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Review article

Advancement of technology towards developing Na-ion batteries

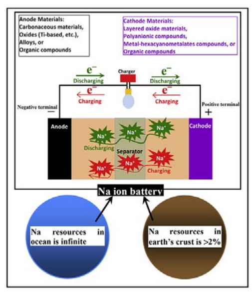
Mohammed Ibrahim Jamesh, A.S. Prakash*

CSIR-Central Electrochemical Research Institute-Chennai Unit, CSIR Madras Complex, Taramani, Chennai 600113, India

HIGHLIGHTS

- Recent potential cathode/anode candidates for Na-ion batteries (SIBs) are identified.
- Na-ion full-cell with high operating voltage range, and capacity are reviewed.
- Na-ion full-cell with high cycling performance, and energy density are discussed.
- Promising full-cell with hard carbon, $Na_3V_2(PO_4)_3$, and other electrodes are reviewed.
- Comparison between aqueous and non-aqueous SIBs in terms of performance is discussed.

GRAPHICAL ABSTRACT



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ABSTRACT

The Na-ion-batteries are considered much attention for the next-generation power-sources due to the high abundance of Na resources that lower the cost and become the alternative for the state of the art Li-ion batteries in future. In this review, the recently reported potential cathode and anode candidates for Na-ion-batteries are identified in-light-of-their high-performance for the development of Na-ion-full-cells. Further, the recent-progress on the Na-ion full-cells including the strategies used to improve the high cycling-performance (stable even up-to 50000 cycles), operating voltage (even ≥ 3.7 V), capacity (> 350 $mAhg^{-1}$ even at 1000 mAg^{-1} (based-on-mass-of-the-anode)), and energy density (even up-to 400 $Whkg^{-1}$) are reviewed. In addition, Na-ion-batteries with the electrodes containing reduced graphene oxide, and the recent developments on symmetric Na-ion-batteries are discussed. Further, this paper identifies the promising Na-ion-batteries including the strategies used to assemble full-cell using hard-carbon-anodes, $Na_3V_2(PO_4)_3$ cathodes, and other-electrode-materials. Then, comparison between aqueous and non-aqueous Na-ion-batteries in terms of voltage and energy density has been given. Later, various types of electrolytes used for Na-ion-batteries including aqueous, non-aqueous, ionic-liquids and solid-state electrolytes are discussed. Finally, commercial and technological-developments on Na-ion-batteries are provided. The scientific and engineering knowledge gained on Na-ion-batteries afford conceivable development for practical application in near future.

1. Introduction

Sustainable clean energy production from renewable energy sources such as solar, wind, wave, etc. are gaining considerable attention due to the depletion of fossil fuels, increased environmental pollution, and increased energy demands [1–7]. To combine these sustainable energies together with the electrical grid, a large scale energy storage system is essential to peak shift operation [8]. In this regard, energy

* Corresponding author.
E-mail addresses: prakash@cecri.res.in, prakash.as@gmail.com (A.S. Prakash).

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storage through electrochemical secondary batteries is a promising way among the different electrical storage technologies because of its high energy conversion efficiency, flexibility, and simple maintenance [8,9]. Li-ion batteries are widely popular as energy storage devices in portable electronics and electric vehicles while their uses are significantly increasing in recent years [2,10]. However, the ever increasing demand for Li-ion batteries in portable devices and electric vehicles can possibly limits the available Li resources of the earth and is believed to be significantly influence the cost and the source of the Li in the long term [11].

Recently, Na-ion batteries (SIBs) have considered much attention [12–14] for sustainable energy storage devices and it can be an economically alternative for the state of the art Li-ion batteries [15–17]. Na is the fourth most abundant element on earth and its resources are widely distributed but Li resources are geographically localized mainly in South America. The abundance of Li in the Earth's crust is only about 20 ppm whereas the abundance of Na in the Earth's crust is > 2% [18]. Moreover, the Na resources in ocean are infinite. Hence the cost of the Li source in the year 2010 was ~5000 $ per ton whereas the cost of the Na source is only about 135–165 $ per ton [19,20], which indicate that the cost of the Na source is only ~3% compared with Li source (Fig. 1a). Hence, developing efficient Na-ion batteries for sustainable energy storage devices is an important task. However achieving high efficient Na-ion batteries is not an easy task. The ionic radius (1.06 Å) and mass (23 g mol^{-1}) of the Na-ions are larger than the ionic radius (0.76 Å) and mass of the Li-ions (6.9 g mol^{-1}) [16,21] and that influences the interphase formation, phase stability, and transport properties [22]. Hence, Na-ion batteries have lesser power and energy densities than that of Li-ion batteries. To achieve high efficient Na-ion batteries, designing and fabricating suitable anode materials, cathode materials, electrolytes and separators are necessary.

Fig. 1b depicts the schematic diagram of the full Na-ion battery, which composed of anode (Carbonaceous materials, Oxides (Ti-based, etc.), Alloys, or Organic compounds), cathode (Layered oxide materials, Polyanionic compounds, Metal-hexacyanometalates compounds, or Organic compounds), electrolyte, and separator. The overall electrochemical reaction of the SIBs depends on a reversible Na-ions intercalation/deintercalation process between anodes and cathodes. When

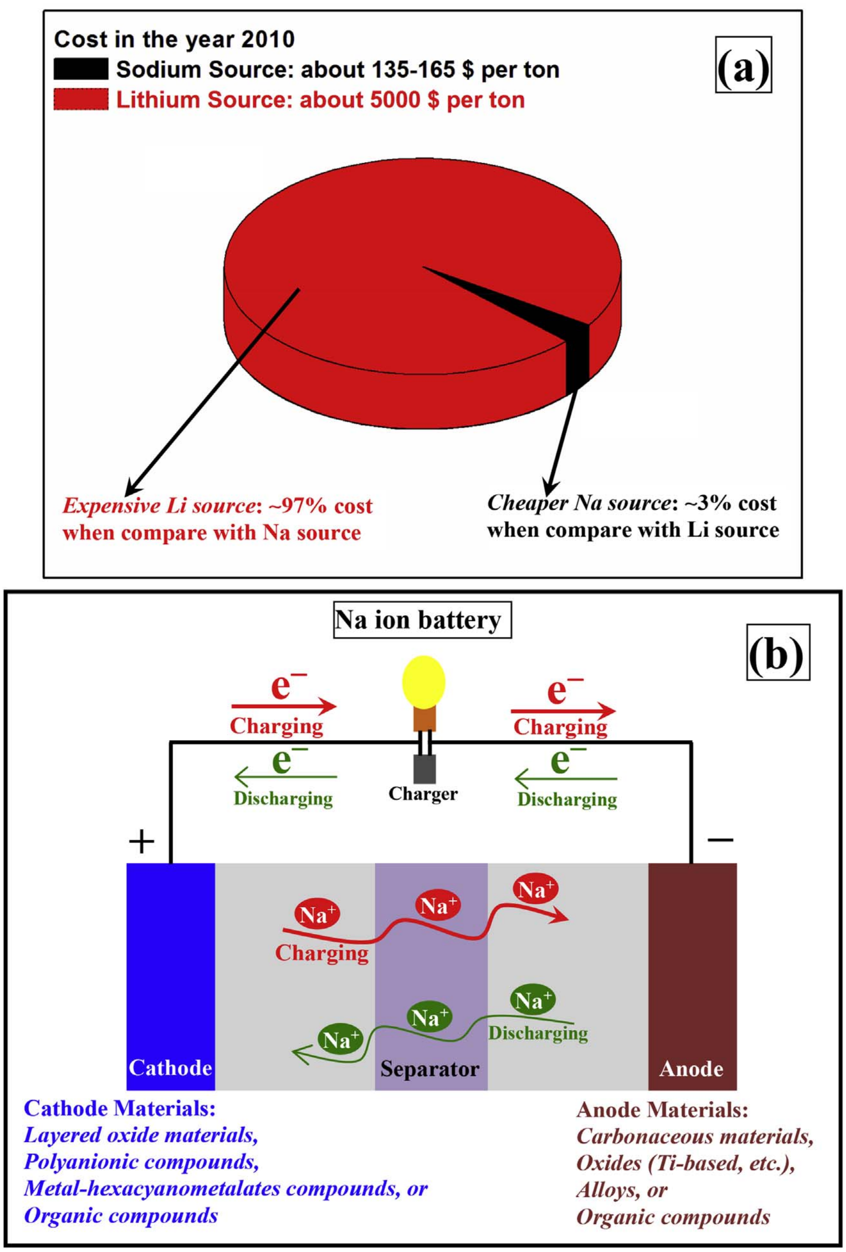

Fig. 1. (a) Schematic illustration depicts the price comparison between Na and Li sources [19,20] (b) Schematic illustration of full Na-ion battery.