



DOI: **10.5958/2249-7137.2021.02082.6**

AN OVERVIEW OF LITHIUM ION BATTERY AND ITS COMPOSITION

Dr. Aniket Kumar*; Mr. Jitendra Kumar Singh Jadon**; Mr. Hamid Ali***

^{1,2,3}School of Electronics,

Electrical & Mechanical Engineering, Faculty of Engineering and Technology,
Shobhit Institute of Engineering and Technology,
(Deemed to be University), Meerut, INDIA

Email id: ¹aniket.kumar@shobhituniversity.ac.in, ²jitendra@shobhituniversity.ac.in
³hamid.ali@shobhituniversity.ac.in

ABSTRACT

For a wide variety of Li-ion battery electrodes, this overview covers important technical advances and scientific difficulties. Many families of appropriate materials are compared using a periodic table and potential/capacity graphs. Commercial intercalation materials such as lithium cobalt oxide (LCO), lithium nickel cobalt manganese oxide (NCM), lithium nickel cobalt aluminum oxide (NCA), lithium iron phosphate (LFP), lithium titanium oxide (LTO), and others are compared to conversion materials such as alloying anodes in terms of performance, current limitations, and recent breakthroughs (F, Cl, Br, I). There's also talk of new polyanion cathode materials. Each kind of electrode material is discussed in terms of cost, abundance, safety, Li and electron transfer, volumetric expansion, material dissolution, and surface reactions. The study covers and categorizes both basic and particular methods for overcoming current problems.

KEYWORD: Anodes, Cathodes, Electrodes, Li-Ion Battery.

1. INTRODUCTION

Li-ion batteries offer an unrivaled mix of energy and power density, making them the preferred technology for portable gadgets, power tools, and hybrid/full electric cars. Li-ion batteries will substantially decrease greenhouse gas emissions if electric vehicles (EVs) replace the bulk of gasoline-powered transportation. Li-ion batteries' high energy efficiency may allow them to be used in a variety of electric grid applications, such as improving the quality of energy harvested from wind, solar, geo-thermal, and other renewable sources, allowing for more widespread use

and the development of an energy-sustainable economy. As a result, both business and government funding organizations are interested in Li-ion batteries, and research in this area has exploded in recent years[1].

However, many people believe that Li-ion batteries will not be able to meet the world's requirements for portable energy storage in the long term. Li-ion batteries are presently expensive for certain uses (such as transportation and grid), and a shortage of Li and some of the transition metals now used in Li-ion batteries may become a problem in the future. Li-ion batteries, on the other hand, offer certain basic benefits over other chemistries. To begin with, Li has the lowest reduction potential of any element, enabling Li-based batteries to achieve the greatest cell potential conceivable. Li is also the lightest element, with one of the lowest ionic radii of any single charged ion. Li-ion batteries have a high gravimetric and volumetric capacity, as well as a high power density, due to these reasons. Finally, although multivalent cations have a larger charge capacity per ion, the extra charge decreases their mobility considerably. Given that ionic diffusion in solid electrodes is often the rate-limiting element for battery power output, developing alternative chemistries poses a significant challenge[2]–[4].

In the foreseeable future, there is unlikely to be a major shortage of Li. Similar predictions about peak oil have been made, but they have failed to materialize as global oil stocks and resources continue to increase as prices rise and exploration and mining technology advance. The quantity of Li present in the Earth's crust is sufficient to power a worldwide fleet of cars in absolute terms. Rising costs, on the other hand, may be an issue for Li-ion batteries, since cost is a significant barrier to their adoption in renewable energy applications. Despite this, Li does not yet play a significant role in the cost of Li-ion batteries. The cathode and electrolyte include lithium, which accounts for just a tiny percentage of the total cost. The cost of processing and the cost of cobalt in cathodes are the main contributing variables within these components. Li-ion batteries will very certainly continue to dominate portable electrochemical energy storage for many years to come, owing to its basic advantages.

Because Li-ion batteries are the most common type of portable electrochemical energy storage, lowering their cost and increasing their performance may significantly extend their applications and allow new energy-related technologies. Electrode materials have gotten a lot of attention in Li-ion battery research so far. Electrodes with greater rate capability, charge capacity, and (for cathodes) adequate high voltage may increase the energy and power densities of Li batteries, allowing them to be smaller and less expensive. However, this is only true if the material isn't prohibitively costly or uncommon[5], [6].

1.1. Cathodes:

1.1.1. Materials for intercalation cathodes:

A solid host network that may store guest ions is known as an intercalation cathode. The guest ions may be reversibly added and deleted from the host network. Li^+ is the guest ion in a Li-ion battery, whereas metal chalcogenides, transition metal oxides, and polyanion compounds make up the host network. There are various crystal forms for intercalation compounds, including layered, spinel, olivine, and tavorite. For the cathode materials in Li-ion batteries, the layered structure is the oldest type of intercalation compounds. Metal chalcogenides, such as TiS_3 and NbSe_3 , have long been investigated as potential intercalating cathode materials. While TiS_3 only

had limited reversibility owing to the irreversible structural shift from trigonal prismatic to octahedral coordination after lithiation, NbSe₃ had reversible electrochemical activity. LiTiS₂ (LTS) was extensively researched among many other kinds of chalcogenides owing to its high gravimetric energy density coupled with extended cycle life (1000+ cycles) and was ultimately commercialized by Exxon. However, owing to their greater operating voltage and consequent better energy storage capacity, most current intercalation cathode research is focused on transition metal oxide and polyanion compounds[7].

1.1.2. Transition metal oxide:

Goodenough's LiCoO₂ (LCO) was the first and most commercially viable kind of layered transition metal oxide cathode. SONY was the first to market it, and it is still utilized in the majority of commercial Li-ion batteries today. Co and Li occupy alternate layers in octahedral sites, forming a hexagonal symmetry. Because of its comparatively high theoretical specific capacity of 274 mAh g⁻¹, high theoretical volumetric capacity of 1363 mAh cm⁻³, low self-discharge, high discharge voltage, and excellent cycle behavior, LCO is a highly appealing cathode material.

1.1.3. Polyanion compounds:

Researchers have discovered a new class of chemicals known as polyanions while researching novel cathode materials. Large (XO₄)³⁻ polyanions (X = S, P, Si, As, Mo, W) occupy lattice sites and enhance cathode redox potential while maintaining its structure. The typical material for the olivine structure is LiFePO₄ (LFP), which is renowned for its thermal stability and high power capacity. In a slightly deformed hexagonal close-packed (HCP) oxygen array, Li⁺ and Fe₂⁺ occupy octahedral sites, whereas P is found in tetrahedral sites in LFP. The LiFePO₄ cathode has many flaws, including a low average potential and poor electrical and ionic conductivity. Over the past decade, intensive research has resulted in substantial advances in both LFP performance and mechanistic knowledge. The use of carbon coating and cationic doping in conjunction with particle size reduction was shown to be beneficial in improving rate performance. It's worth noting that if particles are uniformly nano-sized and conductive nano-carbons are utilized in the cathodes, excellent electrochemical performance may be obtained without carbon coating. For example, a virus-templated amorphous anhydrous FP/ CNT composite showed encouraging results. A curved one-dimensional lithium diffusion route via the [0 1 0] direction has been suggested as a possible explanation for the easy redox reaction in non-conducting LFP. However, the energy density of LFP cells is limited by the low density of nanostructured LFP electrodes and their low average potential. A new non-olivine alluaudite LFP with fundamentally different electrochemical properties than olivine LFP was recently discovered.

1.1.4. Compounds of fluorine and chlorine:

Due to their intermediate operating voltages and high theoretical specific and volumetric capacities, metal fluorides (MF) and chlorides (MCl) have lately been extensively studied. However, MF and MCl have weak conductivity, high voltage hysteresis, volume expansion, undesirable side reactions, and active material dissolution. Because of the wide band gap produced by the highly ionic nature of the metal-halogen interaction, most MF, notably FeF₃ and FeF₂, are renowned for their low electrical conductivity. Their open architecture, on the other hand, may enable excellent ionic conduction. Because of the same reason, chlorides have low

electrical conductivity. For factors such as low electronic conductivity and ion mobility, all of the reported MF and MCI materials have very significant voltage hysteresis.

1.1.5. Sulfur and lithium sulfide:

Sulfur has a very high theoretical capacity of 1675 mAh g^{-1} , is inexpensive, and is plentiful in the Earth's crust. S-based cathodes, on the other hand, have a low potential compared to Li/Li^+ , poor electrical conductivity, solubility of intermediate reaction intermediates (polysulfides) in the electrolyte, and (in the case of pure S) a very low vaporization temperature, which causes S loss during vacuum drying. Sulfur also has an 80% volume change, which may cause the electrical contact in typical carbon composite electrodes to be destroyed. S may be enclosed in a hollow structure with extra internal empty space to minimize the effects of both dissolution and volume expansion. Sulfur was impregnated into polyvinyl pyrrolidone polymer, carbon, and TiO_2 capsules via infiltration and chemical precipitation. These materials have a cycle life of up to 1000 cycles when tested in half cells with thin electrode designs.

1.1.6. Selenium with tellurium:

Se and Te have recently gotten a lot of interest since they have greater electrical conductivities than S and potential volumetric capacities of 1630 mAh cm^{-3} and 1280 mAh cm^{-3} in the completely lithiated form, respectively. Se and Te have better active material usage and rate capacity than S due to their higher electronic conductivity. Similar to S, high order polyselenides dissolve in Se-based cathodes, leading in rapid capacity loss, poor cycle performance, and low coulombic efficiency. Polytelluride dissolution has not been documented thus far.

1.1.7. Iodine:

The lithium-iodine primary battery, which utilizes LiI as a solid electrolyte ($10^{-9} \text{ S cm}^{-1}$), has a low self-discharge rate and a high energy density, and is a popular power source for implanted cardiac pacemakers. During discharge, the cathodic I is reduced first to the tri-iodide ion (I_3^-), then to the iodide ion (I^-). However, because of its limited power capacity, this chemical is troublesome for use in most other applications. Furthermore, iodine, triiodide, and lithium iodide are all soluble in typical organic electrolytes. Due to LiI 's great solubility in organic solvents, iodine ions have been proposed as a replacement for LiI in lithium-flow batteries. Due to the low melting point of I (113°C), active iodine was recently absorbed into the pores of porous carbon. The increased electronic conductivity and reduced active material dissolution resulted in a high discharge voltage plateau, excellent cycle performance, and high rate capability for the as-produced iodine-conductive carbon black composite.

1.2. Anode

Because Li metal develops dendrites, which may cause short circuiting, a thermal run-away reaction on the cathode, and a fire, anode materials are required in Li-ion batteries. Li metal, on the other hand, has a short cycle life. Others have examined the main attempts to enable Li metal anodes, therefore this subject will not be discussed here. Rather, this section gives a quick rundown of secondary anode materials. We suggest reading more in-depth evaluations on carbon lithium titanium oxide (LTO) and Type A and Type B conversion anode materials for additional research[8], [9].

1.2.1. Graphitic and hard carbons:

Carbon anodes were the first to make the Li-ion battery economically feasible over 20 years ago, and they are still the preferred anode material today. The intercalation of Li between the graphene planes, which provides excellent 2D mechanical stability, electrical conductivity, and Li transport, causes electrochemical activity in carbon. This method can store up to 1 Li atom every 6 C. Low cost, plentiful availability, little delithiation potential versus Li, high Li diffusivity, strong electrical conductivity, and very low volume change during lithiation/delithiation are all characteristics of carbon. When compared to alternative intercalation-type anode materials, carbon offers an appealing balance of cheap cost, abundance, moderate energy density, power density, and cycle life. Although carbon has a greater gravimetric capacity than most cathode materials, commercial graphite electrodes have a low volumetric capacity (330–430 mAh cm⁻³).

Carbon anodes for commercial use may be classified into two categories. Graphitic carbons contain big graphite grains and have a charge capacity that is near to theoretical. Graphitic carbons, on the other hand, do not mix well with a PC-based electrolyte, which is favored owing to its low melting point and rapid Li transfer. Between the graphitic planes, PC intercalates with Li⁺, causing the graphite to exfoliate and lose capacity. Li intercalation happens at the basal planes even without solvent intercalation, thus the SEI preferentially develops on these planes as well. Single crystalline graphitic particles experience uniaxial 10% strain along the edge planes during Li intercalation. Such a high level of stress may harm the SEI and shorten the cell's cycle life. To shield the susceptible edge planes from electrolyte and achieve high coulombic efficiency, graphitic carbons have recently been covered with a thin coating of amorphous carbon[10].

1.2.2. Lithium titanium oxide (LiTiO₂):

Despite the greater cost of Ti, the decreased cell voltage, and lesser capacity, LTO has been successfully marketed because it enables the combination of better thermal stability, high rate, relatively high volumetric capacity, and long cycle life (175 mAh g⁻¹ & 600 mAh cm⁻³ theoretical). A “zero strain” intercalation process in conjunction with a high lithiation potential results in a high rate and stability. Because the phase shift produced by lithiation/delithiation only results in a little (0.2 percent) change in volume, LTO is termed “zero strain.” This shows up electrochemically as a tiny volt-age hysteresis in the charge discharge curve. Furthermore, because of the high equilibrium potential (1.555 V vs. Li/Li⁺), LTO may be operated in a potential window above 1 V, substantially avoiding the development and expansion of the anode SEI, which can delay Li insertion and generate Li losses in graphite anodes. The absence of volume fluctuation improves the SEI's stability even after it has been created. LTO nanoparticles, comparable to intercalation cathode material, may be utilized since SEI impedance is not a problem, resulting in better rate performance at the cost of reduced volumetric capacity. LTO is also very safe since its high potential inhibits the production of Li dendrites, even at high rates. As a result, despite its poor Li diffusivity and electrical conductivity, LTO is an excellent material for low-energy, high-power, long-cycle-life Li-ion batteries.

1.2.3. Alloying materials – conversion materials (Type B):

At low potentials, 'alloying materials' refer to elements that electrochemically alloy and produce compound phases with Li (preferably below 1 V). Alloying materials may have very high volumetric and gravimetric capacity, yet they're known for their massive volume shift when lithiated, swelling too many times their original volume. Particles may shatter and lose electrical contact as a result of this. Anodes' SEI protective layer may be destroyed by volume changes, leading in continual electrolyte breakdown, Li inventory loss, and increased cell impedance. Due to the loss of active material and increased cell impedance, alloying anodes have a limited cycle life, particularly at large mass loadings. The most effective approach has been to make a carbon composite with alloying material particles that are tiny enough for mechanical stability, electron transport, and Li transport while preserving Li diffusion pathways inside the electrode. The active material may be encased in a carbon shell with enough empty space to allow for volume expansion to stabilize the SEI. In theory, this should stabilize the SEI and prevent particles from sintering into bigger particles, allowing for long cycle times even at high mass loadings. If a carbon shell is not employed, electrolyte additives may help to further stabilize the SEI and extend the cycle life, while binders that attach to the active material, have a high stiffness, and expand little in electrolytes can help to give further mechanical stability. Even yet, in complete Li-ion battery cells, high mass loading electrodes with high volumetric capacity ($>800 \text{ mAh cm}^{-3}$) and extended cycle life (10^3+ cycles) have yet to be proven. Furthermore, nanoparticles have a large surface area by definition, resulting in significant amounts of SEI generation and irreversible capacity loss during the first cycles.

1.2.4. Other conversion materials (Type A):

Using oxides in which Li_2O is generated during the first charging of the battery was formerly a common method of creating conversion materials. The Li_2O serves as a "glue" to hold alloying material (such as Si or Sn) particles together while also decreasing overall volume change inside the particles. However, since Li_2O has a poor electrical conductivity, this method always results in a high irreversible capacity and a significant voltage hysteresis, which persists even at very slow speeds. If the voltage range is substantially extended, Li_2O itself may be utilized as an active material, allowing non-alloying transition metals to be employed. This lowers first-cycle capacity loss and improves charge capacity, but it also reduces the potential difference between the cathode and the anode. If the Li_2O phase is depleted, active alloying materials' nanoparticles may sinter into bigger particles, increasing resistance. Furthermore, the procedure usually results in a significant volume change, which may cause problems comparable to alloying anodes.

MgH_2 and MgC_{12} are two of the most common Type A conversion anode materials. Both $\text{Li}_{1.07}\text{V}_{0.93}\text{O}_2$ and $\text{Li}_{1.07}\text{V}_{0.93}\text{O}_2$ are intriguing in that they exhibit modest voltage hysteresis and delithiation potentials, although at low rates. However, no research has proven that these electrodes are feasible at greater rates, and the cycle life shown is very limited. Similarly, certain phosphide and nitride electrodes have been found to exhibit minimal voltage hysteresis over many cycles, but only at modest charge/discharge rates.

2. DISCUSSION

Lithium-ion technology is all the rage in the battery world. They are now a popular source of power in a variety of daily goods, including computers, cell phones, power tools, and even

automobiles. The significance of dependable portable power is enormous and constantly increasing as technology develops, concentrating on speed, large data, and mobility. Rechargeable lithium-ion (Li-ion) batteries are becoming more common as a power source for both small and big cleaning equipment at Tennant. Maintenance, lifespan, charging speed, safety, and simplicity of charging are the five areas in which they excel.

2.1. What is the difference between lithium and lithium-ion batteries?

Most lithium batteries are not rechargeable, while lithium-ion batteries are. Li-ion batteries are more stable and can be recharged hundreds of times. Compared to conventional rechargeable batteries, they feature a greater energy density, voltage capacity, and lower self-discharge rate. Because a single cell has a longer charge retention than other battery types, this results in higher power efficiency.

3. CONCLUSION

The Li-ion battery has obvious basic benefits and has been evolved into the high energy density, long cycle life, and high efficiency battery that it is today thanks to decades of study. New electrode materials are still being developed to push the limits of cost, energy density, power density, cycle life, and safety. There are a number of promising anode and cathode materials on the market, but many of them have poor electrical conductivity, sluggish Li transport, dissolution or other undesirable interactions with the electrolyte, low thermal stability, excessive volume expansion, and mechanical brittleness. Various approaches have been tried to overcome these obstacles; various intercalation cathodes have been commercialized, and conversion material technology is steadily approaching broad use. In the area of Li-ion battery electrode materials, the past two decades have been an exciting period for research. Li-ion batteries will undoubtedly have a larger effect on our lives in the years to come as new materials and methods are discovered.

REFERENCES

1. S. Ma *et al.*, "Temperature effect and thermal impact in lithium-ion batteries: A review," *Progress in Natural Science: Materials International*. 2018, doi: 10.1016/j.pnsc.2018.11.002.
2. G. Zubi, R. Dufo-López, M. Carvalho, and G. Pasaoglu, "The lithium-ion battery: State of the art and future perspectives," *Renewable and Sustainable Energy Reviews*. 2018, doi: 10.1016/j.rser.2018.03.002.
3. B. Huang, Z. Pan, X. Su, and L. An, "Recycling of lithium-ion batteries: Recent advances and perspectives," *Journal of Power Sources*. 2018, doi: 10.1016/j.jpowsour.2018.07.116.
4. P. K. Nayak, L. Yang, W. Brehm, and P. Adelhelm, "From Lithium-Ion to Sodium-Ion Batteries: Advantages, Challenges, and Surprises," *Angewandte Chemie - International Edition*. 2018, doi: 10.1002/anie.201703772.
5. C. R. Birkl, M. R. Roberts, E. McTurk, P. G. Bruce, and D. A. Howey, "Degradation diagnostics for lithium ion cells," *J. Power Sources*, 2017, doi: 10.1016/j.jpowsour.2016.12.011.
6. Y. Jin, B. Zhu, Z. Lu, N. Liu, and J. Zhu, "Challenges and recent progress in the development of Si anodes for lithium-ion battery," *Adv. Energy Mater.*, 2017, doi:

10.1002/aenm.201700715.

7. B. Rousseau, V. Timoshevskii, N. Mousseau, M. Côté, and K. Zaghbi, "A novel intercalation cathode material for sodium-based batteries," *Electrochem. commun.*, 2015, doi: 10.1016/j.elecom.2014.12.022.
8. Z. Xiong, Y. S. Yun, and H. J. Jin, "Applications of carbon nanotubes for lithium ion battery anodes," *Materials (Basel)*, 2013, doi: 10.3390/ma6031138.
9. X. Zuo, J. Zhu, P. Müller-Buschbaum, and Y. J. Cheng, "Silicon based lithium-ion battery anodes: A chronicle perspective review," *Nano Energy*. 2017, doi: 10.1016/j.nanoen.2016.11.013.
10. Y. Chen, J. Li, Y. Lai, J. Li, and Z. Zhang, "Tailoring graphitic nanostructures in hard carbons as anode materials achieving efficient and ultrafast sodium storage," *J. Mater. Sci.*, 2018, doi: 10.1007/s10853-018-2295-3.