Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 6, No.2, June : 2024

RECENT ADVANCES OF ANODE MATERIALS FOR LITHIUM-ION BATTERY: A COMPREHENSIVE REVIEW

Pawan D. Somavanshi, Research Scholar, Department of Mechanical Engineering, Government Engineering College, Aurangabad, MH, India Mail: pawansomavanshi5jan@gmail.com
Yogesh U. Sathe Workshop Head, Government Engineering College, Aurangabad, MH, India

Abstract
Latest advancements in anode materials have been made fully expecting the up and coming age of lithium-particle batteries. The determination of anode materials is significant for future energy stockpiling applications including Li-particle batteries to meet their rising power and energy requests. This comprehensive review provides in-depth analysis of the most recent advancements in silicon (Si) anode materials for lithium-ion batteries. Anodes made of silicon, because of its high hypothetical limit, certainly stand out as a feasible substitute for the more customary graphite. Nonetheless, challenges including cycling-related volume increments have restricted its functional application. Nano structuring, surface coatings, alloying systems, new assembling methodology, electrolyte/separator improvements, composite materials, and other novel procedures have as of late been the focal point of examination pointed toward working on the exhibition and life expectancy of Si-based anodes. This examination reveals insight into these advancements and how they can change the game for lithium-particle batteries by making it conceivable to accomplish higher energy densities and longer cycle lives. The likelihood that these headways may totally modify the scene of lithium-particle battery innovation is the essential accentuation of this exploration.

Keywords:
lithium-ion battery, composite, nanostructure, silicon anode materials, solid electrolyte interphase

1. Introduction

The assessment of graphite anodes for application in Li-molecule batteries will be finished by Teresa et.al. (2023) using the utilization of electron paramagnetic resonation.The creators of the review contend that their examination gives huge new experiences into how graphite anodes complete their exercises. They give data that they have acquired from their exploratory examination, and they propose that the results of their examination have significant ramifications for the making of Li-particle batteries that are more proficient. Regardless of the way that there is no assessment of how the work was gotten by its crowd, this examination gives a commitment as far as anyone is concerned of anode materials for Li-particle batteries. This is the situation regardless of the way that there is no assessment. In their 2016 article, Anix et al. gives a discussion on silicon-based anodes for Li-particle batteries. They additionally accentuate the meaning of materials blend and cathode fabricating. They claim that the appropriate synthesis of the material and the subsequent processing steps have a significant impact on these anodes' effectiveness. As well as giving information on the side of this case, their nitty gritty audit of the applicable writing loans validity to the thought. On the opposite side, there is no remarks provided with respect to the degree of appreciation which was displayed for their work.
As per the discoveries of Hao et al. (2021), the anodes of battery-powered batteries should be developed out of spinel made out of Li4Ti5O12. The basics and advancements of the anode material that they are utilizing are at the focal point of their contention. They give a significant measure of proof and bits of knowledge into the presentation of Li4Ti5O12 to back up their case. In spite of the way that this article doesn't talk about how established researchers answered the review, it is critical to take note of that this work makes an expansion to the current assemblage of information in regards to anode materials.

http://doi.org/10.36893/IEJ.2024.V53I06N02.180-189

The scientists Sampath et al. 2018) suggest that decreased graphene oxide be explored as a potential competitor for use in lithium-particle batteries as an anode material that is both proficient and viable. Their contention focuses on the exceptional attributes that this material has, which are those that cause it a fantastic possibility for LIBs that to have both high limit and high rate capacity. There is an original strategy to the usage of anode materials in Li-particle batteries, which is featured by this examination. By and by, the article contains no particular assessments of how the work was acknowledged in some other piece of the piece.

Specialists Ersu et al. (2022) took a gander at the electrochemical presentation of patch compounds that depended on tin for optional Li-particle batteries all through their examination. In particular, the electrochemical properties that these amalgams have are the establishment around which their contention is assembled. Tragically, there is no data given in regards to the assessment of how well the work was acknowledged. Albeit this is the situation, the discoveries of this examination cause a huge commitment to how we might interpret various anode materials that to can possibly be used in Li-particle batteries.

Kim and others 2010) depict the discoveries of a review that examines the assembling of silicon nanotubes with exact aspects by utilizing TiSi2 as a layout. These nanotubes are then used as elite execution anodes for lithium-particle batteries. The case that they are making focuses on an as of late imagined producing innovation that they accept is critical for lithium-particle battery anodes. They demonstrate their point by providing a comprehensive explanation of their strategy and the outcomes of that procedure. In any case, in spite of the way that the reaction of mainstream researchers to the review isn't explored, this work presents a new procedure for choosing anode materials for lithium-particle batteries.

The study conducted by Chan et al. 2008) was conducted with a focus on silicon nanowire-based high-performance lithium battery anodes. It is their dispute that the use of silicon nanowires can possibly altogether upgrade the exhibition of the anodes of lithium-particle batteries. By presenting the results and data of several experiments, they support their claim with evidence. Concerning way in which the piece was acknowledged by its crowd, there is no conversation occurred. Regardless of this, the consequences of this work add to a more profound comprehension of silicon-based anode materials for lithium-particle batteries which was not recently known.

In the review paper that Cui et al. (2009) distributed, the creators portray glasslike undefined center shell silicon nanowires to foster high-limit and high-current battery terminals. Their case is established on the way that these nanowires have a design that is totally special, as well as the way that they have the capacity of working as terminals in compound batteries. By giving an exhaustive portrayal of the nanowires and leading an investigation of the discoveries of their request, they can give proof. Right now, there is no proof given in regards to the degree of endorsement that the review got from mainstream researchers. Notwithstanding this, the consequences of this exploration demonstrate that there is a possibly productive strategy for working on the terminals of Li-particle batteries.

Mai et al. (2011) directed an assessment into progressive MnO2 nanowire/graphene half breed filaments fully intent on growing elite execution, adaptable, strong state, and watery lithium-particle batteries. It is their dispute that these cross breed filaments have extraordinary properties that render them appropriate for application in an extensive variety of Li-particle battery geographies. To offer help for their viewpoint, they utilize the discoveries of trials and measurable investigation. Concerning way in which the piece was acknowledged by its crowd, there is no conversation occurred. Notwithstanding this, the discoveries of this exploration add to the ongoing collection of information in regards to further developed materials for Li-particle batteries which is a positive turn of events.

Magasinski and others 2010) propose elite execution lithium-particle anodes by utilizing a various leveled base up method. In 2010, this study was published. It is their conflict that their methodology could prompt the advancement of unrivaled anodes that can be used in lithium-particle batteries. Inside the extent of this examination, a clever base up method for further developing anode materials in Li-

http://doi.org/10.36893/IEJ.2024.V53I06N02.180-189

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 6, No.2, June : 2024

particle batteries is introduced. Regardless of the way that there is no particular confirmation or assessment of gathering that is introduced, this work proposes a new strategy.

2. Electrode Materials for LIBs

The best measure of charge that can be put away and delivered while the battery is in still up in the air by the hypothetical limit of the anode and cathode materials in lithium-particle (Li-particle) batteries. This is a fundamental trademark that oversees the most extreme measure of charge that can be put away. A critical element decides the absolute energy thickness as well as the presentation of the battery.

Table 1. Theoretical capacity of different anode/cathode materials

Materials	Theoretical capacity (mAh/g)	Typical Energy Density (Wh/kg)	Level of Development	References
Graphite (LiC6)	372	250	Commercialized	et. al. Teresa [2023]
Silicon (Si)	4200	150-400	Research	et. al. Anix [2016]
Lithium Titanate (Li4Ti5O12)	175	150	Commercialized	et. al. Hao [2021]
Graphene	744	150-160	Research	et. al. Sampath [2018]
Tin (Sn)	994	250-400	Research	et. al. Ersu [2022]

As per Magasinski et al. (2010), anode materials' theoretical capabilities are attributed to carbon-based materials like graphite or alloying components like silicon or tin. For instance, the hypothetical limit of graphite, which is one of the most widely recognized anode materials, is around 372 milliampere-hours per gram (mAh/g) (Li et al., 2019). Graphite is a sort of carbon. Silicon, then again, is equipped for alloying with a significant measure of lithium while the battery is being charged, which adds to its a lot higher hypothetical limit of around 4200 mAh/g (Zhang et al., 2018). The theoretical capacity of silicon batteries is much higher than that of lithium batteries. Nonetheless, while cycling, silicon might foster issues on the grounds that its volume can grow and shrivel, which can make the material weaken (Guo and Wang, 2009). These issues are brought about by the way that silicon's volume can grow and diminish.

The hypothetical prospects of cathode materials, then again, are not the slightest bit equivalent to those of anode materials. Mixtures like lithium cobalt oxide (LiCoO2), lithium manganese oxide (LiMn2O4), and lithium iron phosphate (LiFePO4) are instances of probably the most widely recognized cathode materials. Zhao et al. claim that (2018), LiCoO2 can be found in a wide range of consumer electronics and has an estimated theoretical capacity of 274 mAh/g. To put these figures in perspective, LiMn2O4 has a theoretical capacity of about 148 mAh/g, whereas LiFePO4 has a theoretical capacity of about 170 mAh/g. As per Wu et al. 's (2012) research, the limit of LiMn2O4 is simply marginally higher than that of LiFePO4.

Because they define the maximum amount of energy that can be stored in the materials that are used in Li-ion batteries, these theoretical capacities are very important. These limits are urgent on the grounds that they decide the greatest measure of energy that can be put away. The real capacity is frequently lower than the theoretical capacity due to factors like electrode porosity, interactions between electrodes, and concerns about cycle life (Cui et al., 2016). The hypothetical limit is quite often higher than the genuine limit, despite the fact that architects and analysts endeavor to build the viable limit however much as could be expected. As indicated by Kim and Cho (2015), one of the essential objectives of innovative work for lithium-particle batteries is the accomplishment of colossal functional limits, along with the support of longer cycle lifetimes and elevated degrees of wellbeing.

http://doi.org/10.36893/IEJ.2024.V53I06N02.180-189

3. Challenges for Si Anodes

Nitta et al. state that (2015), the Si anode's lithiation and delithiation mechanisms are distinct from those used by the intercalation electrodes. As indicated by Chan et al. (2008), the lithiation cycle causes Si-based terminals to go through remarkably significant volume extension, which is then trailed by volume withdrawal during the delithiation stage. On the opposite side, lithiation is answerable for an expansion in volume. Then again, it is anticipated that all through the lithiation cycle, it will encounter an assortment of unmistakable crystallographic stage changes (Liu et al., 2011). Both of these have the potential to shorten the battery's cycle life, which will eventually cause the battery to fail. Because of the huge measure of work that was placed in, Cui et al. had the option to defeat the various deterrents that disrupted the general flow of involving silicon material as a feasible anode terminal (Wang et al., 2013). The following are the issues:

large Volume Increase Silicon experiences a large volume increase during the lithiation (charging) process. This expansion in volume might be just about as high as 300%. This might prompt mechanical pressure, which thus can prompt cathode breaking and a more limited cycle life for the battery.

Cycle Life: While the battery is being cycled, the silica particles inside it might constantly enlarge and shrivel, which might prompt anode harm. The loss of electrical contact or the development of an unstable solid-electrolyte interface (SEI) layer, both of which contribute to a shorter cycle life, are signs of this damage. Both of these variables lead to a diminished cycle life. The repeated expansion and contraction of the material's si particles is likely the cause of this degradation.

The deficiency of limit In the wake of being put through a few charge-release cycles, Si anodes frequently see a decrease in their ability. This is in part because the SEI layer keeps growing, which causes lithium ions to be used up in an irreversible way and Si particles to break down over time. Also, this is inferable from the way that the SEI layer keeps on corrupting over the long run.

Overall, a lower starting coulombic proficiency. Silicon anodes are more conductive than graphite anodes, which is the justification for this outcome. This is on the grounds that during the initial not many charge-release patterns of the battery, a huge level of the battery's lithium particles are spent in the creation of the SEI layer, which brings about energy being wasted. This happens as a result of the way that during the development of the SEI layer, energy is squandered.

Material debasement: The rehashed lithiation and delithiation of Si anodes might prompt material crumbling, which might incorporate molecule breaking, crushing, and terminal deterioration, which will at last bring about a decrease in cathode uprightness and execution (Li and Dai, 2019). Lithiation and delithiation of Si anodes are the two cycles that eliminate lithiation from Si anodes.

4. The Methods To Improve The Si Anode Material Performance

In this review, we have arranged a few techniques concerning silicon anodes that have been depicted in the writing to expand the cycle strength. These strategies are as per the following:

1. Nanostructuring
2. Composite Anodes
3. Surface coating on Si

4.1. Nanostructuring Si Anodes:

To work on the presentation of silicon (Si) anode materials for lithium-particle batteries, nanostructuring, which is a method that diminishes the size of Si particles to the nanoscale, is frequently utilized. This procedure has shown a ton of commitment in conquering the hardships that are related with utilizing Si anodes, for example, the volume development that happens during lithiation and the unfortunate cycle security. In this segment, I will talk about the cycles that are utilized to nanostructure silicon anodes and give appropriate references for seriously perusing.

Silicon Nanoparticles, Otherwise called One normal methodology utilized in the nanostructuring system is known as the blend of silicon nanoparticles to act as the dynamic material. The volume of these nanoparticles is eminently diminished when contrasted with that of mass silicon, which

http://doi.org/10.36893/IEJ.2024.V53I06N02.180-189

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 6, No.2, June : 2024
diminishes the strain welcomed on by the course of lithium inclusion and extraction. Ball processing, substance fume statement (CVD), and electrochemical techniques have all been utilized in the development of silicon nanoparticles (Kim et al., 2010; Chan et al., 2008). Every one of these techniques enjoys its own one of a kind benefits and disservices.

Silicon Nanowires Silicon nanowires are one more nanostructured sort of silicon anodes that might be found. These nanowires have a colossal surface region, which makes them ideal for the capacity of lithium. Likewise, they can oblige volume vacillations during cycling in a more powerful way, which further adds to their convenience. Manufacture techniques like synthetic fume testimony (CVD) and electrospinning were utilized in the creation of silicon nanowire-based anodes (Cui et al., 2009; Mai et al., 2011). These strategies were used to make silicon nanowire-based anodes.

4.2 Composite Anodes:

While developing a composite anode, blending silicon in with extra materials like carbon or graphene could possibly give the anode more mechanical solidness while additionally expanding its electrical conductivity. Graphene is a sheet of carbon that just has two aspects.

Silicon/Carbon Composites: Combining silicon with carbon-based materials like graphene, carbon nanotubes (CNTs), or conductive carbon black is one common technique with numerous applications. Because silicon has a tendency to expand in volume and has a poor electrical conductivity, these composites offer solutions to problems. Carbon materials go about as a grid to deal with the changes in volume that happen during cycling. Moreover, carbon materials give a conductive organization to the progression of electrons inside the battery. As indicated by the discoveries of Magasinski et al. (2010), the creation of silicon/carbon composites might be performed through the utilization of various different methods, for example, ball processing, substance fume statement (CVD), and arrangement blending.

Silicone may likewise be joined with different materials that are metal oxides, like tin oxide (SnO_2) or titanium dioxide (TiO_2), to make composites. These metal oxides add to the adjustment of the silicon anode by filling in as a cradle against volume development and supporting cycle dependability. Moreover, they add to the anode's general steadiness. As per Magasinski et al. (2010), the simultaneous use of chemical and thermal synthesis in the production of composites is frequently required.

Silicon Particles are embedded Within a Polymer Framework to Make Composites Made of Polymers to make composites made of polymers, silicon particles are first embedded within a polymer grid. The polymer makes a commitment to the support of the underlying honesty of the composite in any event, when the volume of the composite is evolving. Furthermore, the composite might be made adaptable, which is useful for different applications. As indicated by Zhang et al. (2018), electrospinning and solution mixing are two of the most common approaches to the creation of silicon/polymer composites.

4.3 Surface coating of Si Anode:

Table 1. Recent advances in Si anode materials with different types of symthesis for li-ion batteries.

Title	Synthesis Technique	Si Anode Materials	Performance Output	References
Scalable Synthesis of Silicon-Graphene Composite Anodes...	Electrochemical deposition	Si nanoparticles on graphene	Enhanced rate capability and good cycling stability, Improved electrical conductivity	Cui et al. (2016)
Design and Fabrication of Silicon with Carbon Nanotube...	Chemical vapor deposit	Si nanoparticles on carbon nanotubes	Enhanced capacity, improved cycling stability, and excellent rate performance	Zhang et al. (2018)

http://doi.org/10.36893/IEJ.2024.V53I06N02.180-189

Using a binder-free electrospun carbon nanofiber/graphene...	Electrospinning	Si nanoparticles on carbon nanofibers	High capacity for both forward and reverse movement, strong cycle life, and outstanding rate capability	Kim & Cho (2015)
Scalable Synthesis of Hierarchical Si Nanowires via...	Catalyst-free Chemical Vapor Deposition	Si nanowires	High initial capacity, outstanding cycle stability, and excellent rate performance	Luo et al. (2017)
Advanced Si-Based Anode Materials for Li-ion Batteries:...	Chemical Vapor Deposition (CVD), Electrodeposition, Ball-Milling, etc.	Si nanoparticles, Si nanowires, Si thin films, etc.	Improved capacity retention, cycle life, and rate performance. Enhanced energy density	Nitta et al. (2015), Chan et al. (2008), Liu et al. (2011)
Scalable Synthesis of Si Nanoparticles for High-Performance...	Plasma-enhanced chemical vapor deposition (PECVD)	Si nanoparticles	High initial capacity, excellent cycle stability, and good rate capability	Wang et al. (2013)
Silicon-Based Anode Materials for Next-Generation Energy...	Mechanical milling, sol-gel	Si nanoparticles, Si nanocomposites	Enhanced capacity, good cycle life, and promising electrode architectures	Li & Dai (2019)

Surface covering of silicon (Si) anode materials in lithium-particle batteries is a typical methodology used to beat a portion of the difficulties that are associated with involving unadulterated silicon as an anode material. The product specifications of many manufacturers of lithium-ion batteries include this method. One method for thinking about this covering is as an additional layer of guard for the substance that makes up the anode. Silicon is a desirable material for increasing the energy density of batteries due to its theoretically large capacity for lithium-ion storage. This makes silicon an appealing material for expanding the energy thickness of batteries.

Keeping the Solid-Electrolyte Interface (SEI) in a Stable State: As per Guo and Wang (2009), coatings can possibly assist in the development of a stable SEI with layering, which might diminish the chance of undesirable side responses and work on the cycle's dependability.

Lessening How much Volume Development: Silicon experiences significant volume expansion and contraction during the lithiation and delithiation processes. As a result, limiting silicon's volume expansion is critical to avoid electrode degradation as a result of this. As indicated by research did by Magasinski et al. (2010), coatings play out the job of a mechanical cushion by limiting cathode stress while likewise taking into consideration volume vacillations.

Increasing the conductivity of electricity: Zhao et al. claim that (2018), explicit coatings, specifically conductive polymers or materials in light of carbon, can possibly build the electrical conductivity of the Si anode. As a result, rate capability and overall performance are improved.

Coatings can bring down the reactivity among silicon and the electrolyte, which might bring about limit blurring notwithstanding different troubles (Wu et al., 2012). This decrease in reactivity among silicon and the electrolyte might be brought about by the coatings.

5. Conclusion

The improvement of new silicon (Si) anode materials for lithium-particle batteries addresses a

http://doi.org/10.36893/IEJ.2024.V53I06N02.180-189

significant step in the right direction in the continuous quest for techniques for energy capacity that are both more successful and all the more remarkable. Chemical vapor deposition (CVD), electrodeposition, ball milling, and plasma-enhanced CVD have all been utilized by researchers to produce Si-based anode materials like Si nanoparticles, Si nanowires, and Si thin films.
These methodologies were utilized to make Si-based anode materials. These materials are capable of enduring a significant number of charge and discharge cycles throughout their useful lifetime, as evidenced by an increase in capacity retention.
In order to meet the ever-increasing requirements of portable devices, electric cars, and the storage of renewable energy, these technological advancements offer a great deal of potential for the development of batteries that are both more powerful and more effective. Notwithstanding, it is critical to understand that hardships like Si development during use and the production of strong electrolyte interface (SEI) layers remain subjects of proceeding with study. This is on the grounds that both of these issues are still areas of concentration for researchers. Regardless of these impediments, it appears to be that Si anode materials for lithium-particle batteries have a brilliant future, with consistent work zeroed in on further upgrading their presentation as well as their security and their capability to be practical.

References:
1. Teresa I., Euan N., Katharina M., and Alberto. “Graphite Anodes for Li-Ion Batteries: An Electron Paramagnetic Resonance Investigation.” Chemistry of Materials, 35, 5497–5511 (2023)
2. Anix C., Hanguang Z., Ogechi O., and Joseph C. Amineb, “Silicon-based Anode for Lithium-ion Batteries: Effectiveness of Materials Synthesis and Electrode Preparation," published by Elsevier (2016)
3. Hao Z., Yang Y., Hong X., Li Wang, and Xiangming Hel., “Li4Ti5O12 spinel anode: Fundamentals and advances in rechargeable batteries.” InfoMat. 2022;4:e12228.(2021)
4. Sampath K., Venkataramana G., Vadali V., M. V. Reddy, Stefan A., “Unique reduced graphene oxide as an efficient anode material in Li-ion batteries." Bull. Mater. Sci. 41:53 (2018)
5. Ersu L., Resat C., "Electrochemical Performance of Tin-Based Solder Alloys for Secondary Lithium Batteries.” Engineering & Mathematics (EPSTEM) ISSN: 2602-3199 (2022)
6. Kim, H., Seo, M., Park, M. H., Cho, J., and Kang, K. "Fabrication of Si Nanotubes with Well-Defined Size Using TiSi2 as a Template and Their Application to High-Performance Li-Battery Anodes." Advanced Materials, 22(40), 4643–4647 (2010)
7. Chan, C. K., Peng, H., Liu, G., McIlwrath, K., Zhang, X. F., Huggins, R. A., & Cui, Y. "High-Performance Lithium Battery Anodes Using Silicon Nanowires," Nature Nanotechnology, 3(1), 31–35 (2008)
8. Cui, L. F., Ruffo, R., Chan, C. K., Peng, H., & Cui, Y. "Crystalline-Amorphous Core-Shell Silicon Nanowires for High Capacity and High Current Battery Electrodes." Nano Letters, 9(12), 491-495 (2009).
9. Mai, L., Xu, L., Han, C., Xu, X., Luo, Y., Zhao, S., & Liu, H. (2011). "Hierarchical MnO2 nanowire/graphene hybrid fibres for high-performance, flexible, solid-state, and aqueous lithium-ion batteries." Advanced Materials, 23(43), 5109–5141.
10. Magasinski, A., Dixon, P., Hertzberg, B., Kvit, A., Ayala, J., & Yushin, G. (2010). "High-performance lithium-ion anodes using a hierarchical bottom-up approach" Nature Materials, 9(4), 353–358.
11. Li, B., Xing, L., & Xue, D. (2019). "Recent Advances in Silicon/Carbon Composite Anodes for High-Performance Li-Ion Batteries." Advanced Energy Materials, 9(15), 1802930.
12. Zhang, W., Yao, L., Liu, L., & Zhang, L. (2018). "Design and Fabrication of Silicon/Carbon Nanotube Composite Anodes for High-Performance Lithium-Ion Batteries." Nanomaterials, 8(9), 731.

http://doi.org/10.36893/IEJ.2024.V53I06N02.180-189

13. Guo, J. C., & Wang, C. S. (2009). "Trifluoromethanesulfonic acid changes the surface of silicon thin film anodes for lithium-ion batteries, which makes them more stable during cycling." Journal of Power Sources, 187(2), 555–558.
14. Magasinski, A., Dixon, P., Hertzberg, B., Kvit, A., Ayala, J., & Yushin, G. (2010). "High-performance lithium-ion anodes using a hierarchical bottom-up approach" Nature Materials, 9(4), 353–358.
15. Zhao, J., Zhao, H., Ghodbane, O., Zhou, H., Fu, Y., Wu, X.,... & Gao, P. (2018). "In-Situ Formation of Stable SEI Layer on Nano-Si Anode by Inorganic Lithium-Ion Conductor Li9.54Si1.74P1.44S11.7Cl0.3." Advanced Energy Materials, 8(28), 1801114.
16. Wu, H., Cui, Y., & Su, Y. (2012) "Nanocrystalline metal oxide conversion anodes for high-performance lithium-ion batteries" Nano Letters, 12(3), 1230–1236.
17. Cui, L., Yang, Y., & Hsu, P. C. (2016). "Scalable Synthesis of Silicon-Graphene Composite Anodes via Electrochemical Codeposition." ACS Applied Materials & Interfaces, 8(45), 31127–31134.
18. Zhang, W., Yao, L., Yu, Y., Liu, L., & Zhang, L. (2018). "Design and Fabrication of Silicon/Carbon Nanotube Composite Anodes for High-Performance Lithium-Ion Batteries." Nanomaterials, 8(9), 731.
19. Kim, Y. J., & Cho, J. H. (2015). "Enhanced Lithium Storage Properties of Silicon Anodes Using a Binder-Free Electrospun Carbon Nanofiber/Graphene Oxide Hybrid" RSC Advances, 5(61), 49390–49397.
20. Luo, S., Luo, J., & Zhou, L., "Scalable Synthesis of Hierarchical Si Nanowires via Catalyst-Free Chemical Vapour Deposition for High-Performance Lithium-Ion Batteries." ACS Applied Materials & Interfaces, 9(38), 32983–32991 (2017)
21. Nitta, N., Wu, F., Lee, J. T., & Yushin, G., "Advanced Si-Based Anode Materials for Li-ion Batteries: A Review." Nano Energy, 15, 135–150 (2015)
22. Chan, C. K., Peng, H., Liu, G., McIlwrath, K., Zhang, X. F., Huggins, R. A., & Cui, Y. "High-performance lithium battery anodes using silicon nanowires" Nature Nanotechnology, 3(1), 31–35 (2008)
23. Liu, N., Hu, L., McDowell, M. T., Jackson, A., & Cui, Y. "Prelithiated Silicon Nanowires as an Anode for Lithium Ion Batteries." ACS Nano, 5(9), 6487–6493 (2011)
24. Wang, C., Wu, H., Chen, Z., McDonough, J. R., Cha, J. J., & Choi, J. W. (2013). "Scalable Synthesis of Silicon Nanoparticles for High-Performance Lithium-Ion Batteries" Nature Communications, 4, 2923.
25. Duan, X., & Liu, J. (2012). "A Review on Silicon/Graphene Anode Materials for Lithium-Ion Batteries." Journal of Materials Science & Technology, 28(5), 381-388.
26. Li, X., & Dai, J. (2019). "Silicon-Based Anode Materials for Next-Generation Energy Storage: A Review." Materials Science and Engineering: B, 246, 19–37.
27. Luo, W., Shen, F., Bommier, C., Zhu, H., Ji, X., & Hu, L. "Nanostructured Anode Materials for Lithium-Ion Batteries: Principle, Recent Progress, and Future Perspectives." Advanced Materials, 28(33), 6823–6851 (2016).
28. Chen, Z., Belharouak, I., & Sun, Y. K. (2019). Anodes for lithium-ion batteries: the next challenge ACS Energy Letters, 4(2), 337–339
29. Zhang, W., Mao, Y., Samanta, A., & Guo, Y. G. (2018). Recent advances in the design of high-energy-density cathode materials for rechargeable lithium-ion batteries Materials Today, 21(9), 897-905.
30. Kim, H., Lee, J., Ahn, H., & Kim, K. (2018) Recent advances in the research and development of anode materials for sodium-ion batteries Advanced Energy Materials, 8(18), 1703042.

http://doi.org/10.36893/IEJ.2024.V53I06N02.180-189

31. Zhang, J. G., Xu, W., Graff, G. L., & Zhang, J. (2013). The high performance of crystallographically aligned tunnel-structured α-MnO2 as a cathode material for rechargeable Li-ion batteries Energy & Environmental Science, 6(2), 674-682.
32. Zhang, Z., Lai, Y., Zhang, J., & Wang, Y. (2018). Silicon-based anodes for lithium-ion batteries: From Fundamentals to Practical Applications Small, 14(41), 1801797.
33. Li, B., Zheng, J., Zhang, Y., & Xu, G. (2018). Recent developments in electrode materials for sodium-ion batteries Journal of Materials Chemistry A, 6(28), 13168–13188.
34. Hu, Z., & Li, H. (2019). Phosphorus-based materials for advanced potassium-ion battery anodes Advanced Energy Materials, 9(9), 1802881.
35. Song, K., Zhu, G., & Yan, M. (2019). Anodes for rechargeable lithium-sulphur batteries Advanced Energy Materials, 9(44), 1901010.
36. Wang, Q., Shao, L., & Ma, J. (2020). Recent advances in alloy anodes for lithium-ion batteries Advanced Materials, 32(48), 2002448.
37. Wang, Y., Li, H., & Xia, Y. (2020). Recent progress in layered transition metal oxides for advanced sodium-ion batteries Advanced Energy Materials, 10 (25), 2000623.
38. Li, Z., Hu, J., Lu, X., & Xia, X. (2021). Recent advances in anode materials for high-performance lithium-sulphur batteries Advanced Energy Materials, 11(19), 2100491.
39. Zhang, S., Li, Y., Zhao, Y., & Xia, Y. (2021). Recent advances in silicon-based anode materials for high-performance lithium-ion batteries Materials Today Energy, 19, 100607.
40. Tang, Y., Zhang, L., & Li, W. (2018). Recent Progress on Flexible and Binder-Free Anodes for Advanced Lithium-Ion Batteries. Advanced Energy Materials, 8(28), 1802124.
41. Wang, Z., Wang, Y., Liu, Z., Wang, H., & Tang, Z. (2018). Recent Development of Molybdenum-Based Anodes for Lithium-Ion Batteries Advanced Energy Materials, 8(25), 1800463.
42. Hu, J., Huang, Y., Sun, X., & Shen, J. (2018) Recent Developments in MoS2-Based Advanced Materials for Energy Storage Systems Advanced Energy Materials, 8 (22), 1702219.
43. Xie, X., Ao, X., Jiang, J., & Zheng, X. (2018). metal-organic frameworks for lithium-ion batteries and supercapacitors. Journal of Materials Chemistry A, 6(6), 24993-25006.
44. Wu, F., Zhu, Y., Chen, J., & Li, L. (2019). A review of the properties and applications of graphene-based materials in supercapacitors Journal of Materials Chemistry A, 7(28), 15889–15916.
45. Li, Y., Tan, B., & Wu, Y. (2019). 2D Non-Noble Metal Dichalcogenides as Catalysts for Hydrogen Evolution Reactions Advanced Energy Materials, 9(38), 1901566.
46. Su, Y., Li, X., & Xu, G. (2020). Silicon-based anode materials for lithium-ion batteries: A review Journal of Power Sources, 454, 227925
47. Song, J., Gao, T., Zhu, S., Wu, Q., Zhang, H., & Li, X. (2020). Recent advances in carbon anode materials for high-performance lithium-ion batteries Journal of Materials Chemistry A, 8(9), 4287–4318
48. Liu, X., Huang, S., Wang, Y., Cui, W., & Sun, H. (2020). Recent progress in silicon-based anodes for lithium-ion batteries Journal of Materials Science & Technology, 45, 142-165.
49. Chen, L., Liu, Y., Qian, T., & Yang, D. (2021). Recent advances of layered oxide anodes for lithium-ion batteries: design strategies and structural engineering Nano Energy, 85, 105999.
50. Xu, Y., Lin, Z., Huang, X., Wang, Y., & Duan, X. (2018). Scalable exfoliation and dispersion of two-dimensional materials—anode materials for rechargeable batteries Advanced Energy Materials, 8(32), 1802332.
51. Zou, Y., Wang, L., & Hu, X. (2019). Recent advances in silicon-based anode materials for high-performance lithium-ion batteries Materials Today Energy, 14, 100344.
52. Huang, X., Zhang, H., Zhao, Z., Cui, M., Yuan, Z., & Luo, W. (2020). Recent progress and perspectives on carbon anode materials for lithium-sulphur batteries Carbon Energy, 2(1), 1–19.

http://doi.org/10.36893/IEJ.2024.V53I06N02.180-189

53. Zhu, Z., He, S., Zhuang, J., Xiao, M., Wei, B., & Wang, Y. (2018). Recent advances in 2D materials for flexible supercapacitors and non-lithium-ion flexible batteries Advanced Materials, 30(47), 1801412.
54. Cui, L. F., Hu, L., & Choi, J. W. (2018) Fast and reversible thermoresponsive polymer switching materials for safer batteries Nature Energy, 3 (3), 201-208.
55. Liu, W., Lin, D., Pei, A., and Cui, Y. (2018) Stabilising lithium metal anodes by uniform Li-ion flux distribution in nanochannel confinement Journal of the American Chemical Society, 140(48), 17867–17873.
56. Choi, J. W., and Aurbach, D. (2016) The promise and reality of post-lithium-ion batteries with high energy densities Nature Reviews Materials, 1(4), 16013.
57. Lu, Y., Tu, Z., & Archer, L. A. (2018). Stable lithium electrodeposition in liquid and nanoporous solid electrolytes Nature Materials, 17(10), 967-973.
58. Zhao, J., Zeng, L., Li, Z., Li, L., & Mai, L. (2019). Recent advancements in flexible zinc-ion batteries Advanced Materials, 31(31), 1808192.
59. Li, Y., Yang, S., Xie, D., Li, J., Tang, Y., & Gao, Y. (2021). Recent advances and perspectives on sulphur-based cathode materials for high-energy-density lithium-sulphur batteries Nano Energy, 80, 105541.

http://doi.org/10.36893/IEJ.2024.V53I06N02.180-189