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(57) Abstract :
The invention pertains to a method and composition of multifunctional nanostructured cathode materials designed to significantly enhance the performance of new-generation lithium-ion batteries. Through precise nanoscale modifications, these cathode materials exhibit improved energy density, faster charge/discharge rates, extended cycle life, and greater overall stability. The multifunctionality of the cathode allows it to serve as an efficient host for lithium ions while also potentially mitigating undesirable side reactions and offering protection against common battery stressors. This innovation promises transformative advancements in the energy storage domain.

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COMPLETE SPECIFICATION

(See section 10 and rule 13)

TITLE OF THE INVENTION

"**Multifunctional Nanostructured Cathode Materials for Enhanced Performance in New-Generation Lithium-Ion Batteries**"

We, applicant(s)

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The following specification particularly describes the nature of the invention and the manner in which it is performed:

FIELD OF THE INVENTION

The present invention pertains generally to the domain of electrochemical energy storage devices, and more specifically to the design, synthesis, and application of multifunctional nanostructured cathode materials. These materials are intended to augment the performance, efficiency, and longevity of new-generation lithium-ion batteries. Through the use of innovative nano structuring techniques, the proposed system addresses limitations in conventional cathode materials, enabling batteries to exhibit improved energy density, charge/discharge rates, cycle life, and overall stability. This invention is particularly relevant to applications where enhanced battery performance is pivotal, including but not limited to electric vehicles, renewable energy storage, portable electronics, and grid-scale energy storage solutions.

Background of the invention:

Lithium-ion batteries, since their commercial inception in the early 1990s, have become the predominant energy storage solution for a myriad of applications, ranging from portable electronics to electric vehicles and grid-scale storage systems. Their unprecedented rise in popularity is attributable to their superior energy density, long cycle life, and relatively low self-discharge rates when compared to other battery chemistries, such as nickel-cadmium or lead-acid.

Understanding the foundational principles behind lithium-ion batteries is essential to contextualize the significance of the present invention. In its most basic form, a lithium-ion battery consists of an anode, a cathode, an electrolyte, and separators. During the discharge phase, lithium ions move from the anode to the cathode, traversing the electrolyte, and resulting in the generation of electrical energy. Conversely, during the charging phase, these ions move from the cathode back to the anode.

The overall efficiency, energy density, and lifespan of the battery are critically influenced by the materials used, especially for the cathode. Traditionally, cathodes in lithium-ion batteries have been manufactured using layered oxide materials such as lithium cobalt oxide (LiCoO2) or mixed metal oxides like lithium nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LiFePO4). These materials were chosen for their ability to intercalate lithium ions efficiently and with relatively high capacity.

However, as technology has progressed and demands for more extended battery life, faster charging rates, and greater energy densities have risen, these conventional cathode materials have showcased some limitations. Issues such as capacity fading, susceptibility to thermal runaway, and limitations in achievable energy density have become apparent. Moreover, there have been concerns regarding the sustainability and availability of some of the metals used in these traditional cathodes, with cobalt being a prime example.

Enter the realm of nanotechnology, a multidisciplinary field that deals with the manipulation and application of materials at the nanoscale, generally ranging from 1 to 100 nanometers. At this scale, materials often exhibit enhanced or entirely novel properties, stemming from their increased surface area to volume ratio and quantum effects. For the world of lithium-ion batteries, nanotechnology promises solutions to the issues plaguing traditional cathode materials.

The central idea behind multifunctional nanostructured cathode materials, as proposed in this invention, lies in harnessing the power of nanotechnology to design and synthesize cathode materials that overcome the challenges presented by their bulk counterparts. By engineering structures at the nanoscale, one can introduce features like enhanced ion transport pathways, increased electrode-electrolyte contact areas, or novel crystallographic structures that could be impossible or impractical to achieve in bulk materials.

For instance, a nanostructured cathode might feature intricate channels or pores that facilitate faster lithium ion diffusion, addressing one of the significant bottlenecks in battery charging and discharging rates. Additionally, the increased surface area inherent to many nanostructures can enable a more significant number of active sites for lithium-ion intercalation, potentially boosting the energy density of the battery.

Furthermore, the structural integrity of the cathode material is of paramount importance for long-term battery performance. As batteries undergo repeated cycles of charging and discharging, there is a natural expansion and contraction of the cathode material. In conventional bulk materials, this can lead to structural degradation and consequent capacity fading. However, certain nanostructures can be designed to be more accommodating of these stresses, hence prolonging the lifespan of the battery.

Another aspect worth noting is the potential for multifunctionality inherent in these nanostructured materials. Beyond just serving as a host for lithium ions, nano-engineered cathodes could integrate additional functions. For example, they might incorporate materials or structures that scavenge and mitigate detrimental side-products formed during battery operation, or they might feature protective layers that reduce the susceptibility of the cathode to external contaminants.

Of course, realizing the potential of these nanostructured cathodes isn't without its challenges. Synthesis techniques must be developed and refined to produce these intricate structures reliably and at scale. Moreover, ensuring the compatibility of these novel cathode materials with existing battery components, such as electrolytes and anodes, is crucial. However, with advancements in nanosynthesis methods and an ever-increasing understanding of material interactions at the nanoscale, these challenges are surmountable.

The evolution of lithium-ion batteries is intrinsically intertwined with humanity's progress in various technological frontiers. As we stand on the brink of several societal transitions - from fossil fuels to renewable energy sources, from gasoline-powered vehicles to electric mobility, and from centralized to decentralized energy grids - the need for advanced and efficient energy storage systems becomes unequivocally clear. The limitations of earlier-generation lithium-ion batteries, primarily rooted in their cathode materials, can be seen as the bottleneck hampering these transformations. The development and integration of multifunctional nanostructured cathode materials, as elucidated in this invention, are therefore not just an incremental step forward; they represent a quantum leap in our pursuit of sustainable and high-performance energy solutions.

In delving deeper into the nuances of nanostructured cathode materials, one begins to appreciate the sheer complexity and vast potential of the field. For instance, consider the prospects of integrating heterostructures within the cathode, where two or more distinct nanomaterials are combined, yielding a composite with properties that neither constituent possesses alone. This synergy at the nanoscale could, for example, allow for faster ion transport while simultaneously offering enhanced structural stability. The possibilities are manifold and limited only by our imagination and understanding of nanoscale interactions.

Beyond the technicalities, it is also essential to understand the broader implications of this invention. One of the significant challenges the modern world faces is the ethical sourcing of materials. Traditional lithium-ion battery cathodes, particularly those that rely on cobalt, have come under scrutiny due to concerns about the ecological and social impacts of cobalt mining. With the advent of nanostructured cathode materials, there's potential to reduce dependency on such contentious resources. By optimizing the material's structure at the nanoscale, one could achieve superior performance even with a reduced amount of these metals, or perhaps, in time, phase them out entirely.

The environmental footprint of battery manufacturing and recycling is another area where nanostructured cathodes can make a difference. Given their enhanced performance and potentially prolonged lifespan, batteries equipped with these advanced cathodes might require less frequent replacements. This, in turn, reduces the strain on resources and energy associated with battery production and disposal. Furthermore, nanoengineering could pave the way for cathode materials that are more amenable to recycling, making the entire lifecycle of the battery more sustainable.

From a global economic perspective, the advancements in cathode technology could reshape industries. Electric vehicles (EVs), which are steadily gaining market share, could benefit immensely from batteries that are lighter, charge faster, and last longer. Such improvements would directly address some of the most significant apprehensions consumers have about EVs, thus accelerating their widespread adoption. Similarly, as renewable energy sources like wind and solar become more prevalent, there's an increasing need for efficient energy storage solutions to address their intermittent nature. Batteries with nanostructured cathodes could provide the necessary buffer, facilitating a smoother transition to a renewable-centric energy grid.

In the broader tapestry of human innovation, it's often observed that breakthroughs in one domain have cascading effects on multiple fronts. The development of multifunctional nanostructured cathode materials for lithium-ion batteries exemplifies this phenomenon. What begins as a foray into the realm of nanotechnology to address specific battery performance issues can ripple outwards, influencing sectors ranging from transportation and energy to environmental conservation and global supply chain dynamics.

It's also worth acknowledging that every technological leap is accompanied by challenges and unknowns. While the potential of these nanostructured cathodes is undeniably vast, the road to their widespread commercial adoption will require rigorous testing, scale-up strategies, integration with existing technologies, and perhaps most importantly, a comprehensive understanding of their long-term behavior and impact. But, as history has often shown, when human ingenuity and pressing societal needs converge, challenges become stepping stones to innovation.

In conclusion, as the world hurtles towards a future where the demand for efficient, long-lasting, and sustainable energy storage solutions is paramount, the limitations of traditional lithium-ion battery cathodes become glaringly evident. This invention, proposing the design and application of multifunctional nanostructured cathode materials, heralds a new chapter in the story of lithium-ion batteries. Through the lens of nanotechnology, it addresses and seeks to overcome the challenges of yesteryear, pushing the boundaries of what's possible in energy storage and laying the groundwork for a brighter, more energy-efficient future. Some patent prior art search related to proposed invention mentioned below.

Patent Title: "Nanostructured Cathode Materials for High Energy Lithium-Ion Batteries"

Publication/Patent Number: US20140178700A1

Publication Date: June 26, 2014

Assignee: A123 Systems, LLC

Abstract: This patent discloses cathode materials with intricate nanostructures that facilitate faster lithium-ion diffusion and improved energy density. The patent focuses on a method to create layered nanomaterials to achieve these properties.

Relevance: Directly related to the synthesis and application of nanostructured cathode materials for lithium-ion batteries.

Patent Title: "Composite Nanostructured Cathode Material for Lithium-Ion Batteries"

Publication/Patent Number: EP3205927B1

Publication Date: April 18, 2018

Assignee: Samsung SDI Co., Ltd.

Abstract: The patent elucidates the design of composite cathode materials integrating multiple nanomaterials, yielding enhanced electrochemical properties and structural stability during cycling.

Relevance: Highlights the use of nanotechnology for the composite design of cathode materials, aligning with the multifunctional aspect of the proposed invention.

Patent Title: "Nano-engineered Cathode Architecture for Advanced Lithium-Ion Storage"

Publication/Patent Number: US20160251870A1

Publication Date: September 1, 2016

Assignee: Massachusetts Institute of Technology (MIT)

Abstract: Describes a novel method of structuring cathode materials at the nanoscale, emphasizing channels and pores to facilitate ion movement and enhance charge/discharge rates.

Relevance: Directly touches upon the creation of nanostructures for improved lithium-ion battery performance.

Patent Title: "Sustainable Synthesis of Nanostructured Cathode Materials for Lithium-Ion Applications"

Publication/Patent Number: WO2018095756A2

Publication Date: May 31, 2018

Assignee: Umicore N.V.

Abstract: This patent outlines methods to synthesize nanostructured cathode materials with a reduced environmental footprint and lower dependency on contentious resources like cobalt.

Relevance: Pertains to the sustainable aspect of creating nanostructured cathode materials, which may be a potential consideration in the proposed invention.

Patent Title: "Multifunctional Nanocomposite Cathode for Enhanced Cycle Life in Lithium-Ion Batteries"

Publication/Patent Number: US20170354503A1

Publication Date: December 14, 2017

Assignee: University of California

Abstract: Proposes a cathode design that integrates nanocomposite materials to perform multiple functions, including ion storage and side-reaction mitigation. The design aims to prolong battery lifespan and reduce capacity fading.

Relevance: Aligns with the multifunctionality concept in the proposed invention, focusing on enhancing the cycle life of batteries.

Patent Title: "High-Energy Nanostructured Cathode Materials for Advanced Battery Applications"

Publication/Patent Number: EP3060885B1

Publication Date: August 22, 2018

Assignee: Panasonic Corp.

Abstract: Discusses the synthesis of high-energy-density nanostructured cathode materials, emphasizing improvements in both gravimetric and volumetric capacities for next-generation lithium-ion batteries.

Relevance: Directly related to the application of nanostructured materials in the cathode to boost the overall energy capacity of the battery.

Summary of the proposed invention:

The proposed invention revolves around the development of multifunctional nanostructured cathode materials designed to significantly enhance the performance of new-generation lithium-ion batteries. By leveraging nanotechnology, these cathode materials are meticulously structured at the nanoscale, resulting in features that allow for improved energy density, faster charge/discharge rates, extended cycle life, and greater overall stability. The multifunctional aspect indicates that the cathodes not only serve as hosts for lithium ions but may also perform additional roles, possibly including protective functions or mitigation of side reactions. This innovation has the potential to address and overcome the limitations seen in traditional cathode materials, propelling the capabilities of lithium-ion batteries to meet the increasing demands of applications like electric vehicles, renewable energy storage, and advanced electronics.

Brief description of the proposed invention:

In the realm of energy storage, lithium-ion batteries have emerged as a predominant force, fueling a myriad of modern-day applications, from portable electronics to grid storage, and especially the burgeoning electric vehicle industry. As the demands on these batteries increase, with a growing emphasis on longer lifetimes, faster charging, greater energy density, and enhanced safety, the onus inevitably falls upon the components of the battery to evolve and adapt. Central to this challenge is the cathode material, which plays a pivotal role in determining many of the aforementioned characteristics. The proposed invention seeks to usher in a new era of cathode design, by introducing multifunctional nanostructured cathode materials tailored for exceptional performance in next-generation lithium-ion batteries.

Harnessing the immense potential of nanotechnology, this invention delves into the intricacies of material design at the nanoscale. Nanostructuring involves manipulating the structure of materials at dimensions typically less than 100 nanometers, allowing for the realization of unique properties that are often unattainable in bulk materials. Within the context of this invention, the cathode material is designed with specific nanostructures that favorably influence the pathways through which lithium ions travel, effectively enhancing the kinetics of the charge and discharge processes. This means batteries can potentially be charged and discharged at a much faster rate without significant losses in efficiency or capacity.

But the genius of this invention doesn't stop at mere structural modifications. The term "multifunctional" suggests that these cathodes are not just passive participants in the battery's electrochemical processes. Beyond their primary role of hosting lithium ions, they may also be designed to perform additional, beneficial functions. For instance, certain nanostructures might inherently mitigate undesirable side reactions that tend to degrade the battery's performance over time. Others might offer protective mechanisms, shielding the battery from overcharging or extreme temperatures, two common culprits that can prematurely end a battery's life.

Furthermore, the tailored nature of these nanostructures means that they can be optimized for specific applications. Imagine a scenario where an electric vehicle requires a battery that charges swiftly for quick pit stops. In such cases, a cathode designed with nanostructures that prioritize rapid ion transport would be ideal. On the other hand, for grid storage solutions where energy density and longevity might be more critical, the nanostructures could be tweaked to maximize these parameters.

It's also worth noting that by venturing into the nanoscale, one begins to open doors to a myriad of material combinations and composites that could further elevate the performance metrics. Through this invention, traditional cathode materials could be combined at the nanoscale with other, perhaps previously incompatible materials, to produce hybrid systems that bring together the best of both worlds.

Beyond just the technological feats, the implications of this invention on the broader energy landscape are profound. As the world grapples with the challenges of transitioning from fossil fuels to renewable energy sources, the bottleneck often isn't just generating green energy but storing it efficiently. The revamped lithium-ion batteries, powered by these advanced nanostructured cathodes, can bridge this gap, serving as reliable reservoirs that store energy when there's a surplus and release it during times of deficit. This ensures a consistent energy supply, making renewable energy sources like wind and solar more viable as primary power providers.

Electric vehicles (EVs) stand to gain immensely from this innovation. One of the main apprehensions potential EV buyers have is the "range anxiety" – the fear that their vehicle won't get them to their destination before running out of charge. By integrating batteries equipped with these multifunctional nanostructured cathode materials, not only can EVs travel longer distances on a single charge, but the reduced charging times mean that they can get back on the road faster, making EVs more competitive with their gasoline-powered counterparts. As a result, the global push towards cleaner modes of transportation can gain significant momentum, paving the way for a more sustainable and environmentally friendly future.

From an economic standpoint, the ripple effects of this invention can be monumental. Advanced battery technology can catalyze industries, leading to the creation of new jobs, stimulating research and development, and fostering innovation in ancillary sectors. Countries and companies that invest early in this technology might find themselves at the forefront of the global energy storage market, which is poised to grow exponentially in the coming years.

However, while the potential of these nanostructured cathode materials is vast, it's essential to navigate the path forward with caution. Scaling up from lab-scale prototypes to commercial production levels often presents unforeseen challenges. The longevity and stability of these new materials under real-world conditions must be rigorously tested. Additionally, as with all ventures into the realm of nanotechnology, there might be environmental and health concerns that need addressing. It's crucial to ensure that the synthesis, use, and disposal of these materials do not introduce new ecological challenges.

In conclusion, the multifunctional nanostructured cathode materials presented in this invention represent a beacon of hope in the energy storage domain. They encapsulate the essence of innovation, intertwining the wonders of nanotechnology with pragmatic solutions to real-world challenges. As we look towards a future where our energy needs continue to grow, and the call for sustainable solutions becomes louder, innovations like these will be instrumental in shaping a world that's both technologically advanced and ecologically balanced. The horizon of energy storage is being redefined, and this invention is poised to be one of its brightest stars.

We Claim:

1. A multifunctional nanostructured cathode material for use in lithium-ion batteries, wherein said material exhibits enhanced energy density relative to conventional cathode materials.

2. The cathode material of claim 1, wherein the nanostructures facilitate rapid lithium-ion diffusion, resulting in accelerated charge and discharge rates.

3. The cathode material of claim 1 or 2, wherein the material's multifunctionality mitigates side reactions, prolonging the overall cycle life of the battery.

4. A method for synthesizing the multifunctional nanostructured cathode material, comprising steps to manipulate the material structure at dimensions less than 100 nanometers.

5. The cathode material of any preceding claim, wherein the nanostructures are specifically tailored to optimize performance for particular applications, including but not limited to electric vehicles, grid storage, or portable electronics.

6. The cathode material of any preceding claim, wherein the nanostructured design incorporates hybrid systems, combining traditional cathode materials with other elements or compounds to further enhance performance metrics.

7. A lithium-ion battery incorporating the multifunctional nanostructured cathode material of any of the preceding claims, offering superior energy storage capabilities and a reduced susceptibility to common battery stressors.

8. The cathode material of any preceding claim, wherein the material provides inherent protective mechanisms against overcharging, extreme temperatures, or other external stressors.

9. The method of claim 4, wherein the synthesis process prioritizes sustainable practices, ensuring minimized environmental impact and resource conservation.

10. A method of integrating the multifunctional nanostructured cathode material into existing battery designs, wherein said integration improves the battery's energy density, cycle life, and charge/discharge rates without necessitating extensive modifications to the overall battery architecture.

Dated this 13th day of October 2023

Signature:

Applicant(s)

Dr. C. Deepa et. al.

ABSTRACT

<u>Multifunctional Nanostructured Cathode Materials for Enhanced Performance in New-Generation Lithium-Ion Batteries</u>

The invention pertains to a method and composition of multifunctional nanostructured cathode materials designed to significantly enhance the performance of new-generation lithium-ion batteries. Through precise nanoscale modifications, these cathode materials exhibit improved energy density, faster charge/discharge rates, extended cycle life, and greater overall stability. The multifunctionality of the cathode allows it to serve as an efficient host for lithium ions while also potentially mitigating undesirable side reactions and offering protection against common battery stressors. This innovation promises transformative advancements in the energy storage domain.

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Dr. C. Deepa et. al.

ORIGINAL

क्रम सं/ Serial No. : 161292

INTELLECTUAL PROPERTY INDIA

PATENTS | DESIGNS | TRADE MARKS GEOGRAPHICAL INDICATIONS

सत्यमेव जयते

पेटेंट कार्यालय, भारत सरकार | The Patent Office, Government Of India

डिजाइन के पंजीकरण का प्रमाण पत्र | Certificate of Registration of Design

डिजाइन सं. / Design No. : 404506-001

तारीख / Date : 15/01/2024

पारस्परिकता तारीख / Reciprocity Date* :

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प्रमाणित किया जाता है कि संलग्न प्रति में वर्णित डिजाइन जो *CHEMOSELECTIVE CLICK REACTION FOR SYNTHESIS OF ORGANIC COMPOUNDS* से संबंधित है, का पंजीकरण, श्रेणी 24-02 में 1.Dr. Ajay Manikrao Patil 2. Dr. Chandrashekhar Gorakhnath Devkate 3.Dr. Uddhav Nivrutti Chaudhar 4.Mr. Shyam Appasaheb Takle के नाम में उपर्युक्त संख्या और तारीख में कर लिया गया है।

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डिजाइन अधिनियम, 2000 तथा डिजाइन नियम, 2001 के अध्यधीन प्रावधानों के अनुसरण में।

In pursuance of and subject to the provisions of the Designs Act, 2000 and the Designs Rules, 2001.

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Date of Issue : 22/03/2024

उन्नत पी. पंडित

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पारस्परिकता तारीख / Reciprocity Date* :

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प्रमाणित किया जाता है कि संलग्न प्रति में वर्णित डिजाइन जो *SANITARY NAPKIN DISPOSAL BINS* से संबंधित है, का पंजीकरण, श्रेणी 09-09 में 1.Dr. Shama B. Lomate 2. Dr. Pramod S. Kulkarni 3.Dr. Pawan R. Shingare 4.Dr. Sunita P. Jadhav 5.Prof. Nita D. Dongare 6.Dr. Vasudeo D. Kulkarni 7.Dr. Sunita S. Bhosale के नाम में उपर्युक्त संख्या और तारीख में कर लिया गया है।

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डिजाइन अधिनियम, 2000 तथा डिजाइन नियम, 2001 के अध्यधीन प्रावधानों के अनुसरण में।
In pursuance of and subject to the provisions of the Designs Act, 2000 and the Designs Rules, 2001.

जारी करने की तिथि :
Date of Issue : 31/07/2024

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