Biomass-derived porous carbon decorated with NiO nanoparticles for lithium-sulfur batteries

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Lithium-sulfur batteries (LSBs) are recognized as the next-generation energy storage systems in view of their extremely high theoretical specific capacity (1675 mAh g^{-1}) and theoretical energy density (2600 W h kg^{-1}) [1]. However, the major drawbacks commonly associated with low sulfur electrical conductivity, cathode's volume expansion during cycling and irreversible lithium polysulfides shuttle still significantly limit their practical application [2].

To overcome these drawbacks in the current work the highly porous and conductive carbon matrix was developed from the natural biomass source (rice husk) by carbonization and thermo-chemical activation methods, which was further applied as a matrix for fabrication of the cathodes by sulfur immobilization via melt-diffusion process. The studies revealed that the specific surface area of the biomass-derived carbon is higher than 2200 m^2 g^{-1}, the average pore size is in the range from 2 to 4 nm and its consists of the few-layered graphene-like structure. After sulfur immobilization the specific surface area decreased drammaticaly to nearly 200 m^2 g^{-1} confirming the successful sulfur encapsulation in the pores of the carbon. The prepared carbon and carbon/sulfur cathode material were characterized by various techniques including SEM, SEM-EDS, TEM, Raman-spectroscopy, TGA, XPS, BET.

Further, to suppress the lithium polysulfides shuttle effect the prepared carbon was decorated with NiO nanoparticles using $NiNO_3$ aqueous solution. As a result, the homogenious distribution of the NiO particles with an average size of less than 40 nm was achieved and this composite is characterized by the synergistic effect for lithium polysulfides physical trapping (carbon) and chemical confinement (polar NiO).

The electrochemical performance of the prepared cathode materials was investigated. The CR2032 coin-type cells were used for conducting electrochemical measurements. The cell consisted of the developed carbon/sulfur cathode with an areal sulfur loading of nearly 1.5 mg cm^{-2}, Li metal as an anode and commercial Celgard separator modified with carbon/NiO composite. The lithium bis-(trifluoromethane) sulfonamide (LiTFSI, 1 M) with lithium nitrate ($LiNO_3$, 2 wt.%) in 1,3-dioxolane (DOL) and 1,2-dimethoxyethane (DME) (1:1, v/v) was applied as an electrolyte.

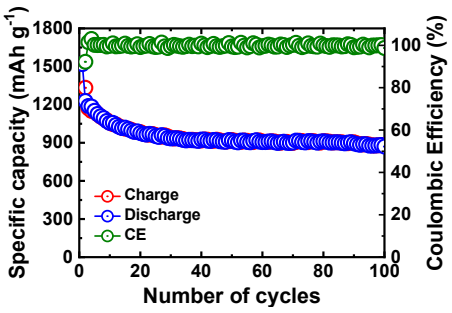

Figure 1. Cycling performance of the assemled cell

As a result, the cell based on biomass-derived/sulfur cathode combined with carbon/NiO modified separator delivered high initial discharge capacity of 1511 mAh g^{-1} at 0.2 C with the capacity retention of nearly 70% from the 3rd cycle. The first 3 cycles are responsible for the stabilization of the battery during which the SEI is formed and the cell is completely stabilized. The Coulombic efficiency of the cell is around 98% over 100 cycles. The cells are under the continious investigation at the moment.

In summary, replacing expensive commercial carbons like graphene, CNTs, and fullerenes with cost-effective biomass carbon is a promising approach for developing practical LSBs. However, further research is necessary to explore sulfur immobilization methods, separator modification, electrolyte customization, and anode protection.

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References

[1] C. Deng, Z. Wang, L. Feng, S. Wang, J. Yu, *J. Mater. Chem. A* 2020, *8*, 19704.

[2] M. Zhao, Y.-Q. Peng, B.-Q. Li, X.-Q. Zhang, J.-Q. Huang, *J. Energy Chem.* 2021, *56*, 203.

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