BATTERY Technology

The Truth About Batteries and How Structured High Surface Area Electrodes Can Make Them Better

ICPE BATTERY

Slobodan Petrovic

11/11/2021

S. Petrovic bp62@outlook.com

Introduction

The lithium battery technology is at an important junction. The fundamental limitations and outdated electrode manufacturing methods have considerably slowed down the pace of progress powered by a variety of applications such as EVs, energy storage for renewables and for grid stabilization. The expected improvements in performance have not happened fast enough and the hope for breakthroughs towards new active materials is unlikely. A battery is still considered the weakest link in many critical applications that address the climate change and the obstacle towards widespread use of groundbreaking devices.

The battery industry has nearly exhausted all improvement options. No new active electrode materials will be found, obvious improvement schemes have been already tested, and new and innovative ideas are short-lived or with a limited impact. And while the battery industry stagnates, the next industrial revolution based on clean energy necessitates better, lighter, and cheaper power sources. The electrical vehicle application is on a high trajectory towards completely taking over the vehicle industry, but it needs a battery that will deliver the performance expectations. Present battery technology is not capable of meeting the demands of the applications in terms of energy density, cycle life, safety, or cost.

Overview

Lithium-ion batteries are by far the most popular battery technology of this generation. They have extraordinary performance expressed mainly in high specific energy and energy density. The lithium-ion battery systems are complex because they comprise not only one combination of anode and cathode, but several different variations or so-called chemistries based on the type of cathode. There are also differences in the anode that make the lithium batteries sometimes difficult to classify and describe. Figure 1 shows different anodes and cathodes in lithium batteries.

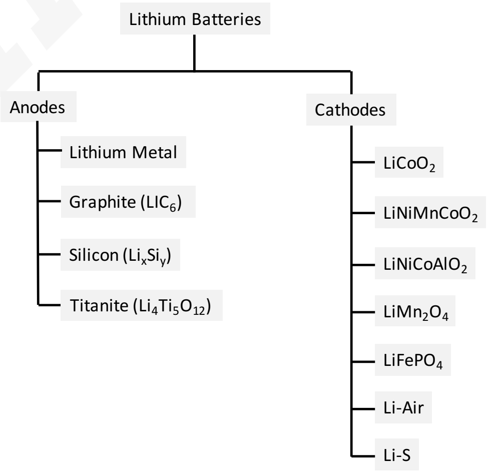


Fig. 1 Classification of lithium batteries

The six most popular cathode materials include lithium cobalt oxide (LCO), lithium cobalt aluminum oxide (NCA), nickel manganese cobalt oxide (NMC), lithium manganese oxide (LMO), lithium iron phosphate (LFP). Each of these systems has different characteristics that determine suitability for a certain application, but none of them have the highest performance characteristics in all performance categories. For example, lithium cobalt oxide system has the highest specific energy, but lithium iron phosphate has the best cycle life; and these two performance factors cannot be combined in the same battery. In general, lithium-ion batteries cannot have both high specific energy and specific power, but one or the other. And a battery with capability for high number of cycles has lower both energy density and power density.

Lithium cobalt oxide is the original commercial lithium-ion battery used for portable devices such as cell phones and laptop computers. It is characterized by high gravimetric and volumetric capacities, moderate cycle life and good energy efficiency. This battery requires expensive raw materials, its safety must be improved, charging times shortened, and cost lowered.

In general, the choice of electrode materials determines battery performance, capacity, and safety risks (Figure 2).

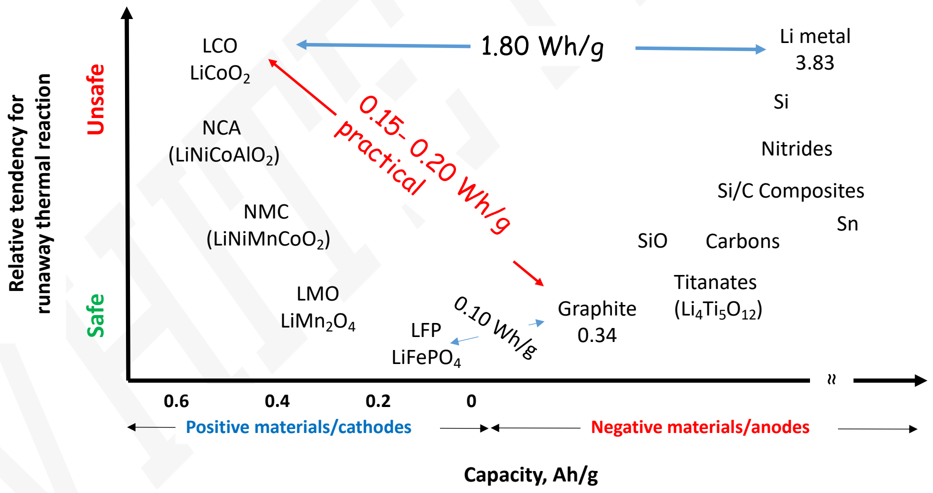


Fig. 2 Illustrative overview of electrode theoretical capacities, and safety considerations.

Lithium manganese oxide battery is one of the first lithium-ion battery types demonstrated. It is characterized by high power density, but lower energy density. It is safer and less expensive than LCO but has poor high temperature stability.

S. Petrovic bp62@outlook.com

Nickel cobalt aluminum oxide has the highest energy density and good cycle life; and is one of the most common choices for electrical vehicle batteries. However, the safety of this battery must be improved, and the cost lowered.

Lithium nickel manganese cobalt oxide cathode uses a combination of three different oxides in roughly equal amounts. Each material contributes with different properties and the resultant battery has good energy density and power density. This battery is commonly used in power tools and powertrains for automobiles.

Lithium iron phosphate battery is the safest version of all lithium-ion batteries because of the better stability of the cathode material, iron phosphate. As a result, this battery has also the best cycle life of about 3000 cycles. However, it has lower specific energy and energy density than the original lithium cobalt oxide. The overview of lithium battery cathodes is given in table 1.

Lithium metal batteries with MoS_2 cathode were commercialized in the 1980s, but quickly discontinued because of safety issues. The main problem is the formation of lithium dendrites during charging, which leads to puncturing the separator and electrical short.

There are several categories of lithium battery anodes, starting with pure lithium metal. All other anodes are materials that enable formation of lithium ions. The most common lithium-ion anode material is graphite. Graphite allows intercalation between its graphene sheets of one lithium atom for every six carbon atoms. The kinetics of this reaction are slow due to long path for lithium ions between the planes. The conductivity of graphite is also limited to only one direction, which creates voltage drop in the electrode.

Table 1 Overview of cathode materials, their characteristics, and applications.

Cathode	General battery characteristics	Applications
LCO ($LiCoO_2$)	Very high energy, limited power, expensive	Mobile phones, laptops, cameras
NMC ($LiNiMnCoO_2$)	High capacity and high power, thermally less stable	Evs, E-bikes, industrial
NCA ($LiNiCoAlO_2$)	Energy cell, high energy density, thermally less stable	Medical, industrial, EVs (Tesla)
LMO ($LiMn_2O_4$)	High power, less capacity, relatively safe	Power tools, medical devices, powertrains
LFP ($LiFePO_4$)	High cycle number, low energy density, very safe	Portable, stationary

Other anodes include lithium silicon and lithium titanate. In silicon anodes, each silicon atom bonds with 4.4 lithium atoms, which leads to high theoretical specific capacity of 4200 mAh/g. The process called lithiation of silicon causes expansion of the silicon crystalline lattice and swelling to several times the original volume. The expansion leads to crumbling of the active material, detachment from the current collector and quick loss of capacity. Lithium titanate has large surface area and the fastest charging time of all lithium-ion batteries.

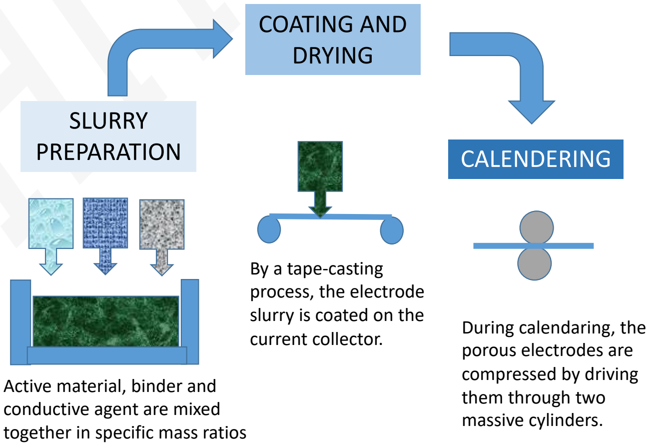
Because of that it is attractive for electrical vehicles. However, it has lower specific energy and energy density; and the lowest voltage of all lithium-ion batteries.

Manufacturing Performance Challenges

The making of lithium-ion batteries is not fundamentally different from some other battery types and has not changed since the first commercial lithium batteries in the 1980s. The process comprises the following steps:

1. Slurry coating
2. Calendaring
3. Winding
4. Cell assembly
5. Electrolyte fill
6. Cap and seal
7. Electrochemical formation charge

The manufacturing process starts with milling and mixing active material into a slurry with the addition of components to increase conductivity and to improve binding. Then, the slurry is coated on a current collector, typically copper, for the anode and aluminum for the cathode. Next, the electrodes are rolled to a required thickness (most commonly 70 – 90 μm), followed by attaching the contact tabs through ultrasonic welding (Figure 3). The electrodes are subsequently stacked together with separator in between. Then, the stacks are placed in the housing such metal can or a pouch, filled with electrolyte in vacuum, and finally sealed.



By a tape-casting process, the electrode slurry is coated on the current collector.

Active material, binder and conductive agent are mixed together in specific mass ratios

During calendaring, the porous electrodes are compressed by driving them through two massive cylinders.

J. Smekens et al., Energies 2016, 9(2), 104

Fig. 3 Schematic depiction of the conventional battery electrode manufacturing process.

The overall manufacturing process is outdated and inadequate for the challenges of improved performance. The mode of fabrication leads to structural problems and affects performance because of the poor electron conduction from the current collector and loss of active material because of poor adhesion between the particles. The critical dilemma is that of a ratio between the surface area (in contact with the electrolyte) and conductivity. The increase in the amount of binding material means extra weight and lower specific capacity, while less or insufficient amount of binder can lead to loss of active material.

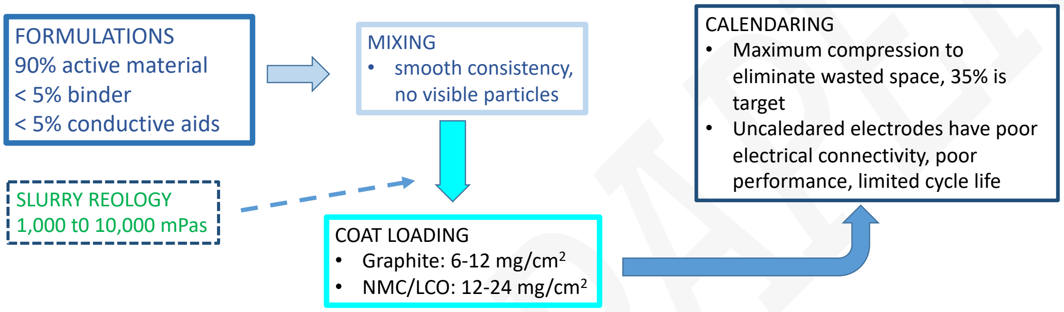


Fig. 4 Critical dilemma: surface area versus conductivity

Furthermore, so far, we have not discussed the progression from a single cell to a battery stack, a critical process step towards the final energy storage device. The conventional battery manufacturing problems continue to limit the performance as single cells are assembled into stacks because of the need to package single cells first, then stack the cells, join electrical contacts, and insert cell stacks into another level of packaging (i.e., housing). Besides complex, multi-step assembly, and high cost, battery stacks face single cell mismatch and thermal distribution problems.

Fundamental limitations

The complexity of different combinations of anodes and cathodes in lithium battery systems makes it difficult to discuss the shortcomings of various batteries in general terms. But we'll try to point to main sources of problems that affect the performance or safety of these batteries using conceptual generalized argument instead of discussing individual component problems. We will use largely illustrative arguments in form of graphs and tables.

First, we define the performance as a totality of the following main battery characteristics:

1. Energy density: the amount of energy stored per volume or weight.
2. Power density: the ability to deliver current per volume or weight. The ability to accept current is related to charging time.
3. Cycle life: number of cycles that a battery can deliver a useful capacity, typically 80% of the nominal or starting capacity.
4. Safety: the ability to reduce the probability of a catastrophic battery failure with violent outcome such as fire or explosion.
5. Battery cost.

There are several fundamentally unwanted reactions in lithium batteries, which in most cases lead to performance degradation. Lithium metal dendrite growth occurs on anodes during charging and can be described as formation of a needle-, or tree-like structures instead of a flat, homogeneous metal layer. The non-uniform and random growth could result in propagation through the separator and causing electrical short with the other electrode, or in dendrites detaching from the electrode and loss of capacity.

The solid electrolyte interphase layer forms on the negative electrode of the lithium battery through reactions in the charge process between the electrode components and the organic solvent. The SEI layer is electrically insulating, but ionically conductive. It provides stabilization of the surface, but over time leads to capacity loss. Under some circumstance the SEI layer promotes initiation of the Li dendrite growth. The fundamental problems with lithium batteries that lead to performance deficiencies can be summarized in the table 2.

Table 2 Summary of main fundamental processes that impact performance

Fundamental problem	Effect on performance
Li dendrite growth	Unsafe, lower charging current
Solid electrolyte interphase layer	Capacity loss, initiation of thermal runaway
Slow Li ion intercalation	Lower power density, longer charge time
Low active mass conductivity	Voltage drop, loss of power

A deeper look and consideration of even more basic analysis of the battery electrode structure reveals serios problems that are the root-cause of all other problems that affect performance. We refer to design shortcomings that come from poor understanding and neglect of an elementary concept called three-phase boundary. It appears that battery manufacturers have forgotten an old principle that three phases, active mass, solid current collector, and liquid electrolyte must all come into an intimate contact for any electrochemical reaction to occur. If only two phases are in contact, the reaction cannot take place (Figure 5).

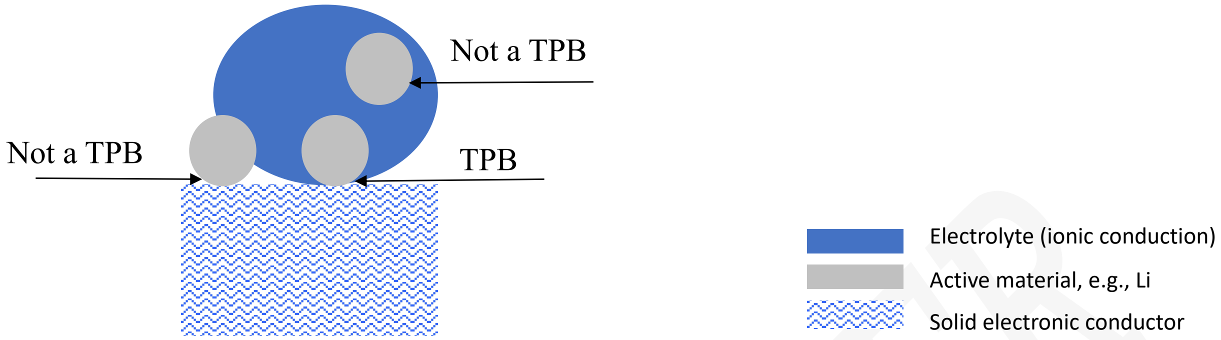


Fig. 5 Generalized description of a Three-Phase-Boundary (TPB).

The electrochemical electricity producing reactions (discharge) and the Li plating reaction (charge) occur in this three-phase-boundary (TPB) area. The density (i.e., length per volume) of this TPB area and the transport rate of reactants to and from the TPB area determine the rate with which the discharge and charge processes proceed. Hence, it is important to optimize the structure of the electrode to reach a large TPB area density and a high transport rate of electrons (low electronic resistance) and Li-ions (low ionic resistance). 3D electrode structures are excellent way to increase the TPB area density and especially the electronic conductivity by reducing the Li thickness.

The electrode manufacturing process for conventional Li batteries described above results in the final structure that has about 60-80 μm of electrode active mass (with additives) coated on 15–20 μm thin metal foil as a current collector (Figure 6).

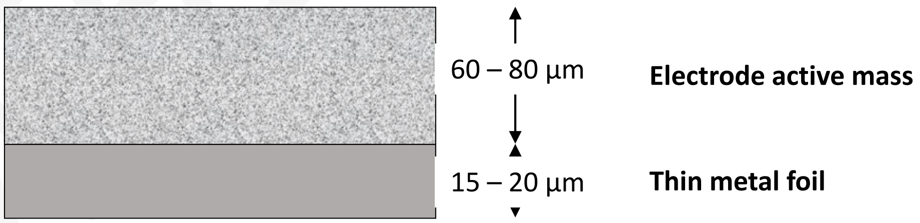


Fig. 6 Conceptual cross section of a battery electrode.

The layer of active mass with additives coated and pressed onto the current collector is non-structured, with non-uniform and potentially tortuous and meandering pores and channels which get partially filled with electrolyte. This fundamental non-uniformity of the structure means that the three-phase-boundary is small, which results in a slow reaction and resistance that contributes to voltage drop and loss of power. The cross section reveals non-structured layers of compressed, but still porous, active mass particles with conductive additives forming random shape cavities that subsequently get filled with electrolyte (Figure 7).

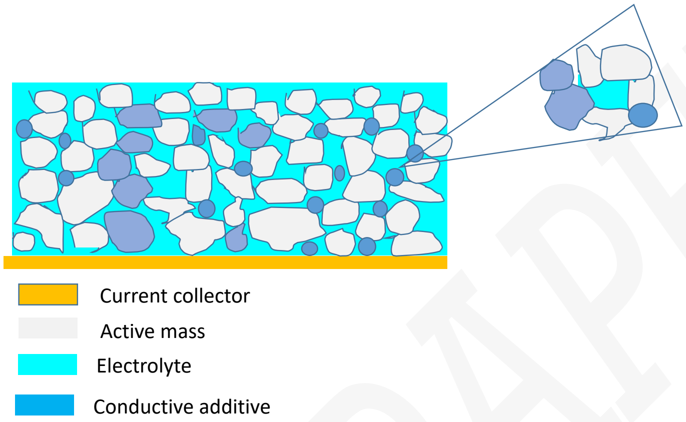


Fig. 7 Conceptual cross section of a Li battery electrode.

It is now possible to envision a reaction mechanism whereby during the charging process Li$^+$ ions first migrate through the bulk electrolyte and arrive at the surface of the electrode (top surface in the figure). Next, upon entering the electrode, Li$^+$ ions may encounter a site that is electrically conductive and can supply electrons to enable reduction reaction:

$$Li^+ + e^- \dashrightarrow Li$$

Such electrically conductive site in case of the most common anode, Li-graphite, could be a graphite particle or a conductive additive particle. If such a site is near the top surface of the electrode structure, Li$^+$ has a short distance to overcome and resistance to its transfer and the power loss is low. The other reactants in this reduction reaction are the electrons, so let's examine their journey to the reaction site. During the charge process, a power supply (i.e., charger) supplies electrons into the Li-graphite electrode through the terminal and the current collector, usually a 15–20 μm metal foil such as copper. Copper of course is very conductive, and electrons face very little resistance while passing through the current collector (resistivity 1.71 $\mu\Omega$cm). However, electrons still have up to 80 μm to pass through the electrode by finding the least resistive path from one particle of graphite to another and crossing in the process multiple interfaces where the resistance is higher. The resistivity of

S. Petrovic bp62@outlook.com

natural graphite is 6.00 x $10^3\mu\Omega$cm, roughly 5000 times larger than in the copper current collector and not even taking into account the random manner of graphite particle compression, tortuosity of pathway and interfacial resistance, the factors that easily increase the resistivity by 1000 times. Undoubtedly, electrons face much higher opposition while travelling through the graphite electrode to an active site at the top of the electrode facing the bulk electrolyte.

Let us now envision another extreme case, the reaction taking place in the part of the electrode near the current collector. The electrons now have a short part to travel and would not create significant resistance and loss of power. However, Li$^+$ ions must travel in this case through the thickness of the electrode (~ 80 μm) to get to active site. The pathway is through the electrolyte that has filled the cavities formed when graphite particles, together with additives, were mixed and compressed in the electrode manufacturing process. Because the electrode structures are not engineered, rather random distribution of electrolyte is likely, whereby electrolyte occupies channels, reservoirs, and other structures. It is also possible and likely that some pathways may end up in "dead-end" formations and ion loss, resulting in poor efficiency.

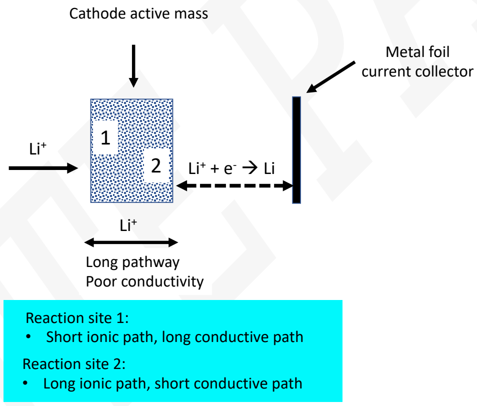


Fig. 8 Schematic depiction of the reaction site locations for cathodic reactions in Li batteries.

While in the example above a charging process on an anode is analyzed, the same considerations are used to explain the inefficiencies in the discharge and cathodic reactions; and point to significant performance limitations of the conventional Li battery electrode structures (Figure 8).

The truth about batteries

Lithium batteries and in particular Li-ion batteries are non-mature technology defined by generally flawed designs and imperfect fabrication processes. Fundamental limitations of the battery performance as a result of antiquated designs and fabrication processes include small surface area of current collectors and lack of three-phase-boundary necessary for successful reaction.

t is also clear that none of combinations of anode and cathode into a full battery, have superior performance in all main performance aspects and that none of them can successfully meet more than one performance element. This is graphically articulated in the figure 9, with the intent to examine the performance of one unit or anode-cathode combination; and not show the possible performance benefit for the whole lithium battery family, as sometimes mistakenly implied. It is, therefore, very difficult that the same battery, i.e., a combination of anode and cathode, would have superior characteristics in two of the categories and it is virtually impossible that a same unit would be the embodiment of three superior characteristics. For example, the most wide-spread, Li graphite – $LiCoO_2$ battery, has superior energy density, but all its other characteristics are mediocre or poor, such as its safety. Or the nickel cobalt aluminum oxide that has the highest energy density and good cycle life; but also has poor safety characteristics and high cost.

Furthermore, some of the advanced batteries with good promise, such as those with oxygen or air cathodes or with silicon anodes, have not been sufficiently tested and proven in high-volume production to make a good assessment of their properties.

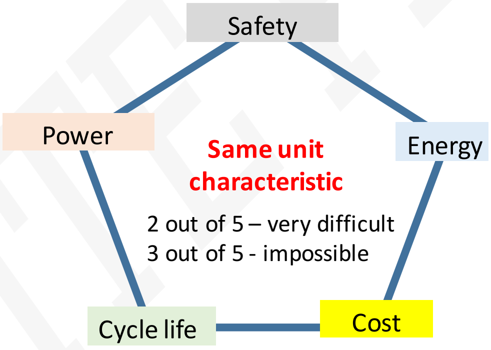


Fig. 9 Representation of the main battery characteristics and overall capability.

In summary, we have discussed the advantages and problems associated with lithium batteries. In the next section, we will present analysis of the novel research directions and propose strategies for systematic and radical improvements.

Analysis of the novel research directions

There is no lack of novel ideas in the field of batteries and in the last decade several hundred thousand patents have been filed related to lithium batteries alone. The development of novel batteries to meet the increasing demand for better energy, power,

S. Petrovic bp62@outlook.com

cycle life, and safety in energy storage (i.e.., stationary) and motive power (i.e., electrical vehicles) has been slow and has not led to satisfactory performance improvement. In addition, the current manufacturing methods are archaic and inefficient. Most of the developments have focused on novel anode materials such as silicon, solid electrolytes that are expected to improve safety by preventing Li dendrite formation, and novel cathodes such as air and sulfur (Figure 10) while a snapshot of the most notable recent investments is presented below (Table 3).

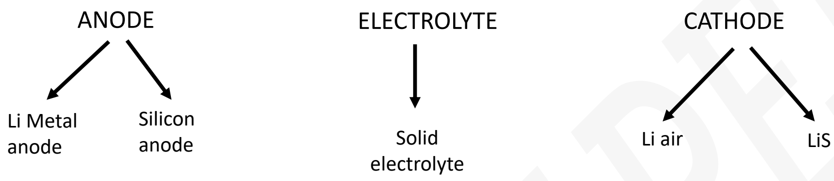


Fig. 10 Illustration of the novel research directions for Li batteries.

Table 3 Analysis of recent battery developments and investments.

Company*	Feature	Claim	Investment*	Fundamental limitation
SSB - 1	Solid electrolyte	High energy density, safe	Automaker $60 M US	Solid electrolyte conductivity Lack of surface area
SSB - 2	Solid electrolyte	High energy density, safe	Automaker ~$80 M US	Solid electrolyte conductivity Lack of surface area
Si anode - 1	Si anode	High energy density, safe	> $60 M US	Anode volume change
Si anode - 2	Si anode	Fast charging	Various, EV maker, unknown	Anode volume change

* Actual company identity and identities of investors is publicly available.

However, despite initial enthusiasm fueled by large investment commitments, none of these new technology concepts have so far materialized into successful and recognized commercial products due to unsubstantiated benefit claims. This can be seen even after a cursory examination of the concept characteristics.

For example, the use of solid electrolyte, described under the overall designation "solid state battery", does reduce formation of Li dendrites, but it can never meet the requirements for high ionic conductivity (i.e., low internal resistance) at room temperature. And while the solid electrolyte is likely to prevent Li dendrite formation, the battery has low performance at room temperature. At higher temperature, for example 80°C, the ionic conductivity of the solid electrolyte becomes satisfactory, but at the expense of reduced elastic stiffness, making Li dendrite penetration possible again. In addition, formation of effective, large surface area of electrode in contact with the electrolyte is virtually impossible, thus reducing power and capacity. One way to overcome the latter is a "hybrid" approach, whereby both liquid electrolyte and solid electrolyte are used. But the verdict in case of solid electrolyte batteries is that the hype is only partially justified and that they are suitable for applications requiring thin form-factor, high temperature and low current, while not suitable for high-current applications and high cycle life.

The Si anode approach, on the other hand, claims to improve the energy that a battery can store, but it comes with serious problems due to electrode mechanical stability and severe expansion of Li-Si alloy in the charge state (Figure 11). This problem has not been successfully resolved so far and there is very little chance of that, therefore, the implementation has dramatically stalled despite some recent, desperate investments into partial, non-complete solutions, which only confirm the above-described inability to address more than one performance factor.

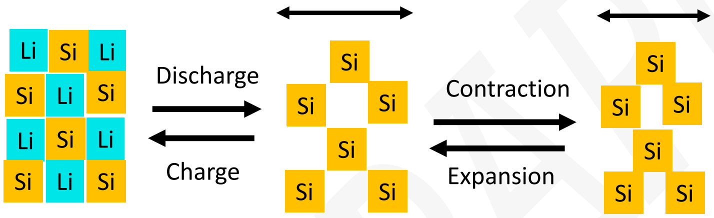


Fig. 11 Illustration of Si anode contraction and expansion during charging and discharging.

Table 4 Summary of design limitations on component level for novel battery developments.

Component/type of limitation	Description of limitation: cause and effect
Anode (Li metal)	Small surface area, equal to geometrical; High local current density
	Dendrites can still form
	Uneven plating of Li) → electrode mechanical stability
	Loss of conductivity and mechanical stability
Anode (silicon)	Electrode contraction and expansion on every cycle
	Cycle life low or unpredictable
Solid electrolyte	Low ionic conductivity at RT, very poor conductivity at low temperatures
	At 80°C elastic stiffness reduced – dendrites can penetrate
Reaction zone	Small reaction zone and undefined 3-phase boundary
	Pathway from active mass to current collector long, i.e., 50-70 µm
Cathode (conventional)	Long ionic path or long conductive path

The verdict is that Si anode batteries have potentially high energy density, but poor prospects for high-current applications and high cycle life. A summary of component design limitations for the most promising new development directions reveals likely unsurpassable obstacles despite public and private displays of optimism. This all translates into the following basic property limitations (Table 5).

S. Petrovic bp62@outlook.com

Table 5 Generalized property limitations in a conceptual solid-state battery (SSB).

Property	Solid State Battery
Mechanical shape	Rigid, button, cylindrical, pouch
Current density	High ionic resistance at RT, no defined 3-phase contact
Volume and thickness	Large: thick electrodes (50 – 80µm)
Energy content, I,.e., specific energy	Low: thick electrodes, heavy current collector, slurry additives
Cycle life	Low: mechanical problems with contraction and expansion
Safety	Critical at High temperatures
Use of solid electrolyte	Very difficult: thick electrodes, contact interphase resistance
Cost	Very expensive

To complete the analysis of the current state-of-art of Li battery manufacturing and performance we present the manufacturing characteristics of conventional single cell design (Table 6).

Table 6 Manufacturing characteristics of a conventional Li battery single cell.

Component	Conventional Li-ion battery
Current collector (both anode and cathode)	15-20 µm metal foil
Anode mass (substrate) application	Coating using mechanical deposition, e.g., slurry of graphite with binder and conductive aid
Cathode mass (substrate) application	Coating using mechanical deposition, e.g., slurry with binder and conductive aid
Additional electrode processing	Calendaring (compression to right porosity and conductivity)
Separator	Different separator materials
Manufacturing time	Slow, slow process steps

Is there a solution?

The evidence presented in this conceptual analysis suggests that the majority of battery research focuses on narrow and random component improvements rather than fundamental and broader evaluation of basic reaction mechanisms that leads to systematic design and ultimate discovery of the most optimal structures.

When we look at any successful, operational electrical device in all possible fields and industries, from electrical power devices such as inverters or rectifiers, and semiconductor devices, i.e., chips or sensors, to medical devices or musical devices, they all have extremely controlled, structured, and very predictable design. Of all electrical devices only batteries comprise electrodes that are unstructured, non-uniform and random. For some inexplicable reason the scientific and technical community remained blind by ignoring this fundamental fact and continued with battery electrode manufacturing using old fabrication methods from more than 150 years ago that result in poorly structured, non-uniform and unpredictable electrodes that are still expected to convert a very predictable electrical signal into chemical energy and then reverse the process. While this random fabrication method had resulted in generations of batteries that were able to meet demands of applications at particular times in history the requirements for modern applications such as EVs have pushed the boundaries for battery performance beyond the capabilities of current knowledge and available technology. This is also the reason that batteries cold not have been considered a mature technology that is produced reliably and reproducibly. However, this also presents an opportunity to dramatically improve the performance. It is time now to fundamentally change design principles and enter an era of predictable battery electrode design and fabrication.

As a result of this introspective analysis a concept starts crystalizing that reveals perfectly structured electrodes, completely uniform and identical on the micrometer scale. The crucially important contact area described as three-phase boundary must be engineered in a structured manner and large. This is the concept of high-surface area electrodes, which has been considered for solving some fundamental performance limitations of batteries. Such a battery is designed to have a very large surface area current collectors on the electrodes, enables safe operation, high specific energy and energy density, fast charging and superior cycle life.

This battery concept is a **platform** – not a single element that determines the success of technology. The concept is agnostic to anode active material, cathode active material, current collector material, liquid electrolyte, solid electrolyte, separator, and any future component improvements. The concept can also use the above critiqued solid electrolyte and Si anode technologies and improve their performance.

The battery is fabricated using assembly process completely different from the traditional process that includes mixing of the active mass and coating a current collector. Instead, the proposed concept involves rapid fabrication using modern techniques of succussive layer deposition. As a result, the proposed flexible electrode technology is manufactured several times faster using roll-to-roll manufacturing process, which consists of embedding and printing of various materials onto a flexible, continuously rolled substrate, The resulting electrodes have very high surface area, are very light for good specific energy and form perfectly structured reaction zone and completely defined three-phase boundary. Based on high surface area of the current collector, the local current density is low and uniform resulting in uniform Li ion distribution; and short transportation pathways for Li ions and electrons, ensuring high power performance. In these structures, the length of pathway for ions through the electrode goes from zero at the beginning of reaction (i.e., no resistance to flow) to maximum 10 μm (Figure 12) – compare this to up to 70 μm in conventional batteries. The reaction takes place inside a micron-size reservoirs with walls coated with current collector conductive material. The three-phase boundary formed along the pores of the structure is perfectly defined and large, embedded in a layered and flexible structure (Figure 13)

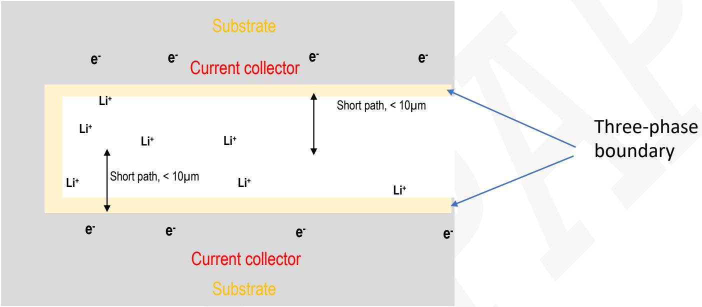


Fig. 12 Depiction of a cross-section of reaction zone showing short diffusion path to the reaction zone.

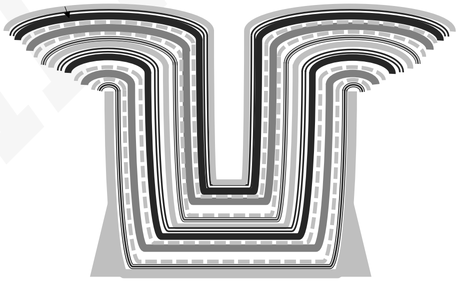


Fig. 13 Schematic representation of the cross-section of the novel battery electrode assembly.

A comparison of single cell manufacturing between the conventional Li battery shows substantial advantages of the high-surface area electrode battery (Table 7).

Table 7 Single cell battery comparison between conventional Li-ion battery and high surface area battery.

Component	Conventional Li-ion battery	High surface area electrode battery
Current collector (both anode and cathode)	15-20 µm metal foil	20 – 30 nm conductive coating
Anode mass (substrate) application	Coating using mechanical deposition, e.g., slurry of graphite with binder and conductive aid	Anode is metallic Li – no substrate needed, i.e., high surface current collector and space for anode active mass
Cathode mass (substrate) application	Coating using mechanical deposition, e.g., slurry with binder and conductive aid	ALD deposition
Additional electrode processing	Calendaring (compression to right porosity and conductivity)	No calendaring or other processing needed
Separator	Different separator materials	No separator
Manufacturing time	Slow, slow process steps	Fast, continuous processing

In addition, the electrode and cell configuration enable rapid assembly of battery stacks as a continuation of the same process used for single cells, effectively eliminating the need to package single cells. This enables significant improvement in performance of battery stacks and dramatic decrease in overall cost (Table 8).

Table 8 Battery stack design: conventional Li-ion battery and high surface area battery.

Conventional Li-ion battery	High surface are electrode Battery
Single cell manufacturing	Done in one continuous process
Cell stacking	
Electrical interconnects	None. part of the overall process – no special process steps
Insert cell stack into housing	Packing as part of the overall process – similar to electronic device packaging
Single cell mismatch an issue	No mismatch
Thermal distribution an issue	Perfect thermal uniformity – controlled in the manufacturing phase

Summary

Evaluation of LI batteries has demonstrated fundamental problems that come from the lack of systematic design and poor manufacturing methods. These lead to performance reduction and a variety of failure modes that cannot be solved with random, unsystematic component improvement attempts.

In response, a disruptive new Li metal battery technology based on high-surface area electrodes has been described that has the potential to deliver better performance in respect to all critical criteria such as specific energy, energy density, cycle life, rate of charge, and safety.

For more information contact Dr. Slobodan Petrovic at 503-913-6819 or at bp62@outlook.com

References

1. Petrovic, Kurzweil, and Garche, "Electrochemical Energy Storage", McGraw Hill, 2021, in print.
2. Slobodan Petrovic, "PV Systems for Developing Countries", Springer, 2022.
3. Slobodan Petrovic, ed., "Handbook of Energy and Energy Resiliency", Springer, 2022.
4. Slobodan Petrovic, " Energy Storage: Facts and Fallacies", Invited talk, 4th Multi/Interdisciplinary Research Conference, University of Namibia, Namibia, 2021.
5. Eklas Hossain and Slobodan Petrovic, "Renewable Energy Crash Course: A Concise Introduction 1st ed. 2021 Edition", Springer 2021, ISBN-13: 978-3030700485, ISBN-10: 3030700488.
6. Slobodan Petrovic, "Electrochemistry Crash Course for Engineers", Springer 2021, ISBN-13: 978-3030615611, ISBN-10: 3030615618.
7. Slobodan Petrovic, "Battery Technology Crash Course: A Concise Introduction 1st ed. 2020 Edition", ISBN-13: 978-3030572686, ISBN-10: 3030572684.
8. S. Petrovic and E. Hossein, "Development of a Novel Technological Readiness Assessment Tool for Fuel Cell Technology" IEEE Access Journal, 16 pages, Print ISSN: 2169-3536, Online ISSN: 2169-3536, Digital Object Identifier: 10.1109/ACCESS.2020.3009193, IEEE 2020.

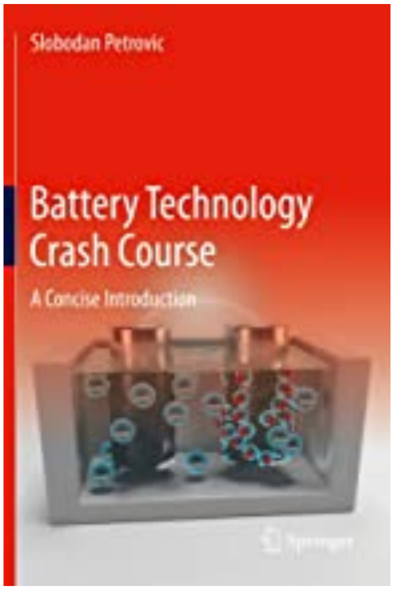
Slobodan Petrovic – biographical sketch

Dr. Slobodan Petrovic is a Professor of Electrical and Renewable Energy Engineering at Oregon Institute of Technology where he teaches numerous courses including batteries, fuel cells hydrogen, energy storage, PV systems, physics of solar cells, materials, solid state devices, and others.

Dr. Petrovic has over 30 years of experience in various areas of science and technology. He has written 5 books and over 120 publication and 50 patents in the field. His current interest is in high-surface area electrodes for Li Ion batteries, Li air cells, battery charging techniques, automotive battery packs design and testing, power supplies for the IoT, MEMS batteries and fuel cells, dye-sensitized solar cells, investigation of carrier lifetime in solar cells, hydrogen production and storage, renewable energy and storage integration, remote sensing for smart grid, and low-cost technologies for developing countries.

Dr. Petrovic was previously a Chief Technology Officer for a battery company, a Vice President of Engineering for a stationary power fuel cell company, and a Director of Systems Integration for a portable fuel cell company.

Dr. Petrovic is also a Founder and a President of the non-profit organization, Solar Hope, dedicated to helping developing countries through use of renewable energy. He has worked extensively in developing countries, mainly in Africa and accomplished over 120 solar PV installations, impacting over 1,000,000 people.

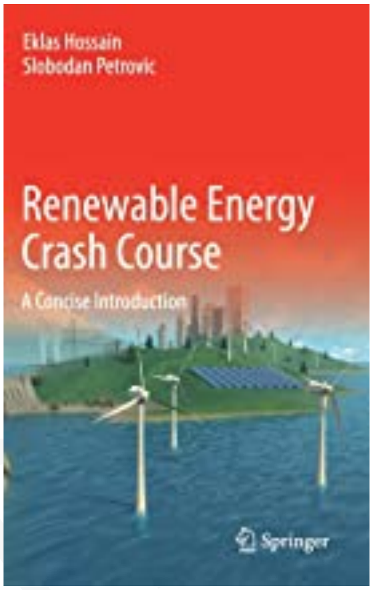


Slobodan Petrovic

Battery Technology Crash Course

A Concise Introduction

Springer



Eklas Hossain
Slobodan Petrovic

Renewable Energy Crash Course

A Concise Introduction

Springer