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Research on sodium sulfur battery for energy storage

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Abstract

Sodium sulfur battery is one of the most promising candidates for energy storage applications. This paper describes the basic features of sodium sulfur battery and summarizes the recent development of sodium sulfur battery and its applications in stationary energy storage. The research work in the Shanghai Institute of Ceramics, Chinese Academy of Sciences (SICCAS) on beta-Al_2O_3 ceramics and the sodium sulfur battery is also introduced.

Keywords: Sodium sulfur battery; Energy storage; Solid electrolyte; Design

1. Introduction

Sodium sulfur battery is one of the most promising candidates for energy storage applications developed since the 1980s [1]. The battery is composed of sodium anode, sulfur cathode and beta-Al_2O_3 ceramics as electrolyte and separator simultaneously. It works based on the electrochemical reaction between sodium and sulfur and the formation of sodium polysulfide and exhibits high power and energy density, temperature stability, moreover low cost because of its abundant low-cost raw materials and suitability for high volume mass production [2–4]. Great achievements have been made during the last two decades, especially under the collaboration of Tokyo Electric Power Company (TEPCO) and NGK Insulator, Ltd., (NGK). The batteries have been applied in various ways such as load leveling, emergency power supply and uninterruptible power supply. The markets covered industrial, commercial owners and wind power generating systems etc.

This paper summarizes the recent development of sodium sulfur battery, especially its applications in stationary energy storage, and introduces the research work in SICCAS.

2. Basic description and state-of-the-art

Details of the sodium sulfur battery were first released in 1966 by Ford Motor Company. Sodium sulfur battery applies sodium and sulfur as the anode and cathode respectively, and beta-Al_2O_3 ceramic acts as both the electrolyte and separator simultaneously. Tubular configuration of the sodium sulfur battery allows the volume change of the electrodes during cycling and minimizes the sealing area and therefore become the popular design for practical battery design [2,5–7]. Fig. 1 illustrates the tubular design of sodium sulfur battery with central sodium electrode. The central sodium geometry is the preferred type for the tubular design, in which the sodium is contained within the electrolyte tube. Besides the central sodium design, central sulfur geometry and planar design are also possible choices for sodium sulfur battery.

The sodium sulfur battery works based on the electrochemical reaction between sodium and sulfur and the formation of sodium polysulfide. While discharge, the sodium metal in the anode compartment is oxidized to Na^+ ions as reaction (1) described and transports across the beta-Al_2O_3 ceramic electrolyte membrane and combines with reduced sulfur anions formed by reaction (2) to generate sodium polysulfide NaS_x in the sulfur compartment. The overall cell reaction is expressed as Eq. (3).

Anode reaction $$2Na = 2Na^+ + 2e^- \quad (1)$$

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Cathode reaction $xS + 2e^- = S_x^{2-}$ (2)

Overall cell reaction $2Na + xS = Na_2S_x$. (3)

While charged, the reverse reactions happened, with the sodium polysulfide decomposed to sodium and sulfur, respectively return to the anode and cathode compartments. The open circuit voltage of the cell at 350 °C is 2.075 V.

Sodium sulfur battery usually works at the temperature raging between 300 and 350 °C, at which sodium and sulfur as well as the reaction product polysulfide exist in liquid state, which affords high reactivity of the electrodes. Therefore, sodium sulfur battery exhibits high power and energy density, temperature stability, moreover low cost and good safety. The specific energy density of the battery reaches 760 W h/kg at 350 °C, nearly three times of that for lead acid battery, leading to about one third the spaces required for the lead acid battery in similar commercial applications. The battery has no self discharge; therefore 100% columbic efficiency could be attained. There is no intermediate reaction and 85% average DC conversion efficiency can be realized. Since no pumps, valves or exchangers are necessary in the batteries, only field maintenance requirements are limited to periodic inspection and cleaning. Sodium sulfur battery is environmentally benign, since the battery is completely sealed and allows no emissions during operation. More than 99 wt.% of the battery materials can be recycled. Only sodium must be handled as a hazard material.

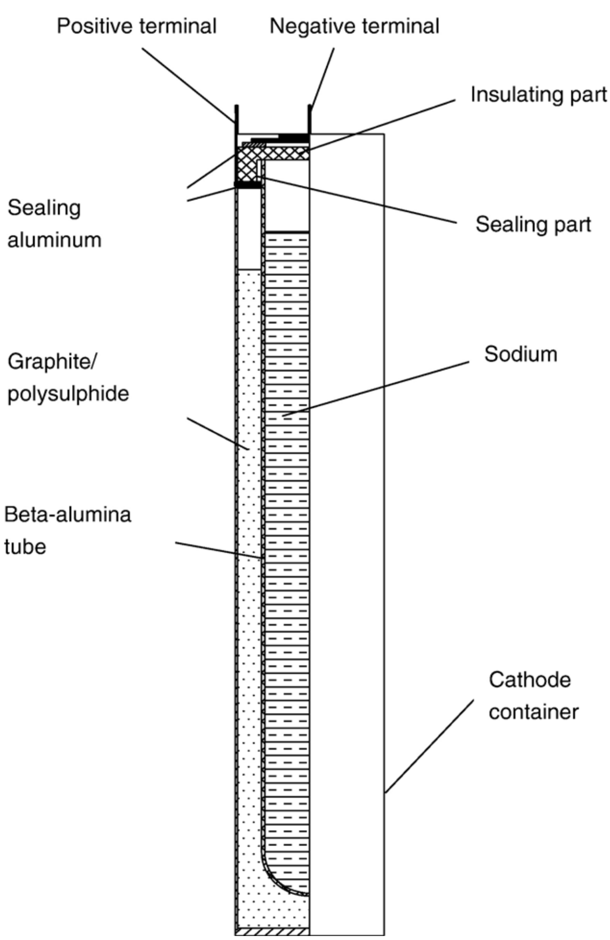

Fig. 1. Schematic illustration of a central sodium electrode tubular Na–S cell.

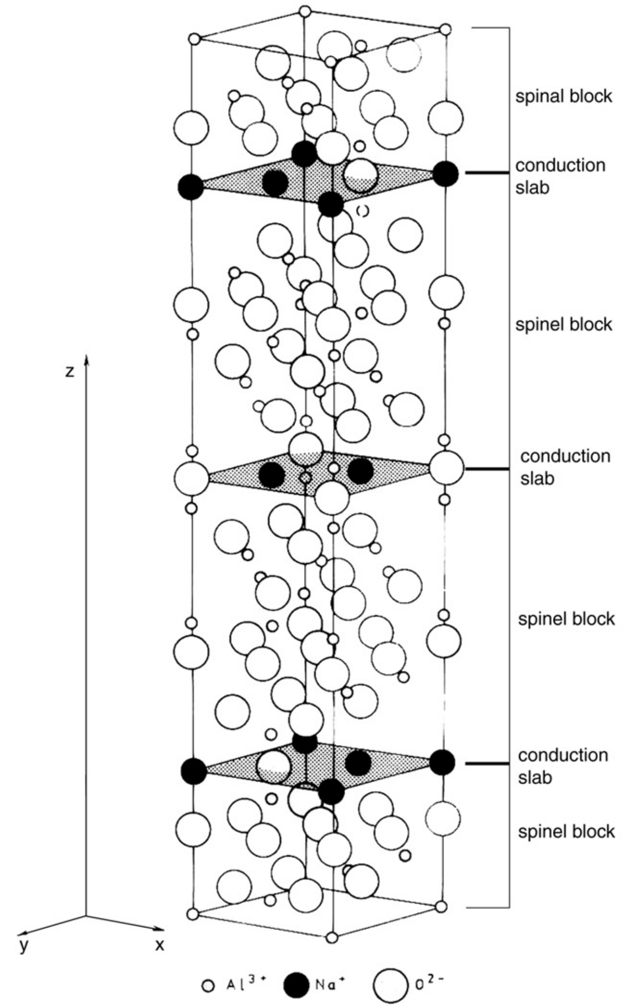

Fig. 2. Perspective drawing of the idealized structure of β″-Al_2O_3 [8].

The main factor determining cell performance is the internal resistance and the main contributor to this is the ceramic electrolyte. A low cell resistance is desirable on two counts, to achieve a high power/weight ratio and to minimize the amount of heat produced on discharge. Although the cell resistance can be reduced by increasing the temperature of operation, there is little advantage in operating in higher temperature. Properties of beta-Al_2O_3 ceramic electrolytes are most essential factor to determine the overall performance of the batteries.

Beta-Al_2O_3 electrolyte, served normally in tubular form as the electrolyte and separator simultaneously for the battery, is actually a sodium aluminate stabilized by lithium or magnesium. Its nominal chemical formula is expressed as $NaAl_{(5.33-11)}O_{17}$. With different content ratio of sodium/aluminum, β- or β″-type structure is formed. Fig. 2 shows schematically the structure of β″-Al_2O_3 which contains tightly packed spinel block and