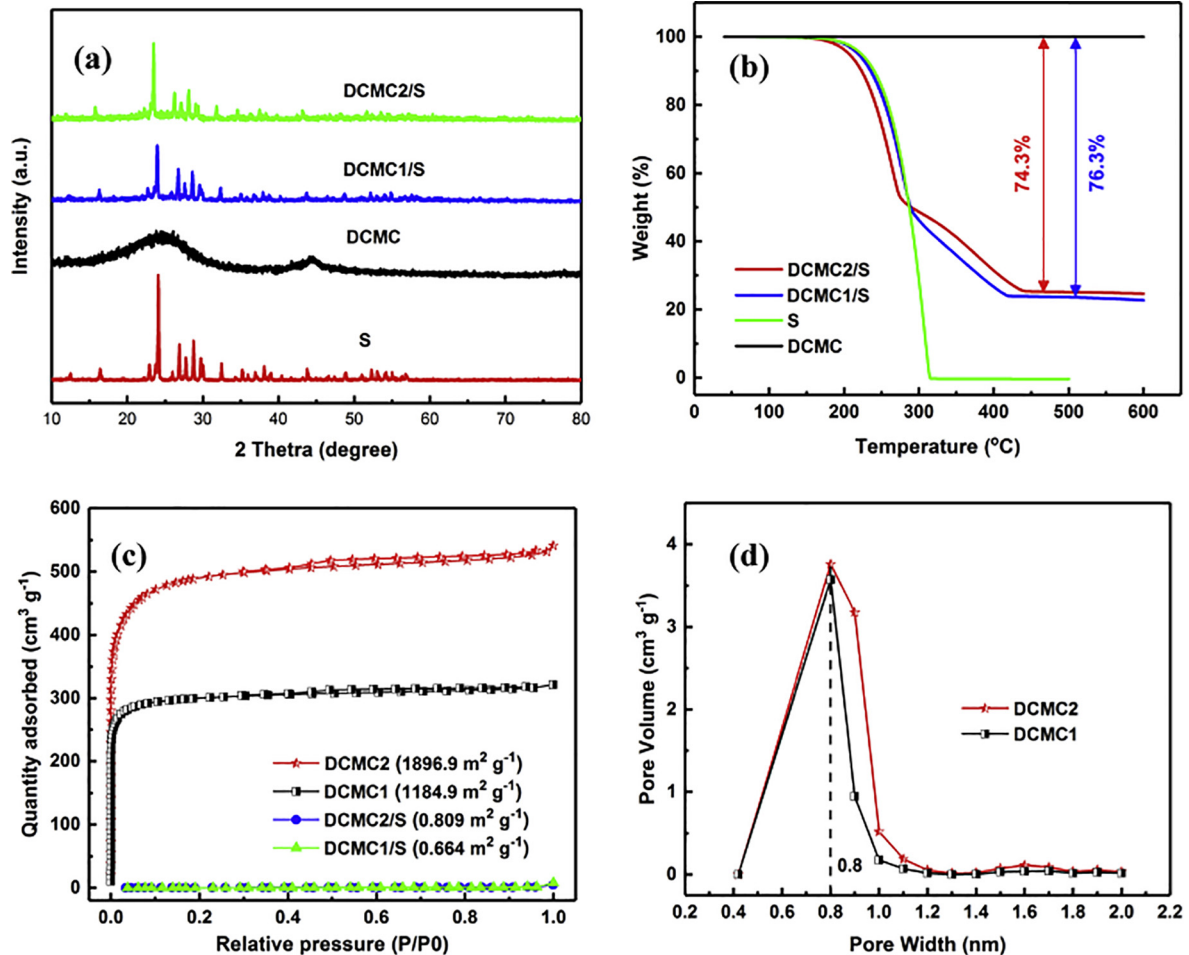


Fig. 2. (a) XRD pattern of sulfur, DCMC, DCMC1/S and DCMC2/S; (b) TGA curves of DCMC1/S, DCMC2/S and sulfur; (c) Nitrogen adsorption–desorption isotherms of DCMC1, DCMC2, DCMC1/S and DCMC2/S; (d) Pore size distribution of the DCMC1 and DCMC2.

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