Novel Cathode Materials for Na-Ion Batteries: Design and Understanding.

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Abstract: Since there are affordable sodium precursors available, sodium-ion batteries [SIBs] seem like a reasonable alternative to existing lithium-ion batteries [LIBs] for developing big energy storage framework applications with the demand for sustainable energy sources on the rise. With the benefits of plentiful sodium resources and a low price, high levels of safety and all-solid-state sodium-ion batteries are seen as the next generation battery to replace the current commercial lithium-ion battery. The solid-state electrolyte should have better operational safety and a simple design as it is a critical part of a sodium-ion battery. Rechargeable battery technology has significant economic and societal implications for mobile and stationary energy storage. Although lithium-ion battery technology is progressive advancement and a rapidly expanding market is likely to place great strain on resources and supply chains. Recently, sodium-ion batteries [SIBs] have been given another consideration to offer a less expensive option that is less vulnerable to supply and resource risks. This article provides an analysis of recent developments in the construction of sodium ion batteries and solid-state electrolyte materials for sodium-ion batteries.

Keywords: Design of cathode materials, Crystal Structure, and Strategies: LTMOs [Layered transition metal oxides], Structural Modulation, Sodium Compensation and Anionic Redox, Lithium-ion to sodium ion.

- **Introduction**

Solar, wind, and geothermal energy sources have emerged as green and sustainable energy alternatives to merge the rising energy needs of the world's population as a result of universal concern regarding the consumption of fossil fuels and climate change. the requirement for efficient Electrical Energy Storage (EES) is unavoidable in order to successfully integrate these non-stop, sporadic energy sources into the grid. Battery rechargeables appear as the most hopeful energy storage tech among those currently in use because of their environmental friendliness, adaptability, and high conversion efficiency. Due to the conventional fossil fuels resource limitations, the development of renewable energy sources, such as wind, solar, and nuclear energy sources, is now essential [1][3]. Due to the conventional fossil fuels resource limitations, the development of renewable energy sources, like wind, solar, and nuclear energy sources, has now become essential [1]. However, due to the sources' erratic timing and diffuse spatial distribution, these green energy sources could not provide a consistent supply of power. In order to mitigate the intermittent nature of the energy sources, attention has thus been turned to electrical energy storage [2][4]. Rechargeable batteries have the capacity to hold chemical energy and efficiently transform it into electrical energy [5].

Batteries are a critical component of our contemporary civilization because they deliver electrical energy on demand for a wide range of uses. Within the last 10 to 20 years, there has been a significant increase in R&D with a primary emphasis on lithium-ion battery (LIB) technology due to a constant demand for "better batteries." For a long time, portable user electronics served as the main driver of this development, but more recently, two other factors have drawn attention to battery research as follows [6]:

1) electric vehicles (EVs), which would finally reach the ground market in the upcoming years after several failed attempts over the past century; and

2) stationary grid storage, which could store excess electrical energy produced by wind and solar power on a very large[7].

2. Design of cathode materials

Due to their superior voluminal and gravimetric (volumetric analysis) energy density and extended life cycle, lithium-ion batteries (LIBs) are currently widely used in a variety of electronic applications. However, there are issues with lithium metal's involvement in the long-term growth of grid-scale applications due to its high demand and limited availability. Sodium-ion batteries (SIBs), in addition to LIBs, also use an intercalation-based "rocking chair" process during discharging in which Li+ or Na+ Ions from the electrochemically oxidized anode diffuse into the electrolyte and intercalate into the cathode. Meanwhile, with the passage of an external electrical circuit, electrons travel toward the cathode to balance the positive charge of these incoming ions. The research of viable anode materials for SIBs is currently being restricted by low initial Columbic efficacy and cyclic stability[11-12]. Transition metal oxides, disordered carbons, metal alloys, and transition materials with the suited distribution of particle size are the focus of most negative electrode resource studies. Due to their lower mass and potential for incorporating more cathode material, anode-free sodium batteries have recently attracted a lot of attention [8-9][10]. This will ultimately result in the sustainability of high-energy-density battery operation. [14] In addition, the cathode component, which represents one-third of the overall battery cost, serves as a crucial and unavoidable component of electrochemical performance for SIB. [15][13] As a result, the perfect cathode component must be made of a material that is abundant on Earth, nontoxic, and extremely stable.

2.1. Techniques of Crystal Structures:

Currently under discussion Na-ion batteries are the best electrode material for intense investigation among numerous researchers worldwide. As a result of their work, below distinctive materials as structured, whose electrochemical activity has been summarised in Table 1, have emerged.

Table1. Summary of Electrochemical Performance of SIB Cathode Materials

Type	Material	Synthesis
LTMO(a)	P2-	solid state [24]
LTMO(b)	-	solid state [24]

2.1.1 LTMOs

The sodium-based layered transition metal oxide, with the generic chemical formula (M = transition metal), alternately organizes the edge-sharing and octahedral layers. These layered materials can alternatively be grouped using Delmas' nomenclature as O3 and P2 dependent on the octahedral and polygonal coordination environments of the Na+ ion, respectively. Here, the numbers "2" or "3" indicate the number of levels of a particular type of transition metal in this direction, the Na ions are all located at two different types of trigonal prismatic sites, namely [] and[], which encounter two layers. The P2 configuration consists of two varieties of layers [AB and BA]. The [] and [] trigonal prismatic sites, meet two octahedral slabs in the neighbouring faces and octahedral along its six edges, where all the Na ions are located respectively.

2.1.2. Structural Modulation

In addition, morphology control for the creation of micro sheets, nanomaterials, and axially aligned patriarchal column compositions became common usage as a result of performance optimization in terms of conductivity, excellent rate, and tap density. Hence, utilizing the electro-spun technology and calcination, a hierarchical Nano-fibrous structure was created in order to further enhance the performance of previously reported P2-. Sol-gel synthetic technology has been used to generate high-powered electrode material, which is a key tool for creating homogeneous nanostructured compounds [16-17].

2.1.3. Sodium Compensation

However, the Na conciliatory salt compensatory method has additionally been carried out, which lightens the Na inadequacy somewhat, it is not appropriate for large-scale manufacturing. In order to overcome the challenges of individual designs and accomplish their benefits to achieve acceptable Na particle capacity execution, layer-based compositing has been used. Sodium-ion batteries stand out for their likely application in large-scale fixed energy capacity because of the minimal expense and plentiful Na resources on the earth. Notwithstanding, the presentation of electrochemical sodium-ion full cells (SIFCs) experiences the non-reversible utilization of Na particles of the cathode during the strong electrolyte interphase (SEI) arrangement of the hard carbon anode. promising applicants in huge scope energy capacity, sodium-particle batteries stand out enough to be noticed by either scientific establishments or organizations because of the simple accessibility and overflow of Sodium sources [18]. Much movement has been accomplished for getting progressed terminal materials and electrolytes toward Sodium-particle full cells (SIFCs) [19]. In any case, the further treatment of Sodium-particle full cells (SIFCs) from a primitive problem that during the underlying process of charge, the development of passivating strong electrolyte interphase (SEI) layer on the outer layer of anode materials could irreparably use halfway sodium particles from the negative electrode materials. Hence this sodium involvement and elimination to the anode terminal causes low Coulombic efficiency and genuinely hinders the growth of the limit, energy thickness, and cycle security of Sodium-particle full cells (SIFCs) [20].

2.1.4. Anionic Redox

Apart from traditional cationic oxidation-reduction of progressing metals, both materials Na-shortcoming and Na-overabundance have exhibited the capacity to take the advantage of oxygen oxidation-reduction movement as an /for a charge compensation system. In order to acknowledge galvanic cells with upgraded power thickness, the strategy of the consolidation of soluble base metal particles to change layers to metal is embraced. More committed endeavours to understand the highest level of capability of anionic redox should be done from now on [15,17,19].

2.1.5. Lithium ion to sodium ion: Benefits

It is critical to understand that in extraordinary endeavours in battery research, a couple of battery-powered frameworks have accomplished a pertinent portion. According to a notable point of view, the lead corrosive battery innovation is the most seasoned one it rules the market concerning the result taken annually in power limit. Such frameworks are 150 years old, acute, and to a great extent to utilized in car applications (beginning battery) and for helper power[19,20]. Late, additionally, (Ni- battery) and lastly metal composites (NiMH battery) are utilized, as a last option being these days liked. Lithium-particle batteries are the latest turn of events and have been marketed in the mid1990s. Because of the strong energy thickness, these structures immediately start to overwhelm the market for buying hardware. Hence Cell science depends on the inclusion of Li particles in an assortment of host structures. By and large; the Na-particle battery innovation is a genuine example of overcoming adversity. Since its commercialization [20].

Table 2. Characteristic features of Lithium to Sodium ion batteries

Features	**Lithium**	**Sodium**
Atomic Weight	6.9	23 [12]
Cation radii	0.68	0.97 [12]
Potential	-3.04	-2.70 [12]
Capacity	3860	1160 [12]
Price	5800	250-300 [12]

3. Data reporting standard for NIBs

As framed in this composition, the maintainable plan of the cathode materials is urgent for possible investigations of the up-and-coming age of sodium particle batteries. Our top-to-bottom audit exhibited that there are a few points that are not very much investigated in current NIB concentrates, for example, (I) cathode corruption component, (ii) cathode-electrolyte interphase (CEI) plan, and (iii) strong electrolyte interphase (SEI) designing. Regardless of their crucial significance, there has been an extremely restricted examination of these points that requires more in-profound principal examination utilizing progressed strategies. Future investigations on these can give a superior point of view toward cutting-edge NIBs[12,15,18].

Commercial development and assembling of batteries are primarily not considered at laboratory-level exploration. Examinations at the cell level are essential for materials testing, notwithstanding the increased need for the examination of ideal boundaries and situations at large-scale levels. The scholarly community with lab scale concentrates on the business with enormous applications and scopes altogether. Such an approach saves the additional costs in exploration and assists with working in a way towards assembling materials. The factual outline of detailed information from sodium-particle half-cells distributed in the script has been shown in figure1. The information shows that just around 37 percent of the examinations announces the cathode stacking and just under 1 percent of them revealed the electrolyte sum. It is likewise seen that around 69 percent of other examinations revealed the cell structure [17,18,].

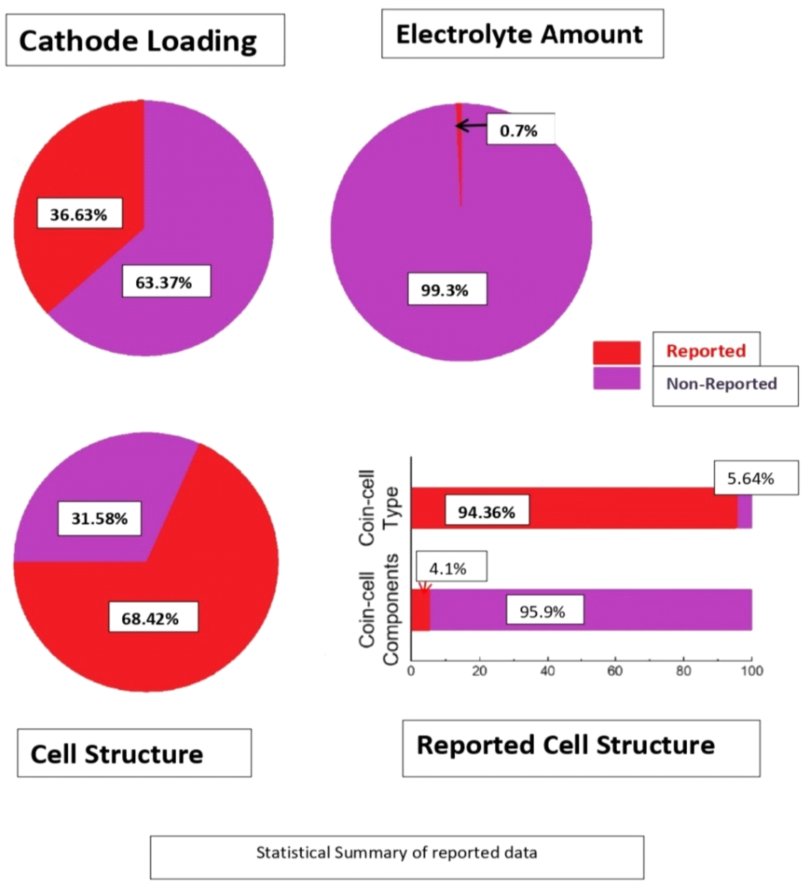

Figure: Statistical Summary of reported data [23]

Therefore, it is important to have normalized and straightforward information revealed in the battery's local area. The accompanying data is essential in battery information detailing- areal limit, cathode stacking and structure, conductive specialist and items, electrolyte sum, cathode negative to anode positive proportion, type of separator used, cycle number, current thickness, temperature, and cell arrangement [21]. Comparative arrangements of conventions are proactively being spread out from the Battery500 Consortium by the US-driven Office of Energy Productivity for LIBs which is environmentally friendly power as continued in crafted by Niu et al [22].

Conclusion:

A few procedures are recognized to achieve a good electrochemical science presentation winning cathode materials have made sense of in past segments, and still, at the end of the day the top-to-bottom material comprehension and novel overhauling strategies are yet expected to relieve the current escape clauses and recognize the business parts of the separate materials. In the most recent five years, research on Na-particle batteries has become extremely powerful. Also, quick advances in material improvement and execution are accomplished. We see no question that commercialized sodium-ion batteries (SIBs) is in fact conceivable. This, in any case, is a market requirement specialty where sodium-ion batteries (SIBs) show explicit benefits over lithium-ion batteries (LIBs) or other laid-out kinds of batteries. Cost-productive batteries in view of plentiful components may be such a specialty that could become pertinent later if asset endlessly supply chains for lithium-ion batteries (LIBs) will be tested excessively; obviously, this requires a coordinated methodology. Experimentally, for a given host structure it is captivating to look at what the size of the particles means for the terminal response. This survey focussed on distinctions in stage conduct while progressing towards lithiation/Sodiation of such assorted of such host structures. Producing maintainable green and minimal expense NIBs with high energy thickness considering earth-plentiful components can assume a huge part in the up-and-coming age of energy stockpiling frameworks. To lay out a material plan standpoint for this objective, here we fundamentally assessed 295 examination articles in view of different cathode structures for NIBs, distributed in the beyond 10 years.

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