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Review

Prelithiation of electrodes in lithium-ion capacitors: A review

Aston Sam D'Silva[1], **M. P. Eldho**[1], **K. Lekha**[1], **J. Anushree**[1], **Vinayambika S. Bhat**[1], **Raghavendra Sagar**[2,*]

[1] Department of Electronics & Communication Engineering, Mangalore Institute of Technology & Engineering, Badaga Mijar, Mangaluru 574225, India
[2] Department of Physics, Mangalore Institute of Technology & Engineering, Badaga Mijar Moodabidri, Mangaluru 574225, India
*** Corresponding author:** Raghavendra Sagar, raghav_sagar@rediffmail.com

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Abstract: Lithium-ion capacitors (LICs) are one of the modern state-of-the-art hybrid capacitors, comprising a high potential window and imparting a higher energy density than supercapacitors (SCs). These LICs encompass elevated power density and a longer life span than lithium-ion batteries (LIBs). Preparation of high-performance electrode materials with electrochemically active microstructure and prelithiation are two efficient approaches to fabricate highly efficient LICs. But it comes across as a real dilemma of low initial Columbic efficiency if only microstructure is considered as an efficient way to enhance the performance. Nevertheless, prelithiation plays a crucial role in the manufacturing of LICs, improving the initial Coulombic efficiency and enlarging the voltage window. This paper reviews the recent lithiation approaches for lithium-ion capacitors by providing their methods and discussing their results concerning their energy and power density.

Keywords: electrodes; columbic efficiency; prelithiation; LIC; energy density

1. Introduction

An increase in the market size of EVs and consumer electronic goods like computer systems and mobiles has swayed the research attention towards high-density energy storage systems [1]. These energy storage systems should be capable of generating fair output power and safe operational characteristics to be used in both vehicles and consumer electronic applications [2]. Among all types of energy storage devices, lithium-based materials are the most commonly used commercial systems to store energy from renewable energy sources. Among most lithium-based energy storage systems, LIBs have become the most widely used electrochemical energy storage device due to their superior energy density values, much needed for modern-day EVs and consumer electronics [3,4]. Nonetheless, both LIB's and SCs exhibit a notable discrepancy in performance due to their inability to meet the demands of fast charging and slow discharging. Thus, to overcome such discrepancy, an electrochemical energy storage device needs to be able to have both a high energy density and a high power density in order to achieve these requirements [5].

LICs are hybrid energy storage systems where SC's type cathode and LIB's type anode are used to derive high power and energy densities simultaneously. Conventionally activated carbon is used as a cathode material, which imparts greater power density, and compositions like $LiTi_5O_{12}$ are used as anode materials, which result in higher energy density. This asymmetric device construction makes these devices appropriate for both consumer electronics as well as automotive mobility. It is well known that the electrochemical properties of LICs can be easily tuned using prelithiation, where anions move from or towards the cathode, where intercalation occurs [6]. Thus, prelithiation is one of the preferred strategies adopted to compensate for the intercalation. However, the commercialization of LIC increased traction some time ago when graphite was started to be probed as a potential negative electrode material, anticipating its capability to improve energy density and potential window [7].

2. Need for prelithiation

In LIC's, prelithiation is expected to compensate for the loss of Li-ions that occurred due to the formation of solid electrolyte interphase towards the anode terminal since a higher proportion of activated carbon is expected to facilitate higher Li-ion loss [8,9]. Hence, selection and preparation of appropriate cathode and anode materials is one of the useful approaches to make possible LICs to attain high energy density at high power density. However, despite the recent developments in electrode materials, we come across the problem of low initial columbic efficiency in LICs. For example, let us consider $LiCoO_2$//graphite cell where Li-ions de-intercalated from $LiCoO_2$ and intercalated towards graphite at the time of charging. The reaction corresponding to the movement of Li-ions is as follows:

$$LiCoO_2 \leftrightarrow Li_{1-x}CoO_2 + xLi^{+}xe^{-} \qquad (1)$$

$$C + xLi^{+} + xe- \leftrightarrow LixC \qquad (2)$$

$$LiCoO_2 + C \leftrightarrow Li_{1-x}CoO_2 + Li_xC \qquad (3)$$

The above equations represent the reaction of entire cells, i.e., on the anode's and cathode's, respectively. When the anode potential falls below 1V versus Li^+/Li, parasitic processes on the anode surface cause the organic electrolyte to be simultaneously reduced to create the solid electrolyte interphase (SEI) layer during the intercalation of Li-ion. While it is widely known that this SEI layer is essential in preventing electrolyte ions from co-intercalating into the electrode bulk, some lithium ions may be permanently caught in the electrode during lithiation, which causes a rapid shift in the concentration of the electrolyte and the consumption of lithium ions, resulting in low initial coulombic efficiency and high initial capacity loss [10,11]. **Figure 1** shows the formation of SEI in $LiCoO_2$//graphite lithium ion batteries. A significant challenge for LICs is the absence of a lithium source in the cathode, which limits energy density. Here, prelithiation plays a crucial role in the manufacturing of LICs to improve the initial columbic efficiency and boost energy density [12]. It also provides the extra Li-ions to make up the initial loss in the capacitor [13–16].

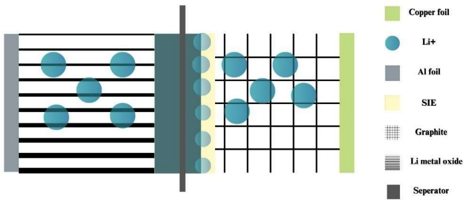

Figure 1. Formation of SEI in $LiCoO_2$//graphite LIBs.

3. Prelithiation approaches

Prelithiation is a strategy to preemptively lithiate pre-doping of extra Li-ions into electrodes before battery/capacitor assembly for active Li^+ loss compensation [17–22]. Currently, numerous prelithiation processes are applied for recovering initial irrevocable capacitance compensation [23–27]. The prelithiation approaches for LICs can be broadly classified into two types, namely the anode prelithiation and cathode prelithiation. Herein all the prelithiation approaches mentioned are expected to enhance the LICs performance.

3.1. Anode prelithiation

In In order to enhance the initial columbic efficiency and improve the life span of LIC's, prelithiation of the anode is one of the most effective strategies. Here the anode can be prelithiated by various processes like chemical prelithiation, electrochemical prelithiation, additive prelithiation, and metal lithium foil/powder prelithiation [28,29]. But they were mainly fabricated through electrochemical prelithiation and direct contact with a Li source [30]. These prelithiation approaches are discussed in detail.

3.1.1. Chemical prelithiation

In chemical prelithiation, organic molecules are used as the mediator for lithium transfer [31,32]. The first method deals with the prelithiation of anode with the chemical prelithiation method for SiO_x/Graphite composite anode. In this, lithium ararene (LiA) was used as a prelithiation reagent for the composite anode. Anaryl lithium impregnation method with 2 min of prelithiation resulted in the increased ICE from 88% to 98%. They found that the ICE can be easily tuned using impregnation time and LiA reagent concentration. The study was limited to half-cell testing and did not assess the performance of the prelithiated anode in a complete battery system [33]. Another chemical prelithiation method deals with the use of 2-methyltetrahydrofuran (MTHF) as prelithiation solvent. MTHF solvent was used to prelithiate soft carbon (SC), where the time for prelithiation was set to be ~5 min, which resulted in the display of a small potential of 0.21 V vs. Li/Li^+. As prelithiated SC was found to be chemically stable and deployed as cathode, excellent capacitance retention was observed even after 5000 charging and discharging cycles. Also, the energy density was computed at ~69.4 Wh/kg, and the power density was 5.7 kW/kg in the fabricated LIC made up of prelithiated SCs [34].

3.1.2. Sacrificial prelithiation material

In order to prevent the use of a metallic lithium electrode during the initial charging phase, provide lithium ions into the anode. It is to be noted that Li_3N is one of the best salts that could be used as a sacrificial source and can be easily produced by reacting lithium with nitrogen gas. Li_3N is investigated as a novel sacrificial material that offers a number of special benefits over existing prelithiation materials. **Figure 2** shows the configuration of LIC with an

AC/Li_3N electrode.

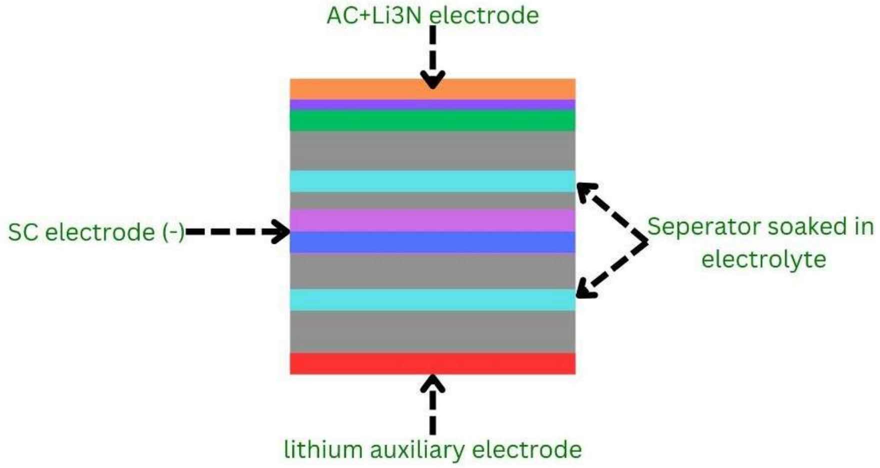

Figure 2. The configuration of LIC with AC/Li_3N electrode, SC electrode and lithium auxiliary electrode.

Here, the LIC was constructed using AC/Li_3N cathode and SC as anode, which showed a high energy density of 214.7 Wh kg^{-1} at 0.18 kW kg^{-1} and 65.0 Wh kg^{-1} at a high power density of 19.5 kW kg^{-1} with excellent cycling stability (75.1% retention after 5000 cycles at 3.2 kW kg^{-1}). Overall, the approach of using Li_3N as prelithiation material offers several advantages, including avoiding electrolyte decomposition, reducing the amount of prelithiation material needed, and simplifying the construction of pouch LICs. The results obtained in this work revealed the difficulties in obtaining high energy and power densities owing to the divergence of electrode kinetics.

Anaiz et al. reported about the use of sacrificial salts as a prelithiation tactic to get efficient LIB and SCs. The prelithiation procedure includes the usage of sacrificial salts, especially dilithium squarate ($Li_2C_4O_4$), in a LIC prototype fabricated in a pilot line. This process gets done during the first ten cycles, and after the needed gas exhaust, the electrochemical performance of prototypes was found to be satisfactory [35].

Veluri et al. proposed the construction of a LIC with a long life span (85% capacity retention after 10,000 charge-discharge cycles at 1A/g and a high energy density of 80 Wh/kg and a high power density of 8.4 kW/kg) utilizing carbon materials obtained entirely from petroleum coke. No additional prelithiation was done; instead, the suggested LIC was prelithiated by keeping a small amount of Li metal foil (ratio of Li to disordered carbon, 1:7) on the anode surface to supply lithium during the initial charging stage. High-surface-area activated carbon made from petroleum coke served as the cathode, and low-surface-area disorder carbon served as the anode. **Figure 3** demonstrates the capacitance retention of petroleum coke-based LIC vs. the petroleum coke-based supercapacitor [36].

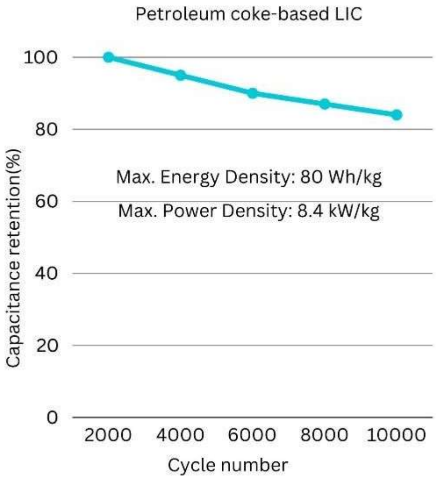

Figure 3. Petroleum coke-based LIC vs the petroleum coke-based supercapacitor.

Kong et al. reported the LICs with anode compositions of high-content P and N co-doped porous carbon nanomaterials (X-PNC) and cathode made using pyrrolic-N-doped porous carbon nanomaterials (X-NC). The working electrodes in the half-cells were X-PNC and X-NC electrodes, whereas the counter electrode was lithium metal foil. With great cycling stability (75.1% retention after 5000 cycles at 3.2 kW kg^{-1}), the built-in LIC demonstrated a high energy density of 214.7 Wh kg^{-1} at 0.18 kW kg^{-1} and 65.0 Wh kg^{-1} at a high power density of 19.5 kW kg^{-1} [37].

Han et al. reported the fabrication of LIC built utilizing pre-lithiated nitrogen-doped porous carbon (NPC) anodes and hierarchical porous carbon (CHPC) cathode electrodes generated from coal. It has a gravimetric capacitance of 139 mAh g^{-1} cathode at 0.5 A g^{-1}. In this work, the NPC electrode was in contact with Li metal foils for 45 minutes for prelithiation without any use of a polypropylene membrane. The CR2032 button cells fabricated in this work demonstrated a specific capacity of 139 mAh g^{-1} with 99% retention after 1000 cycles of charging and discharging at 1 A g^{-1}. The energy density was estimated to be 220 Wh kg^{-1} at a specific power of 805 W kg^{-1}. **Figure 4** shows the schematic representation of pre-lithiated cells prepared using NPC and CHPC [38].

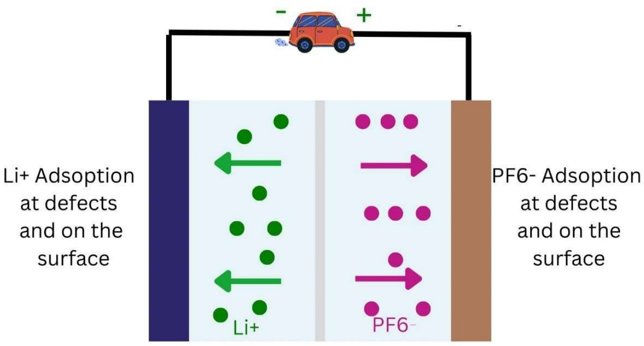

Figure 4. The diagram illustrating charge-storage mechanisms (gray ball: carbon atoms; blue ball: oxygen atoms; red ball: nitrogen atoms; yellow ball: sulfur atoms; purple ball: PF_6^- anion; green ball: Li^+ cation).

3.1.3. Prelithiation by charging/discharging a half cell

Tan et al. reported the fabrication of LIC by means of hollow porous α-Fe_2O_3 nanoparticles and carbon nanospheres derived from glucose as anodes and cathodes, where excellent electrochemical characteristics were observed. Half cell prepared using hollow porous α-Fe_2O_3 nanoparticles was prelithiated using charging/discharging at 0.2 A g^{-1}, resulting in 107 Wh kg^{-1} energy density at 0.24 W kg^{-1} and an energy density of 86 Wh kg^{-1} at a power density of 9.68 kW kg^{-1}. **Figure 5** shows typical LIC comprising important parts like cathode, anode, and electrolyte layers. Besides, it displayed towering-capacity retention ~84% after 2000 CV cycles ~1 Ag^{-1} [39].

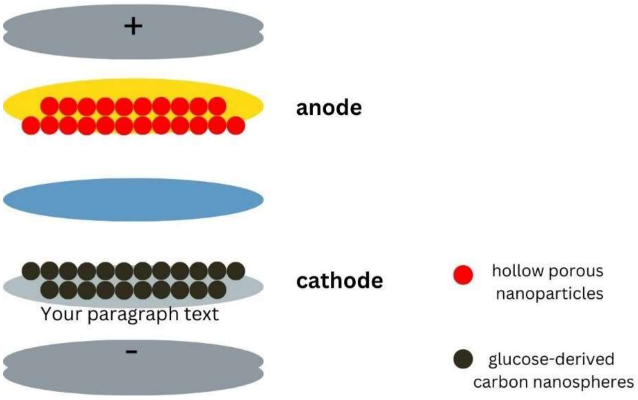

Figure 5. Graphical representation of approach for the Lithium-ion capacitor in coin cell.

An additional step in the prelithiation process is used to activate a graphite half-cell by charging and discharging it five times before assembling it into a full-cell configuration. New peaks were observed in the XPS spectra, and atomic percentages change as the graphite electrode is exposed to particular electrolytes. These changes in elemental composition and chemical bonding occur during this process. These alterations show that during the prelithiation phase, an artificial solid electrolyte interphase (SEI) is formed on the graphite surface [40].

Among the other techniques is the use of lignin, the second most common natural polymer, which is also the primary waste byproduct from the pulp and paper industry and is used as an electrode material for lithium-ion batteries. Here, lignin is transformed into two types of functional carbons that act as the electrode materials in LICs by controlling the porous framework and graphitic degree with the goal of building high-performance LICs. In a manufactured capacitor, lignin-derived hierarchical porous carbon (LPC-3) served as the anode and lignin-derived graphitic carbon (LGC-1500) as the anode. The assembled LGC-1500//LPC-3 LIC delivered a high-energy density of 97W h kg^{-1}, a high-power density of 11.4 kW kg^{-1}, and a superior cyclic stability of 92.3% after 5000 cycles at 1 Ag^{-1} [41].

The "in-situ electrolyte" is a sustainable alternative for the realization of high-power devices [42,43]. These devices, including electric double-layer and metal-ion capacitors prepared using waste products for carbon synthesis, enable the realization of Li- and Na-based EDLCs containing aqueous, water in salt, and organic electrolytes, as well as an alternative for Li-ion capacitors. The prelithiation process involves generating a lithium inventory to ensure the formation of a SEI on the anode and to avoid concentration gradients within the electrolyte solution. This is achieved by utilizing activated carbon (AC) loaded with a selected lithium salt to create a LIC with a high and tunable lithium inventory directly during the assembly process. A mixture of carbonaceous materials, including hard carbon and graphite, serves as the anode material. The study does highlight some of the difficulties in determining the ideal concentration of activating agents for carbon porosity. The fabricated LIC displayed a power density of 10 kW kg^{-1} and a specific capacitance of ~21 Fg^{-1} [44].

The developed hybrid LICs with a prelithiated graphite anode and two cathodes exhibit superior electrochemical performance, including high energy density, power density, and capacity retention. The prelithiation process was conducted by lithiating the graphite anode using a perforated $LiCO_2$ electrode. The anode material was composed of graphite, carbon black, carboxymethyl cellulose (CMC), and styrene butadiene rubber (SBR), and the cathode material was prepared using active carbon, carbon black, CMC, SBR, and $LiCO_2$. Within a voltage range of 2.2 V to 3.8 V, the hybrid LICs showed excellent discharge and charge performance, together with high energy and power densities. After 300 cycles, the hybrid LICs capacitance dropped by less than 1%, demonstrating exceptional cycling performance and capacity retention of up to 99% [45].

The potential for easy and low-cost fabrication of LICs and the feasibility of adopting new technologies such as sodium ion and potassium ion capacitors are extensively reported. Arnaiz et al. reported in-house synthesized olive pit-derived hard carbon (HC) as anode and AC as cathode material. In this report, 1 M $LiPF_6$ in ethylene carbonate (EC) and dimethyl carbonate (DMC) with 3 wt% of vinylene carbonate (VC) was used as an electrolyte. The energy density of LICs, with a 2- to 3-fold enhanced performance, was observed compared to EDLCs in terms of power density and specific capacitance [46].

Anothumakkool et al. reported the development of prelithiated electrodes in LIC, which could help overcome a significant scientific obstacle in the field. The prelithiation process in this paper involves a cascade-type mechanism with two consecutive irreversible reactions within the positive electrode, where oxidative electro-polymerization of pyrene moieties releases electrons and protons. These protons are captured by Li_3PO_4 and exchanged for a stoichiometric amount of Li^+ into the electrolyte, aiming to compensate for the loss of active lithium and electrons during cycling and reach full utilization of the active materials. Carbon black and activated carbon are used as anodes in the construction of LIC, whereas pyrene and Li_3PO_4 additives are used as cathodes. The prelithiation process used in the construction of the LIC revealed an energy density of 63 $WhKg^{-1}$. However, challenges in commercialization and inability to achieve long-term stability, instability in ambient air, and low electron conductivity limit its applications [47].

Park et al. [48] reported the feasibility and advantages of using prelithiated Si/SiO_x nanospheres as an advanced negative electrode. This LIC shows improved cycle performance and excellent energy density compared to conventional graphite electrodes. When compared to traditional graphite LICs, prelithiated C-coated Si/SiO_x nanospheres have better reversible capacity and rate capability. Traditional LICs employing prelithiated C-coated Si/SiO_x nanospheres exhibit significantly better cycle performance and rate capability. The as reported LIC achieves an energy density that is more than twice as high as conventional LICs.

Sugiawati et al. [49] reported another prelithiation technique that is suggested with Li^+ to reduce its potential, which would bring the insertion voltage of anodes closer to 0.1 V. LICs can function within a broader voltage window, which increases the voltage gap between the anode and cathode. When repeating Li^+ insertion/desorption procedures, the extra Li^+ can also restore the consumption of lithium-ion sources. A half-cell containing anode and Li-foil without separators can be assembled, and the anode can be prelithiated for several hours by allowing the anode to have a lower Li^+ insertion plateau. This chemical reaction between metal oxides and lithium sources results in an energy density of around 200 Wh kg^{-1}.

3.2. Cathode prelithiation

The energy density of lithium-ion batteries is greatly reduced by the irreversible loss of lithium during the first cycle. Although anode prelithiation is a popular solution to this issue, it has drawbacks of its own, including strong chemical reactivity and instability in battery production and environmental conditions. Therefore, cathode prelithiation is far less complicated in contrast [50]. Many cathode prelithiation additions have been created to date. Sacrificial Li salt additives, for instance (Li_2C_2, Li_3N, Li_2O, etc.), can effectively offset the ICL. However, undesirable gaseous N_2, CO, or CO_2 will inevitably evolve. On the other hand, ternary compounds (such as Li_5FeO_4, Li_6CoO_4, and Li_2NiO_2) don’t raise issues with gaseous evolution when used as cathode prelithiation additives. We will talk about various cathode prelithiation techniques in the following section [51–55].

3.2.1. Cathode prelithiation approaches

Sacrificial Li-rich additives have recently been considered a promising approach for cathode prelithiation. Due to their irreversible specific capacities during the initial charging process to provide an additional Li^+ source for anode prelithiation, a number of Li-rich additives, such as inorganic binary Li compounds (e.g., Li_3N and Li_2S), inorganic ternary Li compounds (e.g., Li_5Re

and Li_6CoO), and organic Li salts (e.g., Li_2DHBN and $Li_2C_2O_4$), have been investigated as cathode prelithiation additives. However, gas escape is typically associated with the delithiation of cathode prelithiation additives and must be eliminated using a secondary sealing method. A workable and economical prelithiation strategy has been proposed, along with a compatible modification that involves the introduction of Li_2S as a cathode prelithiation additive and lithium difluoro (oxalato) borate (LiDFOB) as an electrolyte additive. The built LICs demonstrated an exceptional capacity retention of 92% after 10,000 cycles at a current density of 1 A g^{-1}, along with a high energy density of 155 Wh kg^{-1} at a power density of 210 Wkg^{-1} and retaining 32 Wh kg^{-1} at an ultrahigh power density of 105 kW kg^{-1} [56].

3.2.2. Capacitive adsorption approach

Using capacitive adsorption, lithium ions are pre-stored in the cathode in this method [57]. Additionally, in the initial cycles, they serve as the supply of lithium to accomplish prelithiation. In the mean time, the capacitive adsorption's charge voltage can be altered to control the prelithiation level. The complete LIC device prelithiated using this technique has a specific capacity of 31.4 mAh g^{-1}.

Figure 6 shows the graphical representation of prelithiation by capacitive absorption. LICs experience capacity loss during their initial charge and discharge cycles due to irreversible lithium intercalation behaviors. Even though prelithiation frequently uses lithium metal, there are concerns about safety and operational complexity. As an alternative, cathode sacrificial lithium salts (CSLSs) present a feasible option because of their affordability, ease of use, and safety. This review compares several prelithiation techniques and thoroughly examines the function of prelithiation in LICs. In particular, it explores the use of CSLSs for prelithiation methods, going over the mechanisms of lithium extraction from them as well as the effects of doping levels and intrinsic properties on LIC performance.

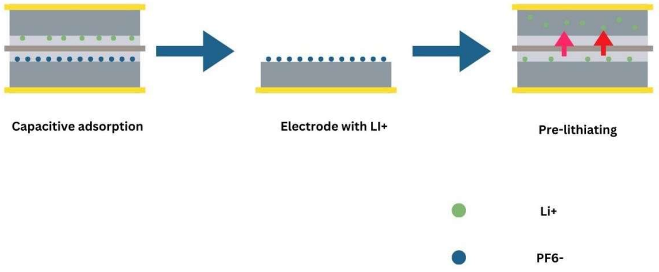

Figure 6. The prelithiation method by capacitive absorption.

The prelithiation procedure begins with the identification of sacrificial lithium salts that have a high capacity, a high degree of irreversibility in the first cycle, a low voltage for lithium extraction, and no "dead" materials left over after the initial charge. Additionally, it makes use of a number of prelithiation technologies, including the in-situ chemical (ISC) and in-situ electrochemical (ISEC) methods. CSLSs, which are used for prelithiation in LICs, are essential to the process, which attempts to make up for the irreversible capacity loss in LICs and is critical to their electrochemical performance [58]. **Table 1** shows the example of LICs using various prelithiation methods and their energy and power densities.

Table 1. Examples of LICs prepared using various prelithiation methods.

Prelithiationmaterials	Cathode	Anode	Energydensity (Wh/kg)	Powerdensity (kW/kg)	Cyclicstability	Ref.
Li		Soft Carbon (SC)	69.4	5.7	96.7 % after5000 cycles	[34]
Li_3N	AC/Li_3N	SC	214.7	19.5	75.1% retention after 5000 cycles at 3.2 $kWkg^{-1}$	[8]
Li	activatedcarbon	low surface area disordered carbon	80	8.4	85% capacity retention after 10,000 cycles	[36]
Li	X-NC	X-PNC	214.7	19.5	75.1% retention after 5000 cycles	[37]
Li	CHPC	NPC	220	0.805	90% capacity retained	[38]
Li	GCNS	HPNP	86	9.68	84% after 2500 cycle	[39]
Li	LGC-1500	LPC-3	197	11.4	92.3% retention after 5000 cycles	[41]
Li_2S	NPCNF	MNCNF	155	0.210	92% after 10,000 cycles	[12]

Basically, Li metal, Li_3N, and Li_2S are extensively used as lithium sources for prelithiation, and it is observed from **Table 1** that, among all prelithiation sources, Li metal is observed to be the best source, notably improving the energy and power densities of devices. Also, it is understood that AC/Li_3N is the best cathode material when used with SC as an anode material, where retention ration was observed to be around 75% after 5000 cycles.

4. Conclusion

A review of prelithiation processes on LICs reveals its significant potential to enhance the performance and efficiency of these devices. The various methods have been discussed with respect to prelithiation, such as chemical prelithiation, lithiation by direct contact of lithium foil, and prelithiation by half cell assembly. Further advancements in prelithiation techniques and materials expected to drive the continued improvement of LICs are discussed. In conclusion, electrochemical prelithiation holds great promise for enhancing the performance and efficiency of LICs. Continued research and development in this area is essential to unlocking the full potential of prelithiation and advancing the field of energy storage technologies.

Conflict of interest: The authors declare no conflict of interest.

References

1. Li F, Wang G, Zheng D, et al. Controlled prelithiation of SnO_2/C nanocomposite anodes for building full lithium-ion batteries. ACS Applied Materials & Interfaces. 2020; 12(17): 19423-19430. doi: 10.1021/acsami.0c00729
2. Mao Z, Song Y, Zhen AG, et al. Recycling of electrolyte from spent lithium-ion batteries. Next Sustainability. 2024; 3: 100015. doi: 10.1016/j.nxsust.2023.100015
3. Wang G, Li F, Liu D, et al. Chemical prelithiation of negative electrodes in ambient air for advanced lithium-ion batteries. ACS Applied Materials & Interfaces. 2019; 11(9): 8699-8703. doi: 10.1021/acsami.8b19416
4. Esen E, Mohrhardt M, Lennartz P, et al. Effect of prelithiation with passivated lithium metal powder on passivation films on high-energy NMC-811 and SiC_x electrodes. Materials Today Chemistry. 2023; 30: 101587. doi: 10.1016/j.mtchem.2023.101587
5. Sun C, Zhang X, Li C, et al. Recent advances in prelithiation materials and approaches for lithium-ion batteries and capacitors. Energy Storage Materials. 2020; 32: 497-516. doi: 10.1016/j.ensm.2020.07.009
6. Cementon C, Ramireddy T, Dewar D, et al. We may be underestimating the power capabilities of lithium-ion capacitors. Journal of Power Sources. 2024; 591: 233857. doi: 10.1016/j.jpowsour.2023.233857
7. Jin L, Shen C, Shellikeri A, et al. Progress and perspectives on pre-lithiation technologies for lithium ion capacitors. Energy & Environmental Science. 2020; 13(8): 2341-2362. doi: 10.1039/d0ee00807a
8. Sun C, Zhang X, Li C, et al. High-efficiency sacrificial prelithiation of lithium-ion capacitors with superior energy-storage performance. Energy Storage Materials. 2020; 24: 160-166. doi: 10.1016/j.ensm.2019.08.023
9. Xu J, Gao B, Huo KF, et al. Recent progress in electrode materials for nonaqueous lithium-ion capacitors. Journal of Nanoscience and Nanotechnology. 2020; 20(5): 2652-2667. doi: 10.1166/jnn.2020.17475
10. Meng Q, Li G, Yue J, et al. High-performance lithiated SiO_x anode obtained by a controllable and efficient prelithiation strategy. ACS Applied Materials & Interfaces. 2019; 11(35): 32062-32068. doi: 10.1021/acsami.9b12086
11. Zou Y, Zhang Z, Chen P, et al. Improving the cycle performance of porous schiff-base polymer electrode materials in lithium-ion batteries by prelithiation. ACS Applied Energy Materials. 2023; 6(21): 11322-11330. doi: 10.1021/acsaem.3c02197
12. Chen M, Huang X, Yang C, et al. Simultaneous prelithiation and compatible modification toward ultrafast and ultrastable lithium-ion capacitors. ACS Applied Energy Materials. 2022; 5(8): 9684-9691. doi: 10.1021/acsaem.2c01339
13. Jang J, Ki H, Kang Y, et al. Chemically prelithiated graphene for anodes of li-ion batteries. Energy & Fuels. 2020; 34(10): 13048-13055. doi: 10.1021/acs.energyfuels.0c01854
14. Shen Y, Zhang J, Pu Y, et al. Effective chemical prelithiation strategy for building a silicon/sulfur li-ion battery. ACS Energy Letters. 2019; 4(7): 1717-1724. doi: 10.1021/acsenergylett.9b00889
15. Yan MY, Li G, Zhang J, et al. Enabling SiO_x/C anode with high initial coulombic efficiency through a chemical pre-lithiation strategy for high-energy-density lithium-ion batteries. ACS Applied Materials & Interfaces. 2020; 12(24): 27202-27209. doi: 10.1021/acsami.0c05153
16. He X, Mu X, Wang Y, et al. Fast and scalable complete chemical prelithiation strategy for Si/C anodes enabling high-performance Li_xSi–S full cells. ACS Applied Energy Materials. 2023; 6(12): 6790-6796. doi: 10.1021/acsaem.3c00980
17. Yang Y, Wang J, Kim SC, et al. In Situ prelithiation by direct integration of lithium mesh into battery cells. Nano Letters. 2023; 23(11): 5042-5047. doi: 10.1021/acs.nanolett.3c00859
18. Choi J, Jeong H, Jang J, et al. Weakly solvating solution enables chemical prelithiation of Graphite–SiO_x anodes for high-energy li-ion batteries. Journal of the American Chemical Society. 2021; 143(24): 9169-9176. doi: 10.1021/jacs.1c03648
19. Wang Y, Lu J, Qiao Y, et al. The efficient solid electrochemical corrosion prelithiation of graphite and SiO_x/C anodes for longer-lasting lithium ion batteries. Journal of Power Sources. 2023; 580: 233402. doi: 10.1016/j.jpowsour.2023.233402
20. Johnson R, Baji DS, Nair S, et al. Spent-graphite anode from failed batteries: Regeneration and chemical prelithiation for sustainable fresh Li-ion batteries. Journal of Industrial and Engineering Chemistry. 2024; 133: 473-481. doi: 10.1016/j.jiec.2023.12.024
21. Wang H, Wu W, Jia Q, et al. Scalable layer-by-layer stacking of the Silicon-Graphite composite: Prelithiation strategy of the high-capacity anode for energy/power-dense li batteries. Industrial & Engineering Chemistry Research. 2022; 61(22): 7442-

7450. doi: 10.1021/acs.iecr.1c04702

22. Ying K C, Ping H H, C, W. Lan. Scalable chemical prelithiation of SiO/C anode material for lithium-ion batteries. Journal of Power Sources. 2023; 558: 232599. doi: 10.1016/j.jpowsour.2022.232599
23. Wang F, Wang B, Li J, et al. Prelithiation: A crucial strategy for boosting the practical application of next-generation lithium ion battery. ACS Nano. 2021; 15(2): 2197-2218. doi: 10.1021/acsnano.0c10664
24. Jia T, Zhong G, Lv Y, et al. Prelithiation strategies for silicon-based anode in high energy density lithium-ion battery. Green Energy & Environment. 2023; 8(5): 1325-1340. doi: 10.1016/j.gee.2022.08.005
25. Berhaut CL, Dominguez DZ, Tomasi D, et al. Prelithiation of silicon/graphite composite anodes: Benefits and mechanisms for long-lasting Li-Ion batteries. Energy Storage Materials. 2020; 29: 190-197. doi: 10.1016/j.ensm.2020.04.008
26. Shi J, Su CC, Amine R, et al. Prelithiation of lithium peroxide for silicon anode: achieving a high activation rate. ACS Applied Materials & Interfaces. 2023; 15(22): 26710-26717. doi: 10.1021/acsami.3c03312
27. Huang B, Huang T, Wan L, et al. Pre-lithiating SiO anodes for lithium-ion batteries by a simple, effective, and controllable strategy using stabilized lithium metal powder. ACS Sustainable Chemistry & Engineering. 2021; 9(2): 648-657. doi: 10.1021/acssuschemeng.0c05851
28. Lai P, Liu C, Sun Z, et al. A highly effective and controllable chemical prelithiation of Silicon/Carbon/Graphite composite anodes for lithium-ion batteries. Solid State Ionics. 2023; 403: 116415. doi: 10.1016/j.ssi.2023.116415
29. Zhang X, Qu H, Ji W, et al. Fast and Controllable Prelithiation of Hard Carbon Anodes for Lithium-Ion Batteries. ACS Applied Materials & Interfaces. 2020; 12(10): 11589-11599. doi: 10.1021/acsami.9b21417
30. Huang YE, Huang PW, Zhong Y, et al. Achieving high initial coulombic efficiencies and cycle stability of free-standing anodes by chemical prelithiation of carbon matrix. Applied Surface Science. 2023; 612: 155691. doi: 10.1016/j.apsusc.2022.155691
31. Yue H, Zhang S, Feng T, et al. Understanding of the Mechanism Enables Controllable Chemical Prelithiation of Anode Materials for Lithium-Ion Batteries. ACS Applied Materials & Interfaces. 2021; 13(45): 53996-54004. doi: 10.1021/acsami.1c16842
32. Divya ML, Aravindan V. Electrochemically generated γ-$Li_xV_2O_5$ as insertion host for high-energy Li-ion capacitors. Chemistry – An Asian Journal. 2019; 14(24): 4665-4672. doi: 10.1002/asia.201900946.
33. Zhang X, Hou X, Hou Y, et al. Insights into chemical prelithiation of SiO_x/Graphite composite anodes through scanning electron microscope imaging. ACS Applied Energy Materials. 2023; 6(15): 7996-8005. doi: 10.1021/acsaem.3c01077
34. Sun C, Zhang X, An Y, et al. Molecularly chemical prelithiation of soft carbon towards high-performance lithium-ion capacitors. Journal of Energy Storage. 2022; 56: 106009. doi: 10.1016/j.est.2022.106009
35. Arnaiz M, Canal-Rodríguez M, Martin-Fuentes S, et al. Roll-to-roll double side electrode processing for the development of pre-lithiated 80 F lithium-ion capacitor prototypes. Journal of Physics: Energy. 2023; 6(1): 015001. doi: 10.1088/2515-7655/ad064e
36. Veluri PS, Katchala N, Anandan S, et al. Petroleum coke as an efficient single carbon source for high-energy and high-power lithium-ion capacitors. Energy & Fuels. 2021; 35(10): 9010-9016. doi: 10.1021/acs.energyfuels.1c00665
37. Kong L, Xu X, Hou L, et al. Phosphorus and nitrogen co-doped carbon nanoparticles as both anode and cathode materials with enhanced Li^+/PF_6^- storage for high energy density lithium-ion capacitors. ACS Sustainable Chemistry & Engineering. 2023; 11(34): 12583-12594. doi: 10.1021/acssuschemeng.3c02068
38. Han L, Kang S, Zhu X, et al. High-performance lithium-ion capacitors produced by atom-thick carbon cathode and nitrogen-doped porous carbon anode. Energy & Fuels. 2021; 35(20): 16894-16902. doi: 10.1021/acs.energyfuels.1c02509
39. Tan JY, Su JT, Wu YJ, et al. Hollow porous α-Fe_2O_3 nanoparticles as anode materials for high-performance lithium-ion capacitors. ACS Sustainable Chemistry & Engineering. 2021; 9(3): 1180-1192. doi: 10.1021/acssuschemeng.0c06650
40. Ahn S, Fukushima M, Nara H, et al. Effect of fluoroethylene carbonate and vinylene carbonate additives on full-cell optimization of Li-ion capacitors. Electrochemistry Communications. 2021; 122: 106905. doi: 10.1016/j.elecom.2020.106905
41. Yang Z, Guo H, Yan G, et al. High-value utilization of lignin to prepare functional carbons toward advanced lithium-ion capacitors. ACS Sustainable Chemistry & Engineering. 2020; 8(31): 11522-11531. doi: 10.1021/acssuschemeng.0c01949
42. Fan Z, Ding B, Li Z, et al. In-situ prelithiation of electrolyte-free silicon anode for sulfide all-solid-state batteries. eTransportation. 2023; 18: 100277. doi: 10.1016/j.etran.2023.100277
43. Wang YK, Yang SY, Yang Y, et al. In-situ synthesized cathode prelithiation additive to compensate initial capacity loss for

lithium ion batteries. Journal of Electroanalytical Chemistry. 2022; 919: 116567. doi: 10.1016/j.jelechem.2022.116567

44. Sander M, Magar SD, Etter M, et al. The “In situ electrolyte” as a sustainable alternative for the realization of high-power devices. Chem. Sus. Chem. 2024; 17(5): e202301746. doi: 10.1002/cssc.202301746
45. Ren Y, Li J, Guo J. Perforated active carbon and pre-lithiated graphite electrodes for high performance hybrid lithium-ion capacitors. International Journal of Electrochemical Science. 2020; 15(3): 2659-2666. doi: 10.20964/2020.03.03
46. Arnaiz M, Shanmukaraj D, Carriazo D, et al. A transversal low-cost pre-metallation strategy enabling ultrafast and stable metal ion capacitor technologies. Energy & Environmental Science. 2020; 13(8): 2441-2449. doi: 10.1039/d0ee00351d
47. Anothumakkool B, Wiemers-Meyer S, Guyomard D, et al. Cascade-type prelithiation approach for Li-ion capacitors. Advanced Energy Materials. 2019; 9(27). doi: 10.1002/aenm.201900078
48. Park E, Chung DJ, Park MS, et al. Pre-lithiated carbon-coated Si/SiO nanospheres as a negative electrode material for advanced lithium ion capacitors. Journal of Power Sources. 2019; 440: 227094. doi: 10.1016/j.jpowsour.2019.227094
49. Sugiawati VA, Vacandio F, Yitzhack N, et al. Direct pre-lithiation of electropolymerized carbon nanotubes for enhanced cycling performance of flexible Li-ion micro-batteries. Polymers. 2020; 12(2): 406. doi: 10.3390/polym12020406
50. Ding R, Tian S, Zhang K, et al. Recent advances in cathode prelithiation additives and their use in lithium–ion batteries. Journal of Electroanalytical Chemistry. 2021; 893: 115325. doi: 10.1016/j.jelechem.2021.115325
51. Wu Y, Zhang W, Li S, et al. $Li_2Cu_{0.1}Ni_{0.9}O_2$ with Copper Substitution: A new cathode prelithiation additive for lithium-ion batteries. ACS Sustainable Chemistry & Engineering. 2023; 11(3): 1044-1053. doi: 10.1021/acssuschemeng.2c05779
52. Pan Y, Qi X, Du H, et al. Li_2Se as a cathode prelithiation additive for lithium-ion batteries. ACS Applied Materials & Interfaces. 2023; 15(15): 18763-18770. doi: 10.1021/acsami.2c21312
53. Watanabe T, Tsuda T, Ando N, et al. An improved pre-lithiation of graphite anodes using through-holed cathode and anode electrodes in a laminated lithiumion battery. Electrochimica Acta. 2019; 324: 134848. doi: 10.1016/j.electacta.2019.134848
54. Huo X, Gong X, Liu Y, et al. Conformal 3D Li/$Li_{13}Sn_5$ scaffolds anodes for high-areal energy density flexible lithium metal batteries. Advanced Science. 2024; 11(14). doi: 10.1002/advs.202309254
55. Shen C, Ye D, Jin L, et al. A simple and scalable prelithiation approach for high energy and low cost lithium ion sulfur batteries. Journal of The Electrochemical Society. 2020; 167(6): 060517. doi: 10.1149/1945- 7111/ab8408
56. Betz J, Nowak L, Winter M, et al. An approach for pre-lithiation of $Li_{1+x}Ni_{0.5}Mn_{1.5}O_4$ cathodes mitigating active lithium loss. Journal of The Electrochemical Society. 2019; 166(15): A3531-A3538. doi: 10.1149/2.1221914jes
57. Zhu H, Li J, Wu D, et al. A novel pre-lithiation strategy achieved by the capacitive adsorption in the cathode for lithium-ion capacitors. Renewable Energy. 2023; 217: 119163. doi: 10.1016/j.renene.2023.119163
58. Su K, Wang Y, Yang B, et al. A Review: Pre-lithiation strategies based on cathode sacrificial lithium salts for lithium-ion capacitors. Energy & Environmental Materials. 2023; 6(6). doi: 10.1002/eem2.12506