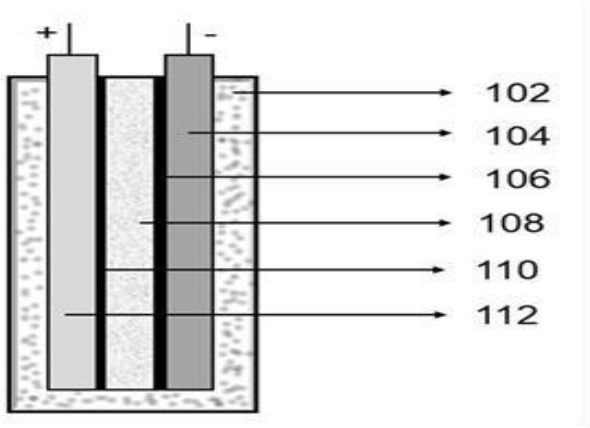


FIGURE-1

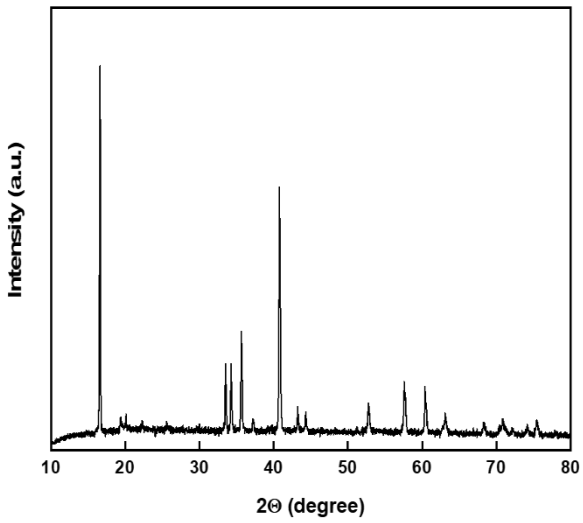


FIGURE 2A

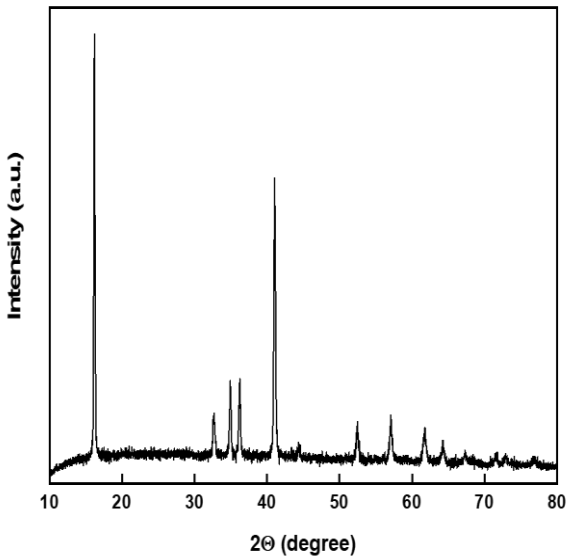


FIGURE 2B

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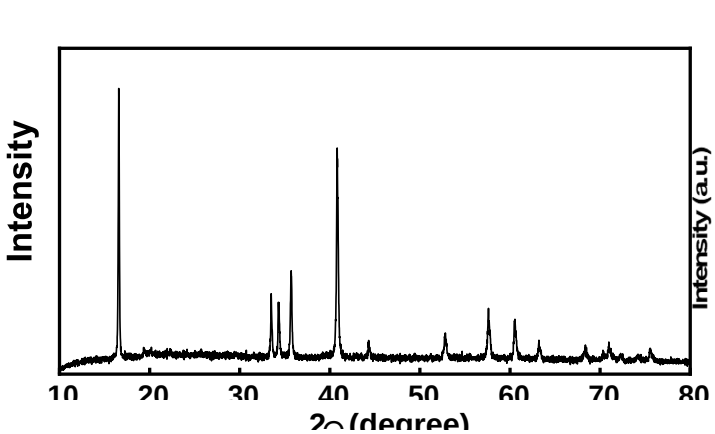


FIGURE 2C

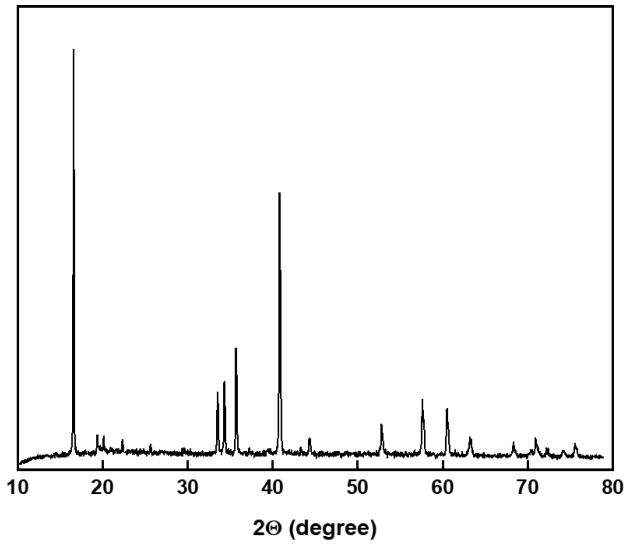


FIGURE 2D

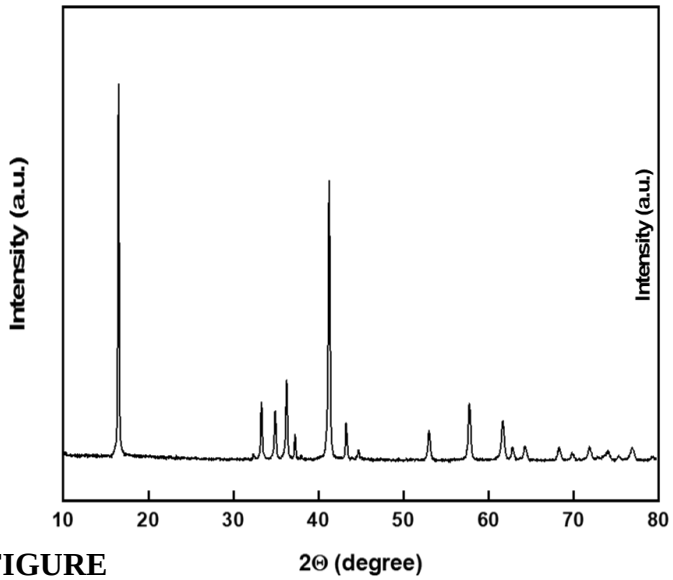


FIGURE 2F

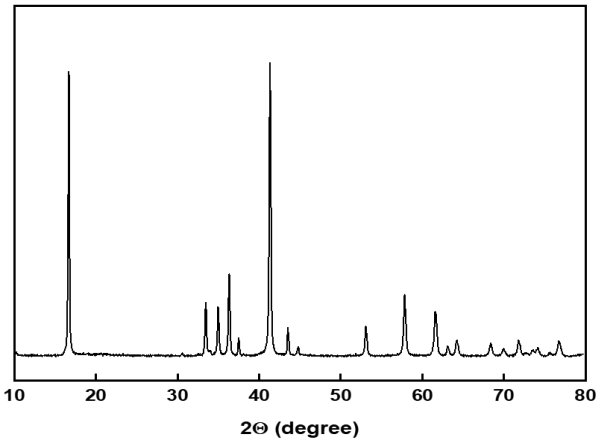


FIGURE 2E

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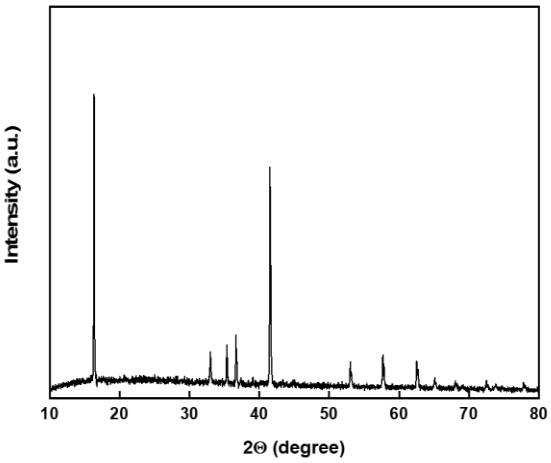


FIGURE 2G

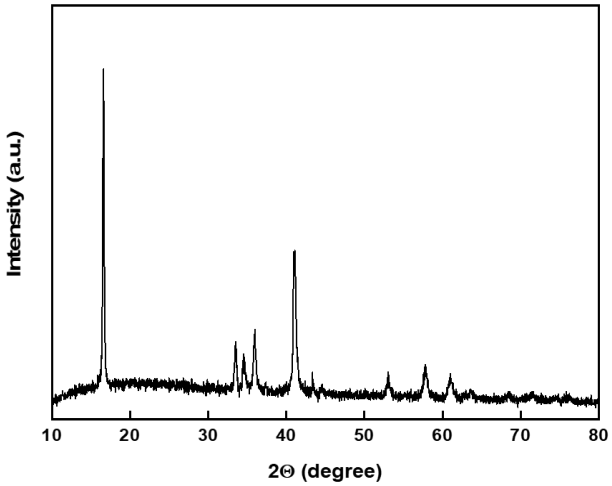


FIGURE 2H

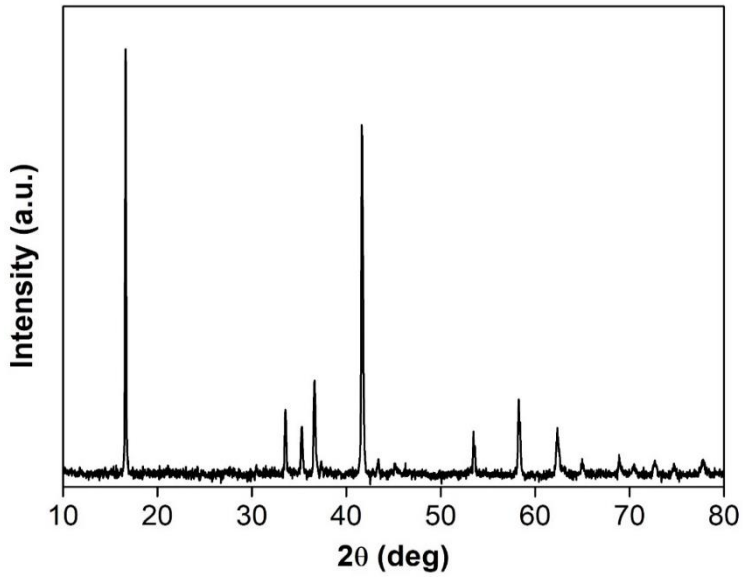


FIGURE 2I

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APPLICANT

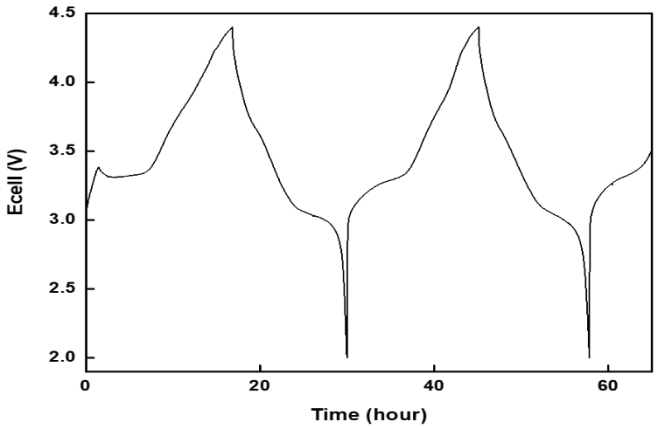


FIGURE 3A

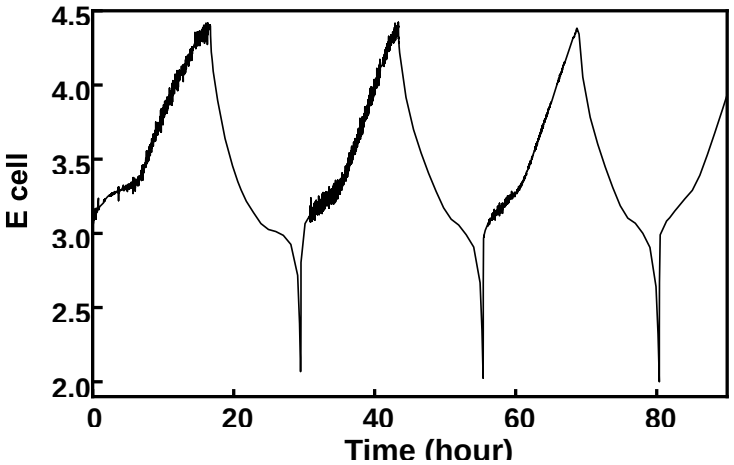


FIGURE 3B

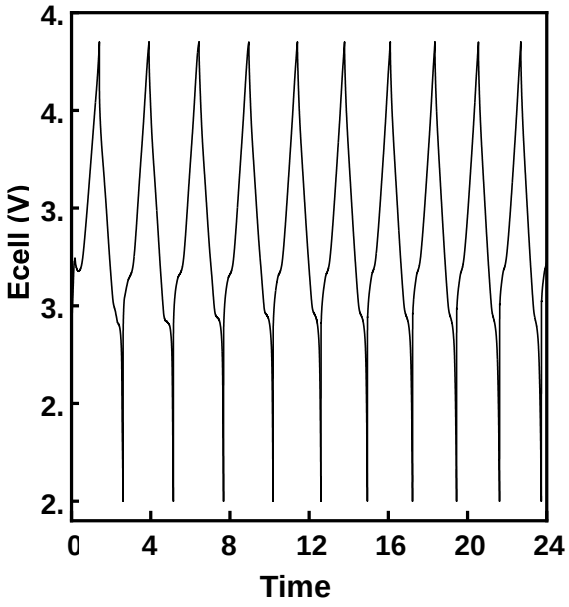


FIGURE 3C

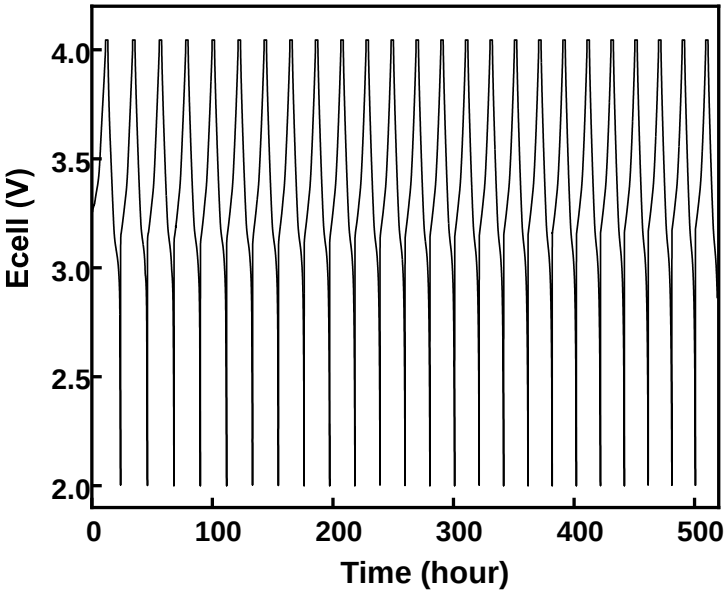


FIGURE 3D

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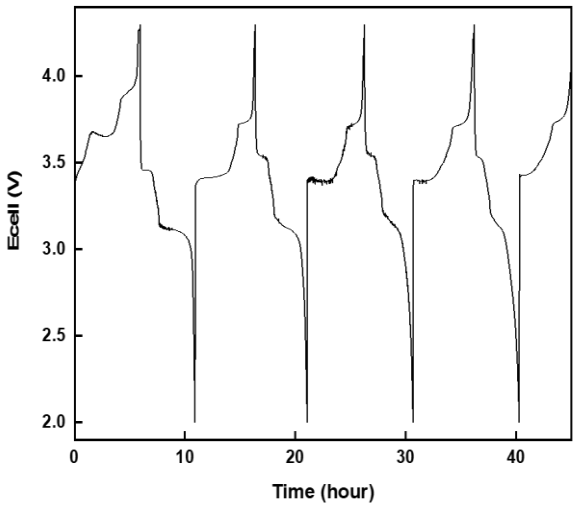


FIGURE 3E

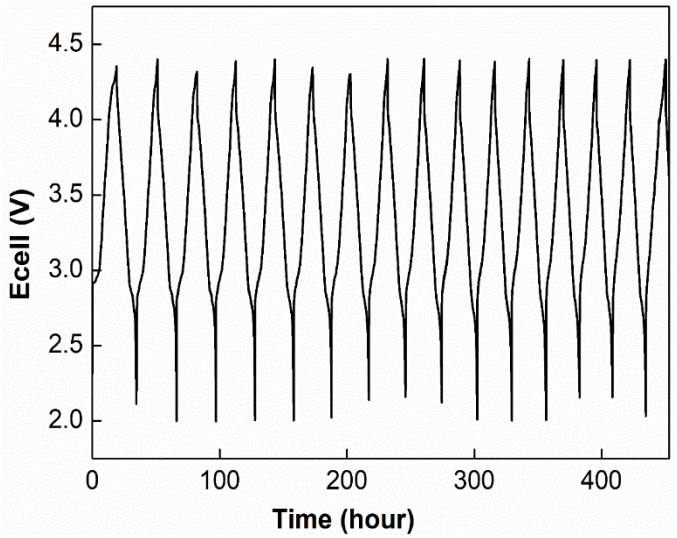


FIGURE 3F

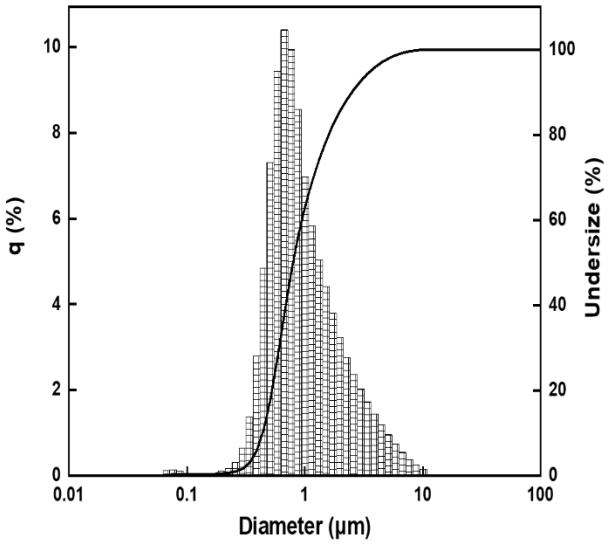


FIGURE 4A

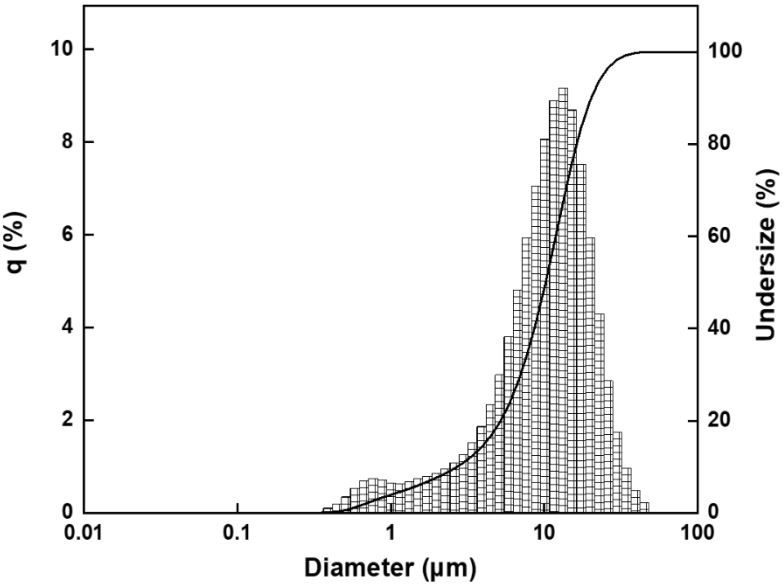


FIGURE 4B

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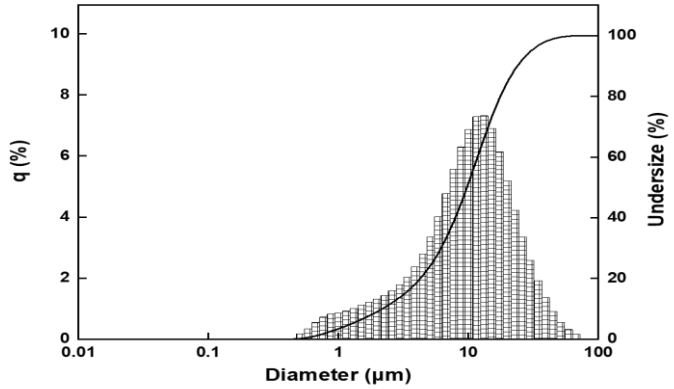


FIGURE 4C

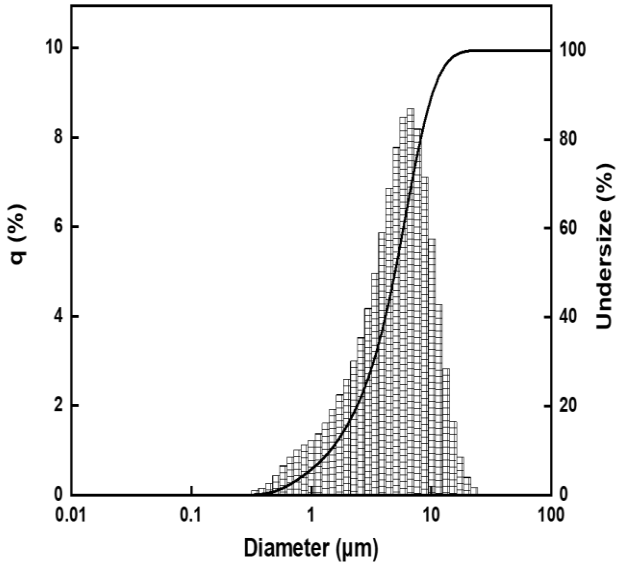


FIGURE 4D

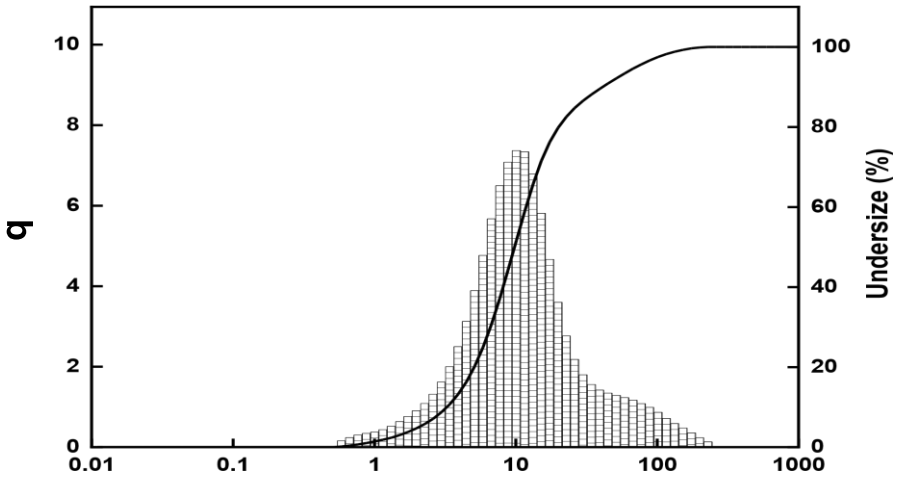


FIGURE 4E

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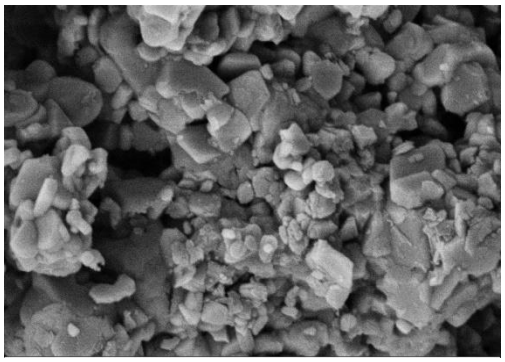


FIGURE 5A

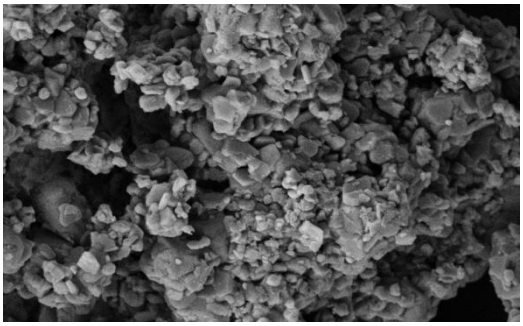


FIGURE 5B

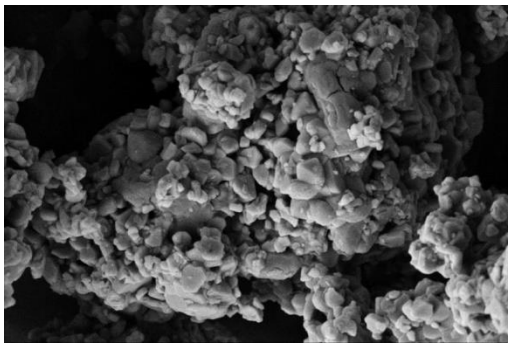


FIGURE 5C

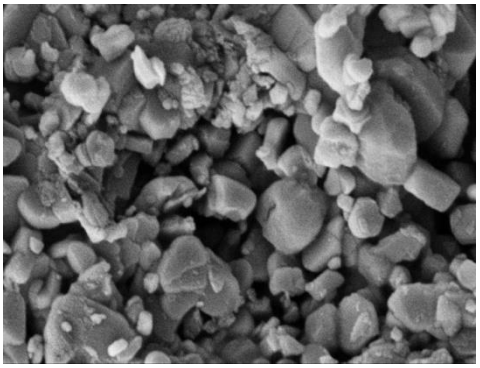


FIGURE 5D

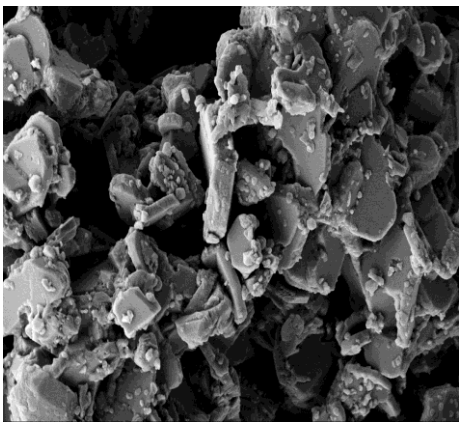


FIGURE 5E

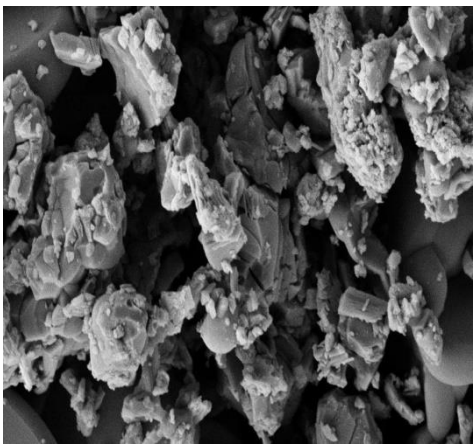


FIGURE 5F

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FORM 2

THE PATENTS ACT, 1970

(39 of 1970)

&

THE PATENT RULES, 2003

[See Section 10 and Rule 13]

COMPLETE SPECIFICATION

Layered Sodium Metal Oxide Compositions as Cathode Materials for Secondary Battery

COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH

Anusandhan Bhawan, 2-Rafi Marg, New Delhi – 110 001, India,

an Indian Registered Body incorporated under the Registration of Societies Act (XXI of 1860)

The following specification particularly describes the invention and manner in which it is to be performed.

FIELD OF THE INVENTION

The present invention relates to layered sodium metal oxide compositions as cathode material for Sodium-ion battery. More particularly, sodium metal oxide having a general formula $Na_xNi_{1-y-z}A_yB_zO_2$ and $0.8 \leq x \leq 1.2$, $0 \leq y \leq 0.3$ $0 < z \leq 0.33$, $y+z \leq 0.6$ the cathode composition comprises a metal in oxidation state in +2, +3 and +4 selected from Ti, Co, Al, Fe, Mn, Zn, Mg or combination thereof, B comprises a metal in oxidation state in +5 or +6 selected from Sb or Te. The sodium metal oxide compositions as cathode material further uses as electrode material for sodium ion battery application.

BACKGROUND OF THE INVENTION

Recently, Na-ion batteries (SIBs) have considered much attention for sustainable energy storage devices and it can be an economical alternative for the state of the art Li-ion batteries. Cathode materials such as layered oxide materials, organic compounds, metal-hexacyanometalate compounds, and polyanionic compounds have been studied as potential candidates for Na-ion batteries. Layered oxide materials can be used as potential cathode materials for Na-ion batteries. However, layered oxides exhibit much less rate performance and rapid capacity loss due to the unusual/irreversible multi-phase transitions results in less electrochemical performance. Hence, tuning the crystal chemistry of the layered oxides ($NaTMO_2$, Transition metal (TM) = Fe, Mn, Ti, Cr, Co, Ni, V and a combination of two or more elements) is essential to achieve reversible phase transformation and high electrochemical performance. The layered oxide material, $NaNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ isostructural to $NaCoO_2$, is also a potential cathode material for SIB.

Sodium-ion batteries are similar in many ways to the lithium-ion batteries that are in common use today. Lithium-ion rechargeable battery technology has received a lot of attention in recent years and is the dominant energy storage technology used in electronic devices and Electric vehicles. Lithium is not a cheap and abundant metal and it is considered to be too expensive for use in some markets requiring rechargeable battery technologies; such as large-scale stationary energy storage applications. In general, the sodium-ion battery is composed of, a sodium cathode, a hard carbon anode, an electrolyte, and a separator. The intercalation mechanism of sodium ion battery is similar to lithium-ion battery though sodium ion is the intercalation ion.

Sodium ion battery is considered to possess certain advantages over lithium-ion battery. Sodium is more abundant than lithium and hence it offers a solution for low cost and

sustainable energy storage system. Presently layered sodium metal oxides, Prussian blue analogs, and Polyanionic compounds have been reported as cathodes for sodium-ion batteries. Among these, layered oxides have a greater advantage in terms of higher voltage and Specific energy density.

Reference may be made to article *Chem. Mater.* 2012, 24, 10, 1846-1853, wherein A layered phase, $NaNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ (NaNMC), isostructural to $NaCoO_2$ has been synthesized. Stoichiometric NaNMC crystallizes in a rhombohedral $R\bar{3}m$ space group where Na is in an octahedral environment (O3-Type). Galvanostatic cycling on NaNMC vs Na cell indicated a reversible intercalation of 0.5 Na, leading to a capacity of 120 $mAh \cdot g^{-1}$ in the voltage range of 2−3.75 V and indicating its possible application in Na ion batteries.

Reference may be made to article *J. Mater. Chem. A*, 2015, 3, 20908-20912, wherein The invention, P2–$Na_{0.67}Ni_{0.25}Mg_{0.1}Mn_{0.65}O_2$ reported as the cathode material for rechargeable Na-ion batteries. It reversibly intercalates ∼0.52 moles of Na per formula unit in the voltage region of 1.5–4.2 V at C/10 rate which corresponds to a specific capacity of 140 mA h g^{-1}. Substituting part of Mn with Ni and Mg increases the average potential of $Na_{0.67}MnO_2$ and improves the energy density of $Na_{0.67}Ni_{0.25}Mg_{0.1}Mn_{0.65}O_2$ to 335 W h kg^{-1}.

Reference may be made to article *Journal of Solid State Chemistry* 183 (2010) 684–691, wherein a family of α-$NaFeO_2$-type oxides $Na_xM_{(1+x)/3}Sb_{(2x)/3}O_2$ (M=Ni, Co, Zn, Mg; x ~ 0.8 or 0.9) prepared by solid state reactions and characterized by powder XRD. At x=1, the powder patterns for $Na_3M_2SbO_6$ (M=Ni, Co) comply with both trigonal $P3_112$ cell and monoclinic C2/m cell.

Reference may be made to article *Chem. Commun*. 2013**,** 49**,** 11376-11378, wherein Layered Li_4NiTeO_6 was shown to reversibly release/uptake ~2 lithium ions per formula unit with fair capacity retention upon long cycling. The Li electrochemical reactivity mechanism differs from that of Li_2MO_3 and is rooted in the Ni^{4+}/Ni^{2+} redox couple, that takes place at a higher potential than conventional $LiNi_{1-x}Mn_xO_2$ compounds.

Reference may be made to patent application US20160181608, wherein materials containing the formula: $A_xM_yM^i_{zi}O_{2-d}$, where A is sodium or a mixed alkali metal including sodium as a major constituent; x>0; M is a metal or germanium; y>0; M^i, for i=1, 2, 3 . . . n, is a transition metal or an alkali metal; $z_i \geq 0$ for each i=1, 2, 3 . . . n; $0<d\leq 0.5$; the values of x, y, z_i and d are such as to maintain charge neutrality; Further the oxidation states may or may not be integers i,e. they may be whole numbers or fractions or a combination of whole

numbers and fractions and may be averaged over different crystallographic sites in the material.

Reference may be made to patent application IN201817020107, wherein method comprising: manufacturing a sodium ion secondary cell having an anode and a cathode the anode comprising a negative electrode active material comprising disordered carbon on an anode substrate and the cathode comprising a comprising a nickel-containing sodium oxide positive electrode active material on a cathode substrate; and in a cycling phase charging the cell to a first voltage; wherein the ratio of the mass of the negative electrode active material to the mass of the positive electrode active material is greater than 0.37 and is less than 1.2 disclosed.

Reference may be made to article *ACS Appl. Mater. Interfaces* 2021, 13, 32948−32956, wherein O3-type sodium-layered oxides as one of the most fascinating cathode materials for sodium-ion batteries disclosed. It reports the preparation of a completely cationic disordered O3-type $Na_{0.8}Ni_{0.6}Sb_{0.4}O_2$ compound by composition regulation. The O3-$Na_{0.8}Ni_{0.6}Sb_{0.4}O_2$ cathode displays a reversible capacity of 106 mA h g^{-1} at 0.1C (12 mA g^{-1}) with a smooth charge−discharge curves, and a high average working voltage of 3.5 V during battery cycling.

From the prior arts as discussed above it was evident that the P2-type structure preferential occupancy of Na can cause different dimensional changes in TMO_6 units in turn can lead to structural stress and performance degradation. The distribution of cations in the TMO_2 layers can affect electrostatic interaction between cations and the coordinated atoms. In O3-type layered structures, Na^+ migrates from one octahedral site to another through the face-sharing intermediate tetrahedral sites, however, needs to overcome high energy barriers. This type of Na^+ movement leads to slow kinetics and a series of inevitable complex phase transitions during deep extraction. Further, the phase transition from O3 to P3 occurs at 3 V (versus Na^+/Na) in most of the O3-type materials and affects the energy density of battery.

These prior arts highlight the importance of searching for a new O′3 type layered sodium compounds having simple synthesis, environment friendliness, high electrochemical activity, high working voltage for realizing high energy sodium-ion batteries.

Thus, keeping in view the drawbacks of the hitherto reported prior arts, there was a need to solve the problem of providing layered sodium metal oxide compositions as cathode material for Sodium-ion battery. More particularly, sodium metal oxide having a general

formula $Na_xNi_{1-y-z}A_yB_zO_2$ and $0.8 \leq x \leq 1.2$, $0 \leq y \leq 0.3$ $0 < z \leq 0.33$, $y+z \leq 0.6$ the cathode composition comprises a metal in oxidation state in +2, +3 and +4 selected from Ti, Co, Al, Fe, Mn, Zn, Mg or combination thereof, B comprises a metal in oxidation state in +5 or +6 selected from Sb or Te. Also, the proposed cathode compositions provide O′3 type layered structure, each SbO_6 or TeO_6 octahedron is surrounded by six NiO_6 octahedrons, forming an ordered honeycomb network in each slab as a result of electrostatic repulsion and ionic radii difference between Ni^{2+} (69 pm) and Sb^{5+} (60 pm) or Te^{6+} (56pm). Further, the phase transitions from O′3 to P′3 of these cathode compositions occurs at high voltages which helps in improving capacity and energy density.

OBJECTIVE OF THE INVENTION

The main objective of the present invention is to develop a sodium metal oxide composition as cathode material for Sodium-ion battery in the layered structure to get the higher capacity with a wider potential window.

Another objective of the present invention provides sodium metal oxide compositions in which elements are chosen in such a way that the combination of elements will provide enhanced structural, thermal, air and moisture stability, higher average potential, higher redox contributing to increased capacity and enhanced Sodium-ion diffusion kinetics.

Another objective of the present invention provide sodium metal oxide compositions as cathode material for Sodium-ion battery is cheaper than the prior art compositions and easily scalable for mass production.

SUMMARY OF THE INVENTION

Accordingly, to meet the aforementioned objects, it is an aspect of the present invention to provides, the cathode composition for the Sodium-ion battery comprises a formula $Na_xNi_{1-y-z}A_yB_zO_2$. According to embodiments of the present invention, the concentration of element Na '*x*' may range from 0.8 to 1.2, concentration of the element A '*y*' may range from 0 to 0.3, the concentration of element B '*z*' may range from 0 to 0.33. The element A may be selected from a metal in oxidation state in +4, +3 or +2 selected from Ti, Al, Co, Fe, Mn, Zn, or Mg or combination thereof, and so forth, the element B may be selected from a metal in oxidation state in +5 or +6 selected from any one Sb or Te. The sum of concentration of $y+z \leq 0.6$, wherein x, y and z are chosen such way that to maintain electroneutrality.

distribution of the particles that may be in the range of 0.1 µm to 50 µm. Analysing the arbitrary percentages of the particle size was 10% ,50% and 90%.

According to embodiments of the present invention, the surface area of the cathode compositions that may be in the range of 0.1 m^2/g to 5 m^2/g.

According to embodiments of the present invention, positive electrode active material compositions exhibit good cycling stability, high operating voltage and good rate performance in a battery.

According to embodiments of the present invention, wherein the composition is a O′3- type layer structure with a space group of C2/m.

According to embodiments of the present invention, wherein a crystalline size of the particles of the composition ranges from 10 nm to 75 nm.

In aspect of the present invention, wherein the composition positive electrode active material voltage window ranges from 2 V to 4.4 V.

In further aspect of the present invention, wherein the composition cathode material capacity ranges from 80 mA h/g to 185 mA h/g.

In further aspect of the present invention, wherein the composition cathode material morphology is irregular granular, plate-like particles, hexagons, cubes, spheres, and elongated hexagons.

In further aspect of the present invention, wherein the sodium ion battery (100) containing composition a positive electrode material (110) coated with aluminum foil(112) ; an anode (106) coated with aluminum or copper foil (104); an electrolyte (102) and an porous separator(108).

These and other advantages will be apparent from the present application of the embodiments described herein.

The preceding is a simplified summary to provide an understanding of some embodiments of the present invention. This summary is neither an extensive nor exhaustive overview of the present invention and its various embodiments. The summary presents selected concepts of the embodiments of the present invention in a simplified form as an introduction to the more detailed description presented below. As will be appreciated, other embodiments of the

present invention are possible utilizing, alone or in combination, one or more of the features set forth above or described in detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and still further features and advantages of embodiments of the present invention will become apparent upon consideration of the following detailed description of embodiments thereof, especially when taken in conjunction with the accompanying drawings, and wherein:

FIG. 1 illustrates a schematic representation of a Sodium-ion battery;

FIG. 2A illustrates an X-ray diffraction pattern of $NaNi_{0.6}Ti_{0.2}Sb_{0.2}O_2$ cathode active material;

FIG. 2B illustrates an X-ray diffraction pattern of $NaNi_{0.6}Co_{0.1}Sb_{0.3}O_2$ cathode active material;

FIG. 2C illustrates an X-ray diffraction pattern of $NaNi_{0.6}Al_{0.1}Sb_{0.3}O_2$ cathode active material;

FIG.2D illustrates an X-ray diffraction pattern of $NaNi_{0.6}Fe_{0.1}Sb_{0.3}O_2$ cathode active material;

FIG.2E illustrates an X-ray diffraction pattern of $NaNi_{0.5}Co_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode active material;

FIG.2F illustrates an X-ray diffraction pattern of $NaNi_{0.5}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode active material;

FIG.2G illustrates an X-ray diffraction pattern of $NaNi_{0.4}Mg_{0.1}$ $Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode active material;

FIG.2H illustrates an X-ray diffraction pattern of $NaNi_{0.6}Mn_{0.1}Ti_{0.1}Sb_{0.2}O_2$ cathode active material;

FIG.2I illustrates an X-ray diffraction pattern of $Na\ Ni_{0.45}\ Mn_{0.3}\ Mg_{0.05}\ Al_{0.05}\ Ti_{0.1}\ Sb_{0.05}\ O_2$ cathode active material;

FIG. 3A illustrates a Voltage-time plot of Sodium-half cells fabricated with $NaNi_{0.6}Mn_{0.1}Ti_{0.1}Sb_{0.2}O_2$ cathode active material;

FIG. 3B illustrates a Voltage-time plot of Sodium-ion half cells fabricated with $NaNi_{0.5}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode material;

FIG. 3C illustrates a Voltage-time plot of Sodium-ion half cells fabricated with $NaNi_{0.5}Co_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode material;

FIG. 3D illustrates a Voltage-time plot of Sodium-ion half cells fabricated with $NaNi_{0.4}Mg_{0.1}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode material;

FIG. 3E illustrates a Voltage-time plot of Sodium-ion half cells fabricated with $NaNi_{0.6}Al_{0.1}Sb_{0.3}O_2$ cathode material;

FIG. 3F illustrates a Voltage-time plot of Sodium-ion half cells fabricated with $NaNi_{0.45}Mn_{0.3}Mg_{0.05}Al_{0.05}Ti_{0.1}Sb_{0.05}O_2$ cathode material;

FIG. 4A illustrates a particle size distribution of the $NaNi_{0.5}Co_{0.1}Ti_{0.3}Sb_{0.1}O_2$ active cathode material;

FIG. 4B illustrates a particle size distribution of the $NaNi_{0.6}Al_{0.1}Sb_{0.3}O_2$ active cathode material;

FIG. 4C illustrates a particle size distribution of the $NaNi_{0.4}Mg_{0.1}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ active cathode material;

FIG. 4D illustrates a particle size distribution of the $NaNi_{0.5}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ active cathode material;

FIG. 4E illustrates a particle size distribution of the $NaNi_{0.6}Mn_{0.1}Ti_{0.1}Sb_{0.2}O_2$ active cathode material;

FIG.5A illustrates a FESEM image of $NaNi_{0.5}Co_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode active material;

FIG.5B illustrates a FESEM image of $NaNi_{0.5}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode active material;

FIG.5C illustrates a FESEM image of $NaNi_{0.6}Mn_{0.1}Ti_{0.1}Sb_{0.2}O_2$ cathode active material;

FIG.5D illustrates a FESEM image of $NaNi_{0.4}Mg_{0.1}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode active material;

FIG.5E illustrates a FESEM image of $NaNi_{0.45}Mn_{0.3}Mg_{0.05}Al_{0.05}Ti_{0.1}Sb_{0.05}O_2$ cathode active material;

FIG.5F illustrates a FESEM image of $NaNi_{0.6}Al_{0.1}Sb_{0.3}O_2$ cathode active material;

DETAILED DESCRIPTION

The following description includes the preferred best mode of one embodiment of the present invention. It will be clear from this description of the invention that the invention is not limited to these illustrated embodiments but the invention also includes a variety of modifications and embodiments thereto. Therefore, the present description should be seen as illustrative and not limiting. While the invention is susceptible to various modifications and alternative constructions, it should be understood, that there is no intention to limit the invention to the specific form disclosed, but, on the contrary, the invention is to cover all modifications, alternative constructions, and equivalents falling within the spirit and scope of the invention as defined in the claims.

In any embodiment described herein, the open-ended terms “comprising,” “comprises,” and the like (which are synonymous with “including,” “having” and “characterized by”) may be replaced by the respective partially closed phrases “consisting essentially of,” consists essentially of,” and the like or the respective closed phrases “consisting of,” “consists of, the like.

As used herein, the singular forms “a”, “an”, and “the” designate both the singular and the plural, unless expressly stated to designate the singular only.

FIG. 1 illustrates a schematic representation of a Sodium-ion battery 100, according to embodiments of the present invention. The Sodium-ion battery 100 known as an electrochemical cell that comprises a cathode 110, an anode 106, an electrolyte 102, a separator 108, an current collector for cathode 112 and an current collector for anode 104.

According to embodiments of the present invention, a Sodium-ion battery (100) fabricated either in the glove box under an inert atmosphere or dry room in humidity level -50RH to -80RH. Further, the performance of the material was tested using the coin cell, cylindrical cell or pouch cell.

Furthermore, the cathode (110) obtained by coating the blended slurry of cathode active material, conducting carbons and a binder in a N-Methyl-2Pyrrolidone (NMP) solvent on the Aluminum foil. According to embodiments of the present invention, the binder is a Polyvinylidene fluoride (PVDF) binder. In a preferred embodiment of the present invention, the cathode (110) fabricated by preparing the slurry followed by coating, the slurry prepared by mixing the active material, the conducting carbon and the binder in the NMP solvent. Then the slurry is coated on an aluminum foil and dried at 70°C-100°C for 12 hours to obtain the cathode (110).

According to embodiments of the present invention, the Sodium-ion battery (100) include the cathode (110) as a positive terminal and the anode (106) as a negative terminal. In an embodiment of the present invention, when an input potential is applied, the Sodium ions move from the cathode (110) to the anode (106) while charging. In discharging the Sodium ions move from anode (106) to cathode (110).

According to embodiments of the present invention, the electrolyte (102) employed for conducting sodium ions. The electrolyte (102) absorbed into the separator (108) that compressed against the cathode (110) and the anode (106) to achieve a chemical reaction. According to embodiments of the present invention, the electrolyte (102) a solution of sodium hexafluorophosphate ($NaPF_6$) in organic solvents.

According to embodiments of the present invention, the separator (108) employed for isolating the cathode (110) and the anode (106) placed in the electrolyte (102). The separator (108) porous in nature so Sodium ions pass freely between two electrodes anode (106) and cathode (110), the separator (108) an isolator with electrical conductivity. In an embodiment of the present invention, the separator (108) a glass microfiber.

FIG. 2A illustrates an X-ray diffraction pattern of $NaNi_{0.6}Ti_{0.2}Sb_{0.2}O_2$ the active cathode material, according to an embodiment of the present invention, X-ray diffraction (XRD) a quick method to identify the formation of the active cathode material composition through a phase and crystal structure analysis. The active cathode material compositions characterized by Bruker D8 ADVANCE Diffractometer. The diffraction peaks correspond to a O′3 layered compound and no other impurity peaks are observed. The high intense peaks confirm that the active cathode material crystalline, the cathode active material belong to a monoclinic crystal system and a layered crystal structure with a crystal space group of C2/m. According to embodiments of the present invention, a crystalline size of the particles of the cathode active material ranges from 10 nm to 75 nm. In a preferred embodiment of the present invention, the estimated crystalline size 44.12 nm.

FIG. 2B illustrates an X-ray diffraction pattern of $NaNi_{0.6}Co_{0.1}Sb_{0.3}O_2$ the active cathode material, In an embodiment of the present invention. The diffraction peaks correspond to a O′3 layered compound, and no other impurity peaks are observed. The high intense peaks confirm that the cathode active material composition is crystalline, the cathode active material composition belong to a monoclinic crystal system and a layered crystal structure with a crystal space group of C2/m. According to embodiments of the present invention, a crystalline size of the particles of the cathode active material ranges from 10 nm to 75 nm. In a preferred embodiment of the present invention, the estimated crystalline size 67.82 nm.

FIG. 2C illustrates an X-ray diffraction pattern of $NaNi_{0.6}Al_{0.1}Sb_{0.3}O_2$ the active cathode material, according to embodiments of the present invention. The diffraction peaks correspond to a O′3 layered compound, and no other impurity peaks are observed. The high intense peaks confirm that the material is crystalline, the cathode active material belong to a monoclinic crystal system and a layered crystal structure with a crystal space group of C2/m. According to embodiments of the present invention, a crystalline size of the particles of the cathode active material ranges from 10 nm to 75 nm. In a preferred embodiment of the present invention, the estimated crystalline size 73.44 nm.

FIG. 2D illustrates an X-ray diffraction pattern of $NaNi_{0.6}Fe_{0.1}Sb_{0.3}O_2$ the active cathode material, according to embodiments of the present invention. The diffraction peaks correspond to a O′3 layered compound, and no other impurity peaks are observed. The high intense peaks confirm that the material is crystalline, the cathode active material belong to a monoclinic crystal system and layered crystal structure with a crystal space group of C2/m. According to embodiments of the present invention, a crystalline size of the particles of the cathode active material ranges from 10 nm to 75 nm. In a preferred embodiment of the present invention, the estimated crystalline size 58.38 nm.

FIG. 2E illustrates an X-ray diffraction pattern of $NaNi_{0.5}Co_{0.1}Ti_{0.3}Sb_{0.1}O_2$ the active cathode material, according to embodiments of the present invention. The diffraction peaks correspond to a O′3 layered compound, and no other impurity peaks are observed. The high intense peaks confirm that the active cathode material is crystalline, the cathode active material belong to a monoclinic crystal system and a layered crystal structure with a crystal space group of C2/m. According to embodiments of the present invention, a crystalline size of the particles of the cathode active material ranges from 10 nm to 75 nm. In a preferred embodiment of the present invention, the estimated crystalline size 44.13 nm.

FIG. 2F illustrates an X-ray diffraction pattern of $NaNi_{0.5}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ the active cathode material, according to embodiments of the present invention. The diffraction peaks correspond to a O′3 layered compound, and no other impurity peaks are observed. The high intense peaks confirm that the material is crystalline, the cathode active material belong to a monoclinic crystal system and a layered crystal structure with a crystal space group of C2/m. According to embodiments of the present invention, a crystalline size of the particles of the cathode active material ranges from 10 nm to 75 nm. In a preferred embodiment of the present invention, the estimated crystalline size 37.93 nm.

FIG. 2G illustrates an X-ray diffraction pattern of $NaNi_{0.4}Mg_{0.1}$ $Al_{0.1}$ $Ti_{0.3}Sb_{0.1}O_2$ the active cathode material, according to embodiments of the present invention. The diffraction peaks correspond to a O′3 layered compound, and no other impurity peaks are observed. The high intense peaks confirm that the material is crystalline, the cathode active material composition belong to a monoclinic crystal system and a layered crystal structure with a crystal space group of C2/m. According to embodiments of the present invention, a crystalline size of the particles of the cathode active material ranges from 10 nm to 75 nm. In a preferred embodiment of the present invention, the estimated crystalline size 14.25 nm.

FIG. 2H illustrates an X-ray diffraction pattern of $NaNi_{0.6}Mn_{0.1}Ti_{0.1}Sb_{0.2}O_2$ the active cathode material, according to embodiments of the present invention. The diffraction peaks correspond to a O′3 layered compound, and no other impurity peaks are observed. The high intense peaks confirm that the material is crystalline, the cathode active material belong to a monoclinic crystal system and a layered crystal structure with a crystal space group of C2/m. According to embodiments of the present invention, a crystalline size of the particles of the cathode active material ranges from 10 nm to 75 nm. In a preferred embodiment of the present invention, the estimated crystalline size 35.86 nm.

FIG. 2I illustrates an X-ray diffraction pattern of $NaNi_{0.45}Mn_{0.3}Mg_{0.05}Al_{0.05}Ti_{0.1}Sb_{0.05}O_2$ the active cathode material, according to embodiments of the present invention. The diffraction peaks correspond to a O′3 layered compound, and no other impurity peaks are observed. The high intense peaks confirm that the material is crystalline, the cathode active material belong to a monoclinic crystal system and a layered crystal structure with a crystal space group of C2/m. According to embodiments of the present invention, a crystalline size of the particles of the cathode active material ranges from 10 nm to 75 nm. In a preferred embodiment of the present invention, the estimated crystalline size 61.73 nm.

FIG. 3A illustrates Voltage-Time plot of Sodium-half cells fabricated with

$NaNi_{0.6}Mn_{0.1}Ti_{0.1}Sb_{0.2}O_2$ cathode material. According to embodiments of the present invention, the cycling performance of cathode materials was study by Bio-Logic BCS-800 series battery cycler. The voltage-time plot help to determine the time period for charge, working voltage window, average voltage and cycling stability of the cathode active material. According to embodiments of the present invention the voltage window ranging from 2.0 V to 4.3 V at a C/25 rate.

FIG. 3B illustrates Voltage-Time plot of Sodium-half cells fabricated with $NaNi_{0.5}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode material. According to embodiments of the present invention, the voltage-time plot help to determine the time period for charge, working voltage window, average voltage and cycling stability of the cathode active material. According to embodiments of the present invention the voltage window ranging from 2.0 V to 4.3 V at a C/25 rate.

FIG. 3C illustrates Voltage-Time plot of Sodium-half cells fabricated with $NaNi_{0.5}Co_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode material. According to embodiments of the present invention, the voltage-time plot help to determine the time period for charge, working voltage window, average voltage and cycling stability of the cathode active material. According to

embodiments of the present invention the voltage window ranging from 2.0 V to 4.3 V at a C/25 rate.

FIG. 3D illustrates Voltage-Time plot of Sodium-half cells fabricated with $NaNi_{0.4}Mg_{0.1}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode material. According to embodiments of the present invention, the voltage-time plot help to determine the time period for charge, working voltage window, average voltage and cycling stability of the cathode active material. According to embodiments of the present invention the voltage window ranging from 2.0 V to 4.0 V at a C/25 rate.

FIG. 3E illustrates Voltage-Time plot of Sodium-half cells fabricated with $NaNi_{0.6}Al_{0.1}Sb_{0.3}O_2$ cathode material. According to embodiments of the present invention, the voltage-time plot help to determine the time period for charge, working voltage window, average voltage and cycling stability of the cathode active material. According to embodiments of the present invention the voltage window ranging from 2.0 V to 4.3 V at a C/10 rate.

FIG. 3F illustrates Voltage-Time plot of Sodium-half cells fabricated with $NaNi_{0.45}Mn_{0.3}Mg_{0.05}Al_{0.05}Ti_{0.1}Sb_{0.05}O_2$ cathode material. According to embodiments of the present invention, the voltage-time plot help to determine the time period for charge, working voltage window, average voltage and cycling stability of the cathode active material. According to embodiments of the present invention the voltage window ranging from 2.0 V to 4.4 V at a C/25 rate.

FIG. 4A illustrates a particle size distribution of the $NaNi_{0.5}Co_{0.1}Ti_{0.3}Sb_{0.1}O_2$ active cathode material, according to embodiments of the present invention, the cathode material compositions characterized by HORIBA laser scattering particle size distribution analyzer LA-960. The plot shows size distribution of the particles that may in the range of 0.1 µm to 50 µm. Analyzing further, the median size (D_{50}) indicates that 50% of the particles in the sample are lesser than 0.79 µm and the remaining 50% are greater, according to embodiments of the present invention. Besides, the graph reveals that 10% of the population lies below 0.43 µm (D_{10}) and 90% of the population lies below 2.50 µm (D_{90}).

FIG. 4B illustrates a particle size distribution of the $NaNi_{0.6}Al_{0.1}Sb_{0.3}O_2$ active cathode material, according to embodiments of the present invention. The plot shows size distribution of the particles that may in the range of 0.1 µm to 50.00 µm. Analyzing further, the median size (D_{50}) indicates that 50% of the particles in the sample are lesser than 10.21 µm and the remaining 50% are greater, according to embodiments of the present invention. Besides, the

graph reveals that 10% of the population lies below 2.70 µm (D_{10}) and 90% of the population lies below 20.24 µm (D_{90}).

FIG. 4C illustrates a particle size distribution of the $NaNi_{0.4}Mg_{0.1}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ active cathode material, according to embodiments of the present invention. The plot shows size distribution of the particles that may in the range of 0.1 µm to 50.00 µm. Analyzing further, the median size (D_{50}) indicates that 50% of the particles in the sample are lesser than 9.73 µm and the remaining 50% are greater, according to embodiments of the present invention. Besides, the graph reveals that 10% of the population lies below 2.17 µm (D_{10}) and 90% of the population lies below 23.85 µm (D_{90}).

FIG. 4D illustrates a particle size distribution of the $NaNi_{0.5}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ active cathode material, according to embodiments of the present invention. The plot shows size distribution of the particles that may in the range of 0.1 µm to 50.00 µm. Analyzing further, the median size (D_{50}) indicates that 50% of the particles in the sample are lesser than 4.96 µm and the remaining 50% are greater, according to embodiments of the present invention. Besides, the graph reveals that 10% of the population lies below 1.43 µm (D_{10}) and 90% of the population lies below 10.14 µm (D_{90}).

FIG. 4E illustrates a particle size distribution of the $NaNi_{0.6}Mn_{0.1}Ti_{0.1}Sb_{0.2}O_2$ active cathode material, according to embodiments of the present invention. The plot shows size distribution of the particles that may in the range of 0.1 µm to 50.00 µm. Analyzing further, the median size (D_{50}) indicates that 50% of the particles in the sample are lesser than 9.80 µm and the remaining 50% are greater, according to embodiments of the present invention. Besides, the graph reveals that 10% of the population lies below 3.25 µm (D_{10}) and 90% of the population lies below 41.13 µm (D_{90}).

FIG.5A illustrates a FESEM image of $NaNi_{0.5}Co_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode active material, according to embodiments of the present invention. The morphology of cathode active material compositions investigated by the TESCAN Field Emission Scanning Electron Microscope (FESEM). In an embodiment of the present invention, micrographs show that the morphologies of the solid-state synthesized cathode active material produce irregular granular morphology and plate-like particles, Further, the cathode active materials are composed of different morphologies, such as, but not limited to, rhombohedra, hexagons, cubes, spheres, elongated hexagons, and so forth.

FIG.5B illustrates a FESEM image of $NaNi_{0.5}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode active material, according to embodiments of the present invention, micrographs show that the morphologies

of the solid-state synthesized cathode active material produce irregular granular morphology, hexagons and elongated hexagons. Further, the cathode active materials are composed of different morphologies, such as, but not limited to, rhombohedra, hexagons, cubes, spheres, elongated hexagons, and so forth.

FIG.5C illustrates a FESEM image of $NaNi_{0.6}Mn_{0.1}Ti_{0.1}Sb_{0.2}O_2$ cathode active material, according to embodiments of the present invention, micrographs show that the morphologies of the solid-state synthesized cathode active material produce irregular granular morphology, cubes and plate-like particles. Further, the cathode active materials are composed of different morphologies, such as, but not limited to, rhombohedra, hexagons, cubes, spheres, elongated hexagons, and so forth.

FIG.5D illustrates a FESEM image of $NaNi_{0.4}Mg_{0.1}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$ cathode active material, according to embodiments of the present invention, micrographs show that the morphologies of the solid-state synthesized cathode active material produce irregular granular morphology, sphere and plate-like particles. Further, the cathode active materials are composed of different morphologies, such as, but not limited to, rhombohedra, hexagons, cubes, spheres, elongated hexagons, and so forth.

FIG.5E illustrates a FESEM image of $NaNi_{0.45}Mn_{0.3}Mg_{0.05}Al_{0.05}Ti_{0.1}Sb_{0.05}O_2$ cathode active material, according to embodiments of the present invention, micrographs show that the morphologies of the solid-state synthesized cathode active material produce irregular granular morphology, sphere and plate-like particles. Further, the cathode active materials are composed of different morphologies, such as, but not limited to, rhombohedra, hexagons, cubes, spheres, elongated hexagons, and so forth.

FIG.5F illustrates a FESEM image of $NaNi_{0.6}Al_{0.1}Sb_{0.3}O_2$ cathode active material, according to embodiments of the present invention, micrographs show that the morphologies of the solid-state synthesized cathode active material produce irregular granular morphology and plate-like particles. Further, the cathode active materials are composed of different morphologies, such as, but not limited to, rhombohedra, hexagons, cubes, spheres, elongated hexagons, and so forth.

While the invention has been described in connection with what is presently considered to be the most practical and various embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope the invention is defined in the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements within substantial differences from the literal languages of the claims.

EXAMPLES

The following examples are given by way of illustration of the working of the invention in actual practice and therefore should not be constrained to limit the scope of the present invention.

EXAMPLE 1

In an exemplary scenario, the cathode composition for the Sodium-ion battery comprises a formula $Na_xNi_{1-y-z}A_yB_zO_2$. According to embodiments of the present invention, the A may Co and Ti, B may Sb. The value of x, y and z are $0.8 \leq x \leq 1.2$, $0 \leq y \leq 0.3$ $0 < z \leq 0.33$. Above elements were substitute to formula the obtained cathode material was $NaNi_{0.5}Co_{0.1}Ti_{0.3}Sb_{0.1}O_2$. FIG 2E shows the X-ray diffraction peaks correspond to the cathode active material is a O′3 layered structure with a monoclinic crystal system and a space group of C2/m without any impurity peak. In a preferred embodiment of the present invention, the estimated crystalline size is 44.13 nm. FIG 4A shows the particle size distribution of the cathode material was analyzing the median size (D_{50}) indicate that 50% of the particles in the sample are lesser than 0.79 µm and the remaining 50% are greater, according to embodiments of the present invention. Besides, the graph reveals that 10% of the population lies below 0.43 µm (D_{10}) and 90% of the population lies below 2.50 µm (D_{90}). FIG 5A shows that the morphologies of the cathode active material were irregular granular morphology and plate-like particles. Surface area of the particles of the cathode material was 1 m^2/g. Sodium-half cells fabricated and tested the charge capacity of first cycle 150 mA h/g and discharge capacity of first cycle 118 mA h/g with voltage window ranging from 2.0 V to 4.4 V at a C/25 rate.

EXAMPLE 2

In an exemplary scenario, the cathode composition for the Sodium-ion battery comprises a formula $Na_xNi_{1-y-z}A_yB_zO_2$. According to embodiments of the present invention, the A may Al

and Ti, B may Sb. According to embodiments of the present invention, the value of $0.8 \leq x \leq 1.2$, $0 \leq y \leq 0.3$ $0 < z \leq 0.33$, $y+z \leq 0.6$, Above elements were substitute to formula the obtained cathode material was $NaNi_{0.5}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$. FIG 2F shows the X-ray diffraction peaks correspond to the cathode active material is a O′3 layered structure with a monoclinic crystal system and a space group of C2/m without any impurity peak. In a preferred embodiment of the present invention, the estimated crystalline size 37.93 nm. FIG 4D shows the particle size distribution of the cathode active material was analyzing the median size (D_{50}) indicate that 50% of the particles in the sample are lesser than 4.96 µm and the remaining 50% are greater, according to embodiments of the present invention. Besides, the graph reveals that 10% of the population lies below 1.43 µm (D_{10}) and 90% of the population lies below 10.14 µm (D_{90}). FIG 5B shows that the morphologies of the cathode active material were irregular granular morphology, hexagons, and elongated hexagons. Surface area of the particles of the cathode material was 0.5 m^2/g. Sodium-half cells fabricated and tested the charge capacity of first cycle 155 mA h/g and discharge capacity of first cycle 120 mA h/g with voltage window ranging from 2.0 V to 4.3 V at a C/25 rate.

EXAMPLE 3

In an exemplary scenario, the cathode composition for the Sodium-ion battery comprises a formula $Na_xNi_{1-y-z}A_yB_zO_2$. According to embodiments of the present invention, the A may Mn and Ti, B may Sb. According to embodiments of the present invention, the value of $0.8 \leq x \leq 1.2$, $0 \leq y \leq 0.3$ $0 < z \leq 0.33$, $y+z \leq 0.6$, Above elements were substitute to formula the obtained cathode was $NaNi_{0.6}Mn_{0.1}Ti_{0.1}Sb_{0.2}O_2$. FIG 2H shows the X-ray diffraction peaks correspond to the cathode active material is a O′3 layered structure with a monoclinic crystal system and a space group of C2/m without any impurity peak. In a preferred embodiment of the present invention, the estimated crystalline size 35.86 nm. FIG 4E shows the particle size distribution of the cathode active material was analyzing the median size (D_{50}) indicate that 50% of the particles in the sample are lesser than 9.80 µm and the remaining 50% are greater, according to embodiments of the present invention. Besides, the graph reveals that 10% of the population lies below 3.25 µm (D_{10}) and 90% of the population lies below 41.13 µm (D_{90}). FIG 5C shows that the morphologies of the cathode active material were irregular granular morphology, cubes and plate-like particles. Surface area of the particles of the cathode material was 3 m^2/g. Sodium-half cells fabricated and tested the charge capacity of first cycle 145 mA h/g and discharge capacity of first cycle 112 mA h/g after third cycle the

discharge capacity 85 mA h/g with voltage window ranging from 2.0 V to 4.3 V at a C/25 rate.

EXAMPLE 4

In an exemplary scenario, the cathode composition for the Sodium-ion battery comprises a formula $Na_xNi_{1-y-z}A_yB_zO_2$. According to embodiments of the present invention, the A may Mg, Al and Ti, B may Sb. According to embodiments of the present invention, the value of $0.8\leq x\leq 1.2$, $0\leq y\leq 0.3$ $0<z\leq 0.33$, $y+z\leq 0.6$, Above elements were substitute to formula the obtained cathode was $NaNi_{0.4}Mg_{0.1}Al_{0.1}Ti_{0.3}Sb_{0.1}O_2$. FIG 2G shows the Xray diffraction peaks correspond to the cathode active material is a O′3 layered structure with a monoclinic crystal system and a space group of C2/m without any impurity peak. In a preferred embodiment of the present invention, the estimated crystalline size 14.25 nm. FIG 4C shows the particle size distribution of the cathode active material was analyzing the median size (D_{50}) indicate that 50% of the particles in the sample are lesser than 9.73 µm and the remaining 50% are greater, according to embodiments of the present invention. Besides, the graph reveals that 10% of the population lies below 2.17 µm (D_{10}) and 90% of the population lies below 23.85 µm (D_{90}). FIG 5D shows that the morphologies of the cathode active material were irregular granular morphology, sphere and plate-like particles. Surface area of the particles of the cathode material was 5 m^2/g. Sodium-half cells fabricated and tested in CC-CV mode charge capacity of first cycle 122 mA h/g and discharge capacity of first cycle 103 mA h/g after 23 cycle the discharge capacity 88 mA h/g with voltage window ranging from 2.0 V to 4.0 V at a C/25 rate.

EXAMPLE 5

In an exemplary scenario, the cathode composition for the Sodium-ion battery comprises a formula $Na_xNi_{1-y-z}A_yB_zO_2$. According to embodiments of the present invention, the A may Al, B may Sb. According to embodiments of the present invention, the value of $0.8\leq x\leq 1.2$, $0\leq y\leq 0.3$ $0<z\leq 0.33$, $y+z\leq 0.6$, Above elements were substitute to formula the obtained cathode was $NaNi_{0.6}Al_{0.1}Sb_{0.3}O_2$. FIG 2C shows the X-ray diffraction peaks correspond to the cathode active material is a O′3 layered structure with a monoclinic crystal system and a space group of C2/m without any impurity peak. In a preferred embodiment of the present invention, the estimated crystalline size 73.44 nm. FIG 4B shows the particle size distribution of the cathode active material was analyzing the median size (D_{50}) indicate that 50% of the particles in the sample are lesser than 10.21 µm and the remaining 50% are greater, according to embodiments of the present invention. Besides, the graph reveals that 10% of the population

lies below 2.70 µm (D_{10}) and 90% of the population lies below 20.24 µm (D_{90}). FIG 5F shows that the morphologies of the cathode active material were irregular granular morphology and plate-like particles. Surface area of the particles of the cathode material was 0.3 m^2/g. Sodium-half cells fabricated and tested the charge capacity of first cycle 120 mA h/g and discharge capacity of first cycle 102 mA h/g after 4^{th} cycle the discharge capacity 82 mA h/g with voltage window ranging from 2.0 V to 4.3 V at a C/10 rate.

EXAMPLE 6

In an exemplary scenario, the cathode composition for the Sodium-ion battery comprises a formula $Na_xNi_{1-y-z}A_yB_zO_2$. According to embodiments of the present invention, the A may be Mg, Al, Mn, Ti and B may be Sb. According to embodiments of the present invention, the value of $0.8 \leq x \leq 1.2$, $0 \leq y \leq 0.3$ $0 < z \leq 0.33$, $y+z \leq 0.6$, Above elements were substitute to formula the obtained cathode was $NaNi_{0.45}Mn_{0.3}Mg_{0.05}Al_{0.05}Ti_{0.1}Sb_{0.05}O_2$. FIG 2I shows the X-ray diffraction peaks correspond to the cathode active material is a O′3 layered structure with a monoclinic crystal system and a space group of C2/m without any impurity peak. In a preferred embodiment of the present invention, the estimated crystalline size 61.73 nm. FIG 5E shows that the morphologies of the cathode active material were irregular granular morphology and plate-like particles. Surface area of the particles of the cathode material was 6.2 m^2/g. Sodium-half cells fabricated and tested the charge capacity of first cycle 183 mA h/g and discharge capacity of first cycle 151 mA h/g after 15^{th} cycle the discharge capacity 120 mA h/g with voltage window ranging from 2.0 V to 4.4 V at a C/25 rate.

ADVANTAGES OF THE INVENTION

The main advantages of the present invention are:

1. Layered sodium metal oxide compositions as cathode material exhibit higher energy density.
2. Sodium is more abundant in nature and will offer a solution for a low cost and durable energy storage requirement.
3. Layered sodium metal oxide compositions easily scalable for mass production.
4. Active material composition can be utilized for battery industry.

We Claim:

1. A sodium ion battery(100) having layered sodium metal oxide compositions as cathode electrode material comprising of:

   (a) a cathode electrode material (110) coated with aluminium foil (112) ;

   (b) an anode (106) coated with aluminium or copper foil (104);

   (c) an electrolyte (102) and

   (d) an porous separator(108).

2. The sodium ion battery as claimed in claim 1, wherein cathode electrode material composition for a Sodium-ion battery having a formula

   $Na_xNi_{1-y-z}A_yB_zO_2$ and $0.8\leq x\leq 1.2$, $0\leq y\leq 0.3$ $0<z\leq 0.33$, $y+z\leq 0.6$ the cathode composition comprises: wherein

   A comprises a metal in oxidation state in +2, +3 and +4 selected from Ti, Co, Al, Fe, Mn, Zn, Mg or combination thereof ; B comprises a metal in oxidation state in +5 or +6 selected from Sb or Te.

3. The sodium ion battery as claimed in claim 1, wherein cathode electrode material composition selected from the formulas consisting of

   $Na\ Ni_{0.6}\ Ti_{0.2}\ Sb_{0.2}\ O_2$

   $Na\ Ni_{0.6}\ Co_{0.1}\ Sb_{0.3}\ O_2$

   $Na\ Ni_{0.6}\ Al_{0.1}\ Sb_{0.3}\ O_2$

   $Na\ Ni_{0.6}\ Fe_{0.1}Sb_{0.3}\ O_2$

   $Na\ Ni_{0.45}\ Mg_{0.15}\ Ti_{0.2}\ Sb_{0.2}\ O_2$

   $Na\ Ni_{0.45}\ Zn_{0.15}\ Ti_{0.2}\ Sb_{0.2}\ O_2$

   $Na\ Ni_{0.45}\ Co_{0.26}\ Ti_{0.14}\ Sb_{0.15}\ O_2$

   $Na_{1.05}\ Ni_{0.2}\ Co_{0.55}\ Ti_{0.1}\ Sb_{0.1}\ O_2$

   $Na\ Ni_{0.45}\ Fe_{0.26}\ Ti_{0.14}\ Sb_{0.15}\ O_2$

   $Na_{1.05}\ Ni_{0.2}\ Fe_{0.55}\ Ti_{0.1}\ Sb_{0.1}\ O_2$

$Na\ Ni_{0.45}\ Mn_{0.26}\ Ti_{0.14}\ Sb_{0.15}\ O_2$

$Na_{1.05}\ Ni_{0.2}\ Mn_{0.55}\ Ti_{0.1}\ Sb_{0.1}\ O_2$

$NaNi_{0.45}Mn_{0.3}Mg_{0.05}Al_{0.05}Ti_{0.1}Sb_{0.05}O_2$

$NaNi_{0.5}Mn_{0.1}Al_{0.1}Ti_{0.2}Sb_{0.1}O_2$

$NaNi_{0.6}Mn_{0.1}Ti_{0.12}Sb_{0.18}O_2$

$NaNi_{0.5}Mn_{0.125}Al_{0.125}Ti_{0.125}\ Sb_{0.125}O_2$

$Na\ Ni_{0.5}\ Co_{0.1}\ Ti_{0.3}\ Sb_{0.1}\ O_2$

$Na\ Ni_{0.47}Co_{0.23}\ Ti_{0.1}\ Sb_{0.2}\ O_2$

$Na\ Ni_{0.5}\ Al_{0.15}\ Ti_{0.325}\ Sb_{0.05}\ O_2$

$Na\ Ni_{0.47}\ Al_{0.25}\ Ti_{0.14}\ Sb_{0.15}\ O_2$

$Na\ Ni_{0.5}\ Al_{0.1}\ Ti_{0.3}\ Sb_{0.1}\ O_2$

$Na\ Ni_{0.65}\ Co_{0.1}\ Ti_{0.05}\ Te_{0.2}\ O_2$

$Na\ Ni_{0.5}\ Co_{0.2}\ Ti_{0.2}\ Te_{0.1}\ O_2$

$Na\ Ni_{0.5}\ Co_{0.3}\ Ti_{0.05}\ Te_{0.15}\ O_2$

$Na\ Ni_{0.65}\ Co_{0.1}\ Ti_{0.2}\ Te_{0.1}\ O_2$

$Na\ Ni_{0.65}\ Al_{0.1}\ Ti_{0.05}\ Te_{0.2}\ O_2$

$Na\ Ni_{0.5}\ Al_{0.2}\ Ti_{0.2}\ Te_{0.1}\ O_2$

$Na\ Ni_{0.5}\ Al_{0.3}\ Ti_{0.05}\ Te_{0.15}\ O_2$

$Na\ Ni_{0.65}\ Al_{0.1}\ Ti_{0.2}\ Te_{0.1}\ O_2$

$Na\ Ni_{0.65}\ Fe_{0.1}\ Ti_{0.05}\ Te_{0.2}\ O_2$

$Na\ Ni_{0.5}\ Fe_{0.2}\ Ti_{0.2}\ Te_{0.1}\ O_2$

$Na\ Ni_{0.5}\ Mn_{0.3}\ Ti_{0.05}\ Te_{0.15}\ O_2$

$Na\ Ni_{0.65}\ Mn_{0.1}\ Ti_{0.2}\ Te_{0.1}\ O_2$

$NaNi_{0.6}Mg_{0.1}Ti_{0.1}Te_{0.2}O_2$

$NaNi_{0.6}Zn_{0.1}Ti_{0.1}Te_{0.2}O_2$.

3. The cathode electrode material composition as claimed in claim 2, wherein the composition is a O′3 - type layer structure with a space group of C2/m.
4. The cathode electrode material composition as claimed in claim 2, wherein a crystalline size of the particles of the composition ranges from 10 nm to 75 nm.
5. The cathode electrode material composition as claimed in claim 2, wherein the composition positive electrode active material voltage window ranges from 2 V to 4.4 V.
6. The cathode electrode material composition as claimed in claim 2, wherein the composition cathode material capacity ranges from 80 mA h/g to 185 mA h/g.
7. The cathode electrode material composition as claimed in claim 2, wherein the composition cathode material particles having a size distribution of the particles between 0.1 µm to 50.00 µm.
8. The cathode electrode material composition as claimed in claim 2, wherein the composition cathode material morphology is irregular granular, plate-like particles, hexagons, cubes, spheres, and elongated hexagons.
9. The cathode electrode material composition as claimed in claim 2, wherein a surface area of the cathode composition ranges from 0.1 m^2/g to 10 m^2/g.

Dated this ___**25th**____day of_____**April**___**2022**.

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ABSTRACT

Layered Sodium Metal Oxide Compositions as Cathode Materials for Secondary Battery

The present invention related to layered sodium metal oxide compositions as cathode material (110) for Sodium-ion battery (100) are described, A sodium metal oxide having a general formula $Na_xNi_{1-y-z}A_yB_zO_2$ and $0.8 \leq x \leq 1.2$, $0 \leq y \leq 0.3$ $0 < z \leq 0.33$, $y+z \leq 0.6$ the cathode composition comprises: wherein A comprises a metal in oxidation state in +2, +3 and +4 selected from Ti, Co, Al, Fe, Mn, Zn, Mg or combination thereof, B comprises a metal in oxidation state in +5 or +6 selected from Sb or Te. The cathode composition uses as electrode material for sodium ion battery (100) application.

Figure 24.

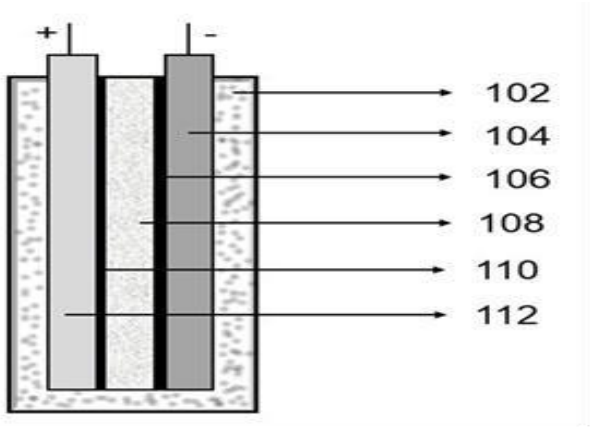


FIGURE-1

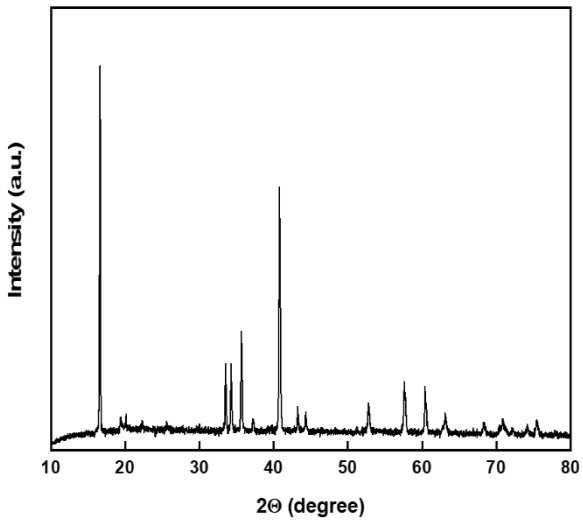


FIGURE 2A

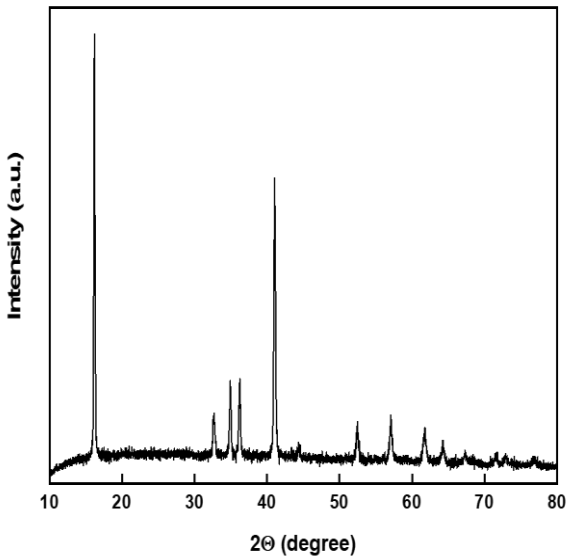


FIGURE 2B

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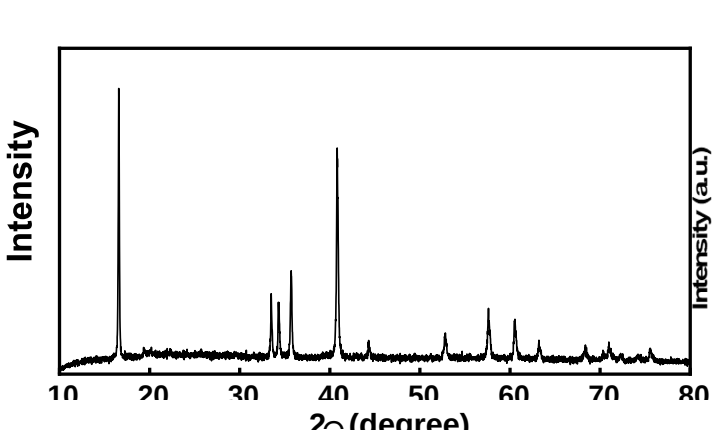


FIGURE 2C

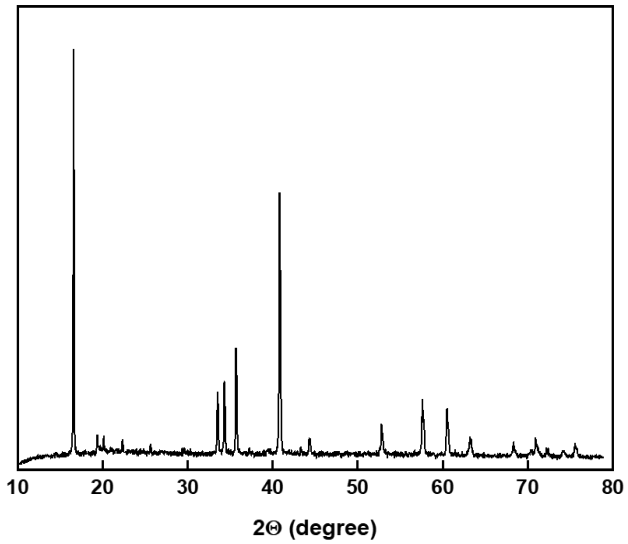


FIGURE 2D

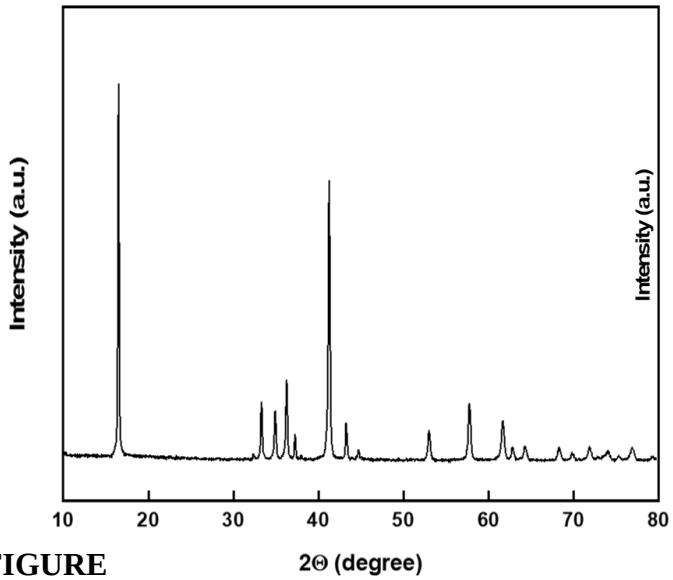


FIGURE 2E

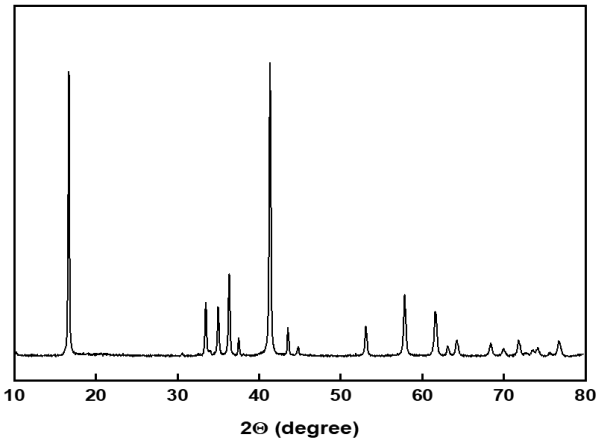


FIGURE 2F

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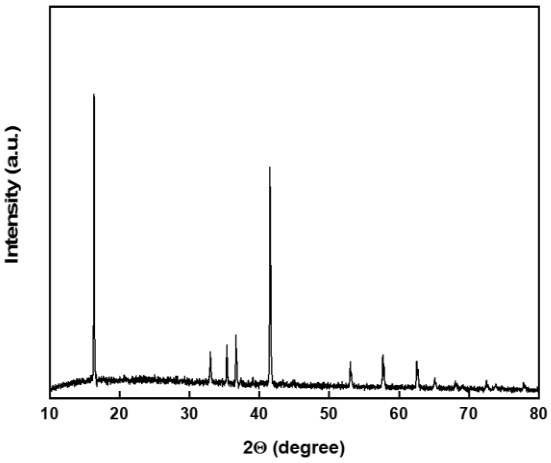


FIGURE 2G

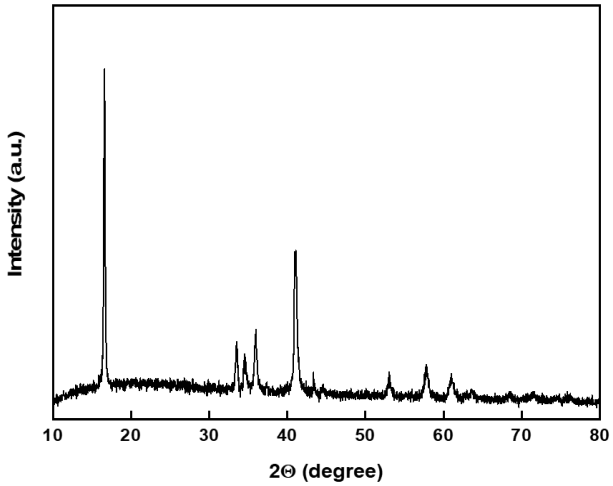


FIGURE 2H

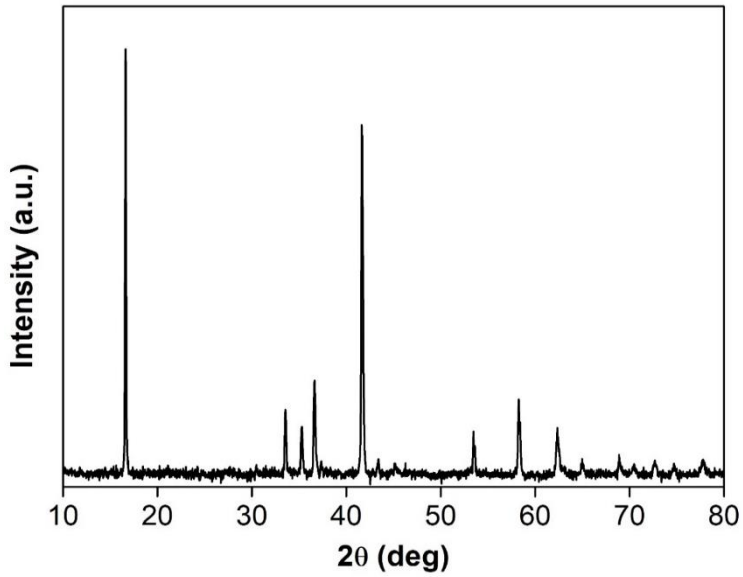


FIGURE 2I

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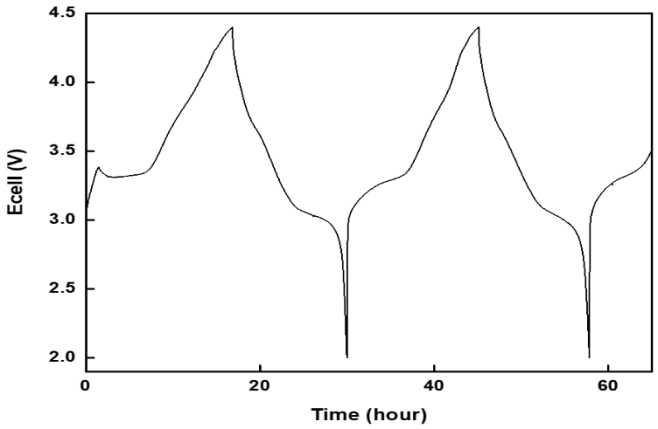


FIGURE 3A

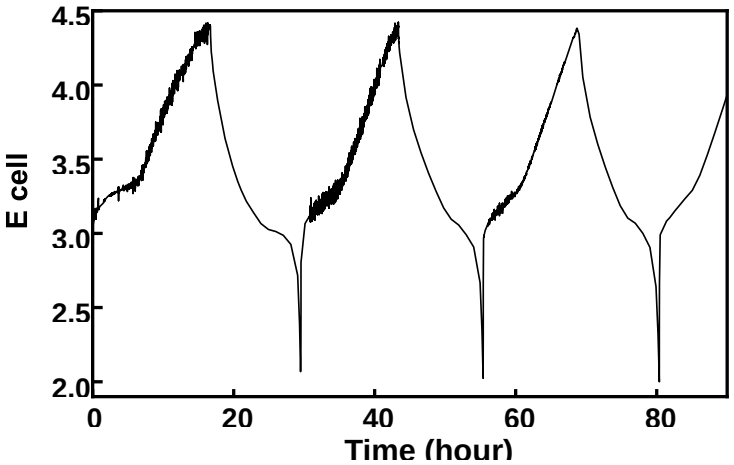


FIGURE 3B

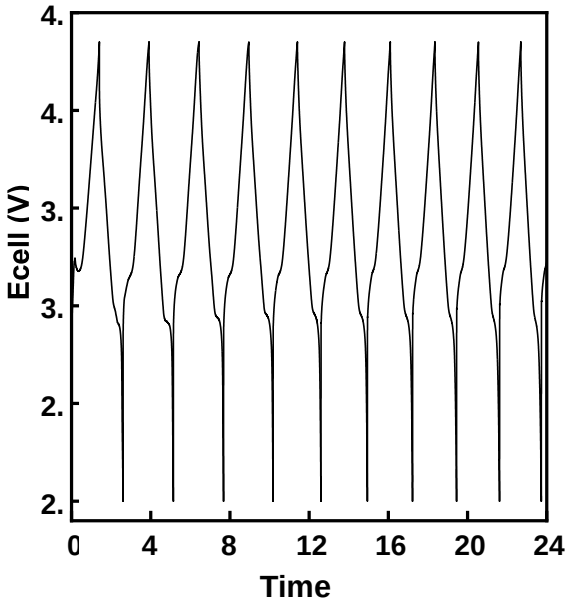


FIGURE 3C

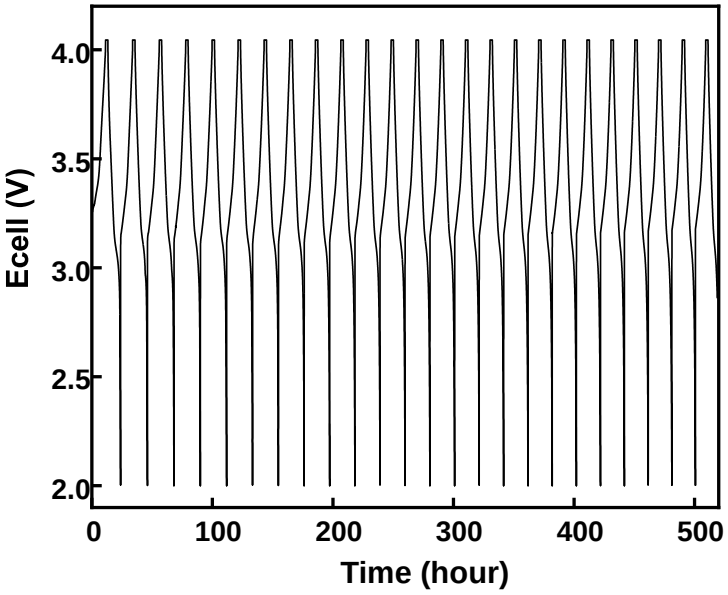


FIGURE 3D

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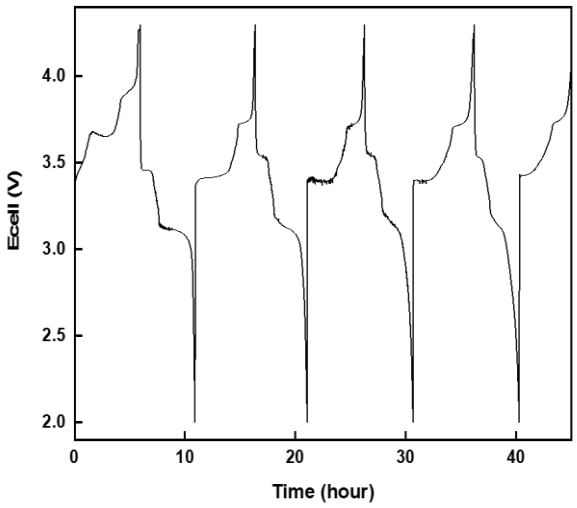


FIGURE 3E

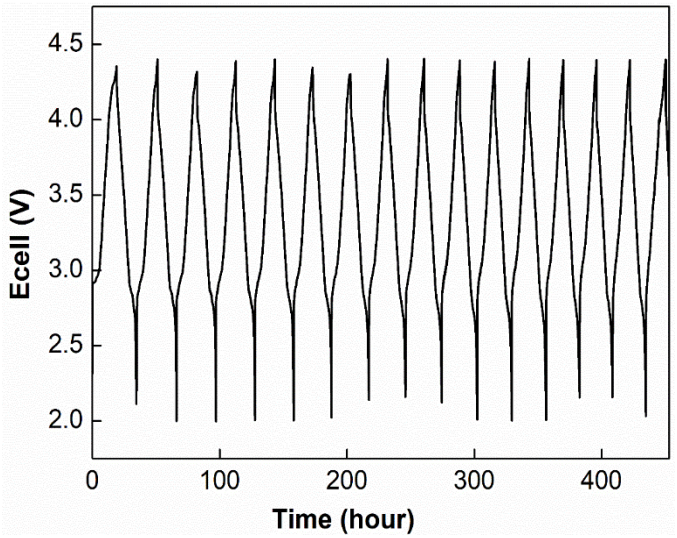


FIGURE 3F

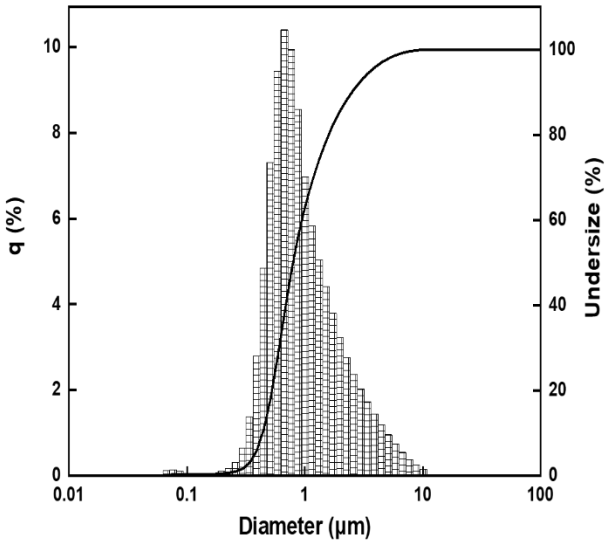


FIGURE 4A

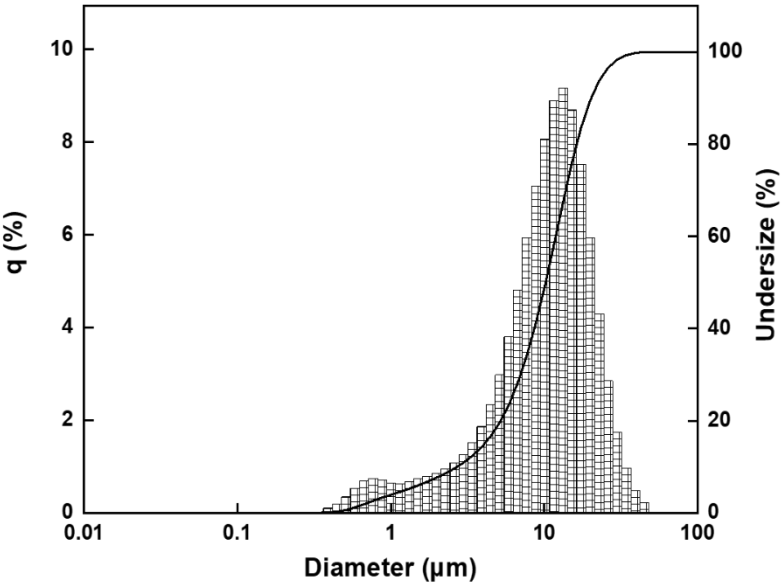


FIGURE 4B

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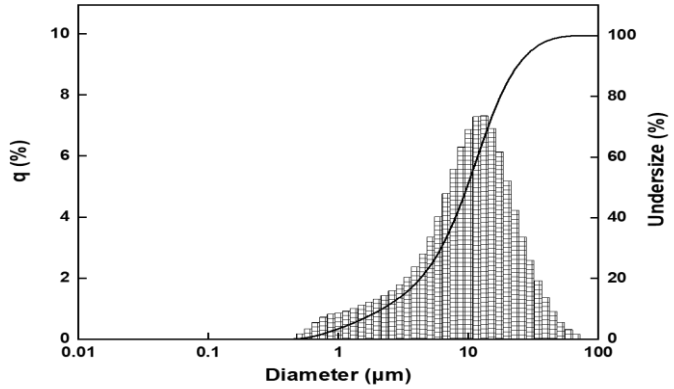


FIGURE 4C

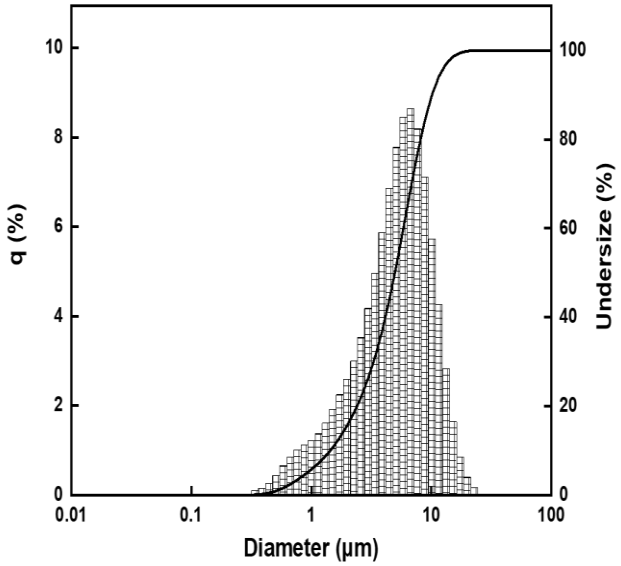


FIGURE 4D

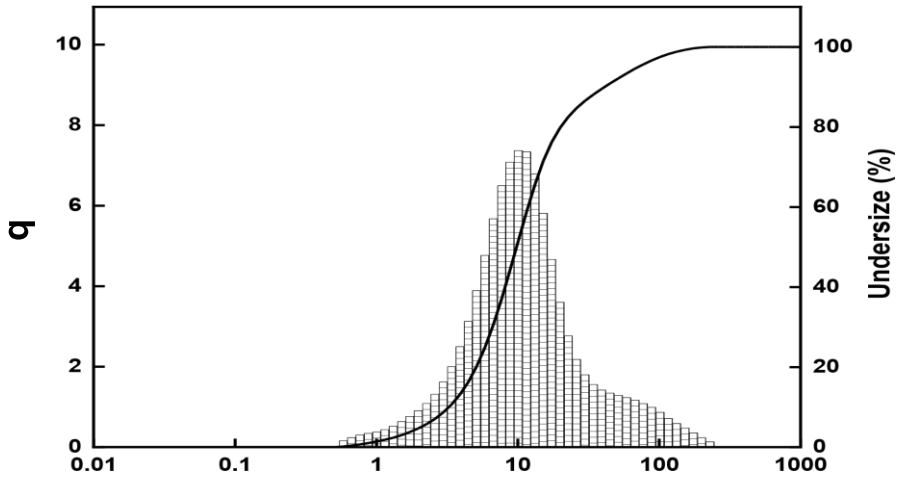


FIGURE 4E

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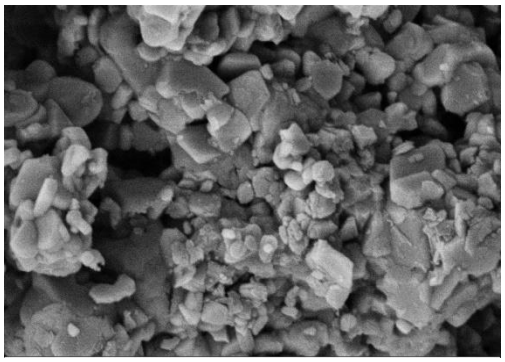


FIGURE 5A

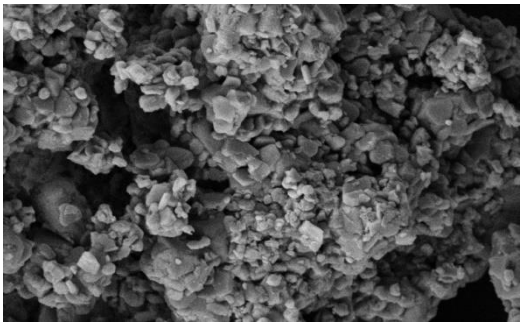


FIGURE 5B

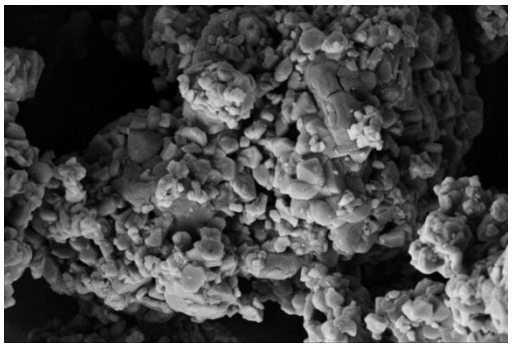


FIGURE 5C

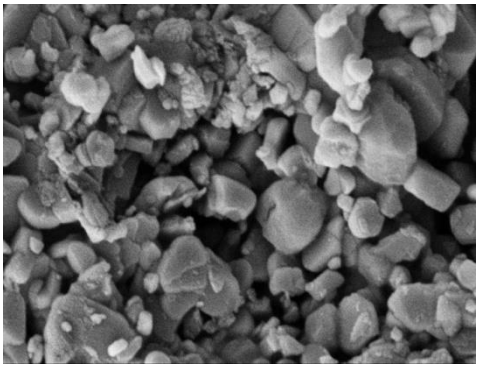


FIGURE 5D

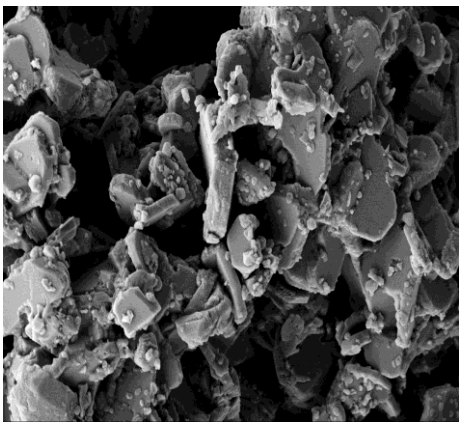


FIGURE 5E

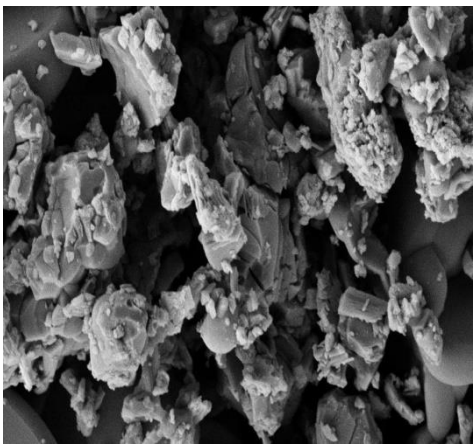


FIGURE 5F

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