(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 February 2025 (27.02.2025)

WIPO | PCT

(10) International Publication Number
WO 2025/040586 A1

(51) International Patent Classification:
H01M 4/36 (2006.01) *H01M 4/525* (2010.01)
H01M 4/505 (2010.01)

(21) International Application Number:
PCT/EP2024/073101

(22) International Filing Date:
16 August 2024 (16.08.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2350984-7 18 August 2023 (18.08.2023) SE

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

(54) Title: COATED CATHODE ACTIVE MATERIAL FOR LITHIUM ION BATTERIES

(57) Abstract: The disclosure provides a coated lithium intercalation cathode active material for a lithiumion battery and a method of forming said coated cathode active material. In particular, the coated cathode active material comprises a coating of lithium iron manganese phosphate (LFMP) and conductive carbon. In some examples, the cathode material comprises lithium nickel manganese cobalt oxide (NMC) or lithium nickel cobalt aluminium oxide (NCA). The coated cathode active material of the disclosure is suitable for use in electrodes resulting in electrodes having a high energy density.

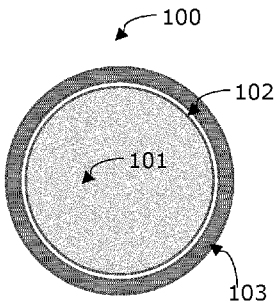


Figure 1a

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COATED CATHODE ACTIVE MATERIAL FOR LITHIUM ION BATTERIES

FIELD OF THE INVENTION

The present description relates to coated cathode materials for lithium-ion batteries.

BACKGROUND

Rechargeable or 'secondary' batteries find widespread use as electrical power supplies and energy storage systems. For example, in automobiles, battery packs formed of a plurality of battery modules, wherein each battery module includes a plurality of electrochemical cells, are provided as a means of effective storage and utilization of electric power.

Secondary cells such a lithium-ion cells comprise a positive and a negative electrode, the cathode and the anode, respectively. Each electrode typically includes three components: active material, conductive additives, and polymeric binders.

The active material is the major component of the electrode. Exemplary cathode active materials (CAM) include the layered lithium metal oxide ($LiMO_2$) cathode materials. For example, active cathode materials such as lithium nickel manganese cobalt oxide (NMC) and lithium nickel cobalt aluminium oxide (NCA) are two possible active cathode materials for high-energy Li-ion batteries. Often the CAM are further functionalized to improve different properties. For example, coatings are often applied to protect the surface of the CAM. However, these coatings often form an inactive phase on the surface of the active cathode materials which may impede the charging and discharging.

The remaining components of the cell are not able to reversibly bind Li-ions and hence they do not improve the capacity of the cell. The conductive additive increases the conductivity inside the electrodes for rapid charging and discharging, while the polymer binder adhesively connects all the electrode materials for long-term charge/discharge cycling. As these components add mass to the cell without increasing the capacity of the cell, the overall energy density will drop as the amount of these components increases. As a result, there is an interest in minimising the amount of conductive material within the electrode while still obtaining good cycling characteristics to achieve a high energy density battery with good electronic and charge/discharge properties.

This disclosure relates to a novel composite particle for the positive electrode of an energy storage device comprising a core of CAM and a coating of lithium iron manganese phosphate (LFMP) and conductive carbon, and a method of forming the compositive particle. The use of the novel composite particle allows for reduced use of conductive additives which results in increased energy density.

SUMMARY

The object of the present disclosure is to provide a coated CAM and a method for fabricating said coated CAM. The resultant coated cathode active material has increased conductivity and better thermal stability. Specifically, the increased conductivity of the CAM allows for the production of a battery with increased energy density, since the addition of conductive additives in the electrode can be decreased.

According to a first aspect of the invention is provided a composite particle for the positive electrode of an energy storage device, the composite particle comprising:

a core comprising a cathode active material (CAM);

a coating comprising lithium iron manganese phosphate (LFMP) and conductive carbon.

According to a second aspect of the disclosure is provided a process for coating the surface of a CAM comprising combining the CAM, LFMP, and conductive carbon to provide a composite particle having a core of CAM surrounded by LFMP and conductive carbon.

According to a third aspect of the invention is provided a coated CAM, obtained by the process for coating a CAM with LFMP and conductive carbon.

While the disclosure is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example and will be described in detail. It should be understood, however, that other embodiments, beyond the particular embodiments described, are possible as well. All modifications, equivalents, and alternative embodiments falling within the spirit and scope of the appended claims are covered as well.

The above discussion is not intended to represent every example embodiment or every implementation within the scope of the current or future Claim sets. The figures and Detailed Description that follow also exemplify various example embodiments. Various

example embodiments may be more completely understood in consideration of the following Detailed Description.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1a/1b/1c schematically show the various forms of the coated composite particle of the invention. In the drawings, the sizes and relative thicknesses of layers and regions may be exaggerated, and the same reference numerals denote the same elements throughout the present invention.

DETAILED DESCRIPTION

The disclosure relates to a coated cathode active material and a method of producing said coated cathode active material. The obtained coated cathode active material is a composite particle comprising a core comprising a cathode active material (CAM), and a coating comprising lithium iron manganese phosphate (LFMP) and conductive carbon. Figures 1a, 1b, and 1c show various embodiments of a coated composite particle.

Importantly, only small amounts of conductive carbon are required in the coating to achieve the beneficial effect of improved electrical properties. This means that addition of conductive additives in the cathode (for instance as components in the slurry to make the cathode) can be reduced and even omitted, resulting in an increased energy density of the cell.

Cathode active material

The disclosure relates to a coated cathode active material and a method of producing said coated cathode active material.

In the context of the disclosure "cathode active material" (CAM) refers to any material that is suitable for use as the electrochemically active material in a cathode, and suitable for use in a cell. The role of the CAM is to reversibly intercalate ions (such as lithium ions) during cell charge and discharge cycles.

The cathode active material of the disclosure is an intercalation material, wherein the intercalation metal is lithium.

Preferably, the cathode active material is a transition metal complex such as layered lithium metal oxide ($LiMO_2$) cathode materials. Even more preferably, the cathode active material is a lithium nickel manganese cobalt oxide (NMC) and/or a lithium nickel cobalt aluminium oxide (NCA).

In some embodiments, the cathode active material comprises lithium nickel cobalt manganese oxides (NMC) ($LiNi_{1-x-y}Co_xMn_yO_2$ ($0<x+y<1$)).

In some embodiments, the cathode active material comprises lithium nickel cobalt aluminium oxides (NCA) ($LiNi_{1-x-y}Co_xAl_yO_2$ ($0<x+y<1$)).

In other embodiments, the layered lithium metal oxide (L_1MO_2) cathode materials are high in nickel. The high-nickel active cathode material may include one or more of the NCA or the NCM. A ratio of the components of the high-nickel active cathode material may range from 1:1:1 to 8:1:1. For example, a ratio of the NCA (e.g. nickel:cobalt:aluminium) or the NCM (e.g. nickel:manganese:cobalt) may be 8:1:1. In one example, the ratio may be 6:2:2. In another example, additionally or alternatively, the ratio may be 5:3:2. In some examples, the NCM or the NCA may comprise a ratio of about 1:1:1.

In some embodiments, the cathode active material comprises lithium nickel cobalt manganese oxides (NMC) ($Li_bNi_{1-x-y}Co_xMn_yA_zO_2$ ($0<x+y<1$)), where A is an element other than Li, Ni, Co, Mn or O and wherein $0\geq z\geq 0.05$, preferably $0>z\geq 0.03$, and wherein $0.9\geq b\geq 1.1$.

In preferred embodiments, the NMC cathode materials are high in nickel. As such, the cathode active material typically comprises lithium nickel cobalt manganese oxides (NMC) represented by the formula $Li_bNi_{1-x-y}Co_xMn_yA_zO_2$, wherein $0<x+y<0.4$, preferably $0<x+y<0.25$, and wherein $0\geq z\geq 0.05$, preferably $0>z\geq 0.03$, and wherein $0.9\geq b\geq 1.1$.

The ratio of the nickel of the high-nickel NMC material may range from 33 mol% to 98 mol %. Preferably, the ratio may range from 60 mol% to 95 mol%. Even more preferably, the ratio may range from 80 mol% to 95 mol%.

In preferred embodiments, the NMC cathode materials is defined as $Li_bNi_{1-x-y}Co_xMn_yA_zO_2$, wherein $0<x+y<0.4$, preferably $0<x+y<0.25$, and wherein $0\geq z\geq 0.05$, preferably $0.002\geq z\geq 0.03$, and wherein $0.9\geq b\geq 1.1$. A is one or more chosen from the group Al, B, Zr, Ba, Ca, Ti, Mg, Ta, Nb, V, Fe, Ru, Re, Pt and Mo.

In some embodiments, preferably z is 0.

In an embodiment of the invention, the CAM may be present in an amount of from about 75 wt% to about 99 wt%, for example from 80 wt% to about 98 wt%, such as from about 86 wt% to about 98 wt%, preferably from about 91 wt% to 98 wt%, based on the total weight of the composite particle.

Lithium iron manganese phosphate (LFMP)

An exemplary coating material includes lithium iron manganese phosphate (LFMP), which may be represented by the formula $LiFe_{1-x}Mn_xPO_4$ ($0<x<1$).

LFMP is used as coating material to provide the a number of benefits. Firstly, its redox potential is compatible with NCM and NCA, resulting in efficient charge/discharge processes. This means that the cycle life performance is improved. Secondly, it provides a protective layer (i.e. a layer that reduces unwanted interactions between the CAM and electrolyte), which results in increased thermal stability.

In an embodiment, the LFMP may be present in an amount of from about 0.8 wt% to about 24 wt%, for example from 1 wt% to about 19 wt%, such as from about 1.5 wt% to about 13 wt%, preferably from about 1.8 wt% to 8.5 wt%, based on the total weight of the composite particle.

To achieve a uniform distribution of the LFMP material around the core of CAM, the LFMP material may comprise nanoscale LFMP-particles.

Conductive carbon

The disclosure relates to composite particles of cathode active material comprising a surface coating of LFMP and conductive carbon and a method of producing said coated cathode active material.

In the context of the disclosure "conductive carbon" refers to any material that has electronically conductive properties, while having carbon as a major constituent. As such, the carbon content of the conductive carbon is at least about 90 wt%, such as above 92 wt%, or above 94 wt%. Preferably, the carbon content is above 95 wt%. More preferably, the carbon content is above 98 wt%.

For example, the conductive carbon may comprise graphene, graphene fiber, fibrous graphene, porous graphene, nanoporous graphene, nanoporous graphene fiber, holey graphene, perforated graphene, graphene foam, graphene aerogel, carbon nanofiber (CNF), porous carbon nanofiber, carbon nanofoam, carbon microfoam, graphite, amorphous carbon, carbon black, acetylene black, mesocarbon microbead (MCMB), pitch-based carbon, coke powders, single-walled carbon nanotube, thin-walled carbon nanotube, multi-walled carbon nanotube, or a combination thereof.

In a preferred embodiment, the conductive carbon is selected from the group of graphene, carbon black, acetylene black, carbon nanotubes, or a combination thereof. More preferably, the conductive carbons are selected from the group of carbon black, graphene, or a combination thereof.

The role of the conductive carbon is to improve the electronic properties of the cathode active material. When formulating the cathode according to the prior art, the conductive carbon would be added in the slurry used for preparing the cathode. When formulated in this way, often more than 1 wt% of conductive additive is required to ensure sufficient levels of conductivity in the resultant electrode.

Without wishing to be bound by theory, it is proposed that the inclusion of small amounts of conductive carbon in the coating of the CAM results in a particularly good conductive properties of the formed composite particle. This in turn means that reduced amounts of conductive carbon are required to get the desired conductive properties when producing the cathode. As the overall amount of conductive carbon is lower, an overall increase in energy density is obtained.

In an embodiment, the conductive carbon may be present in the coating in an amount of from about 0.01 wt% to about 1 wt%, for example from about 0.02 wt% to about 0.9 wt%, such as from about 0.04 wt% to about 0.8 wt%, for example from about 0.03 to about 0.7, such as from about 0.05 to 0.5 wt%, for example from 0.1 to 0.4, based on the total weight of the composite particle.

Coated cathode active material

The cathode active material of the disclosure is coated with LFMP and conductive carbon to provide a composite particle comprising a core of CAM and a coating of LFMP and conductive carbon.

In the context of the disclosure, "coating" or "coated" refers to a cathode active material wherein the cathode active material particle surface comprises LFMP and conductive carbon.

In the context of the disclosure, "composite particle" refers to a particle comprising a core and a surface. In this disclosure, the core comprises CAM, while the surface comprises LFMP and conductive carbon.

The term "composite particle" and "coated particle" are used interchangeably.

Benefits of providing a cathode active material coated with LFMP and conductive carbon include improved electronic properties such as ion conduction, improved thermal stability and thus improved battery performance. The LFMP and conductive carbon coating also protects the cathode active material from side-reactions with the electrolyte and therefore provides improved capacity retention thus prolonging cell lifetime.

Preferably, the particles of cathode active material of the disclosure comprise a thin coating. In the context of the disclosure "thin" with respect to the coating, refers to a surface coating comprising LFMP and conductive carbon which may be 2 microns or less, for instance 1 micron or less, preferably 0.8 microns or less. Additionally, the thickness of the coating may be 0.01 microns or more, such as 0.05 microns or more.

In one embodiment, the resulting composite particle consists of or comprises 75-99 wt% CAM, 0.8-24 wt% LFMP, and 0.01-1 wt% conductive carbon based on the total weight of the composite particle. For example 86-98 wt% CAM, 1.5-13 wt% LFMP, and 0.02-0.9 wt% conductive carbon, such as 91-98 wt% CAM, 1.8-8.5 wt% LFMP, and 0.04-0.8 wt% conductive carbon, for example 91-98 wt% CAM, 1.8-8.5 wt% LFMP, and 0.05-0.5 wt% conductive carbon based on the total weight of the composite particle.

Various forms of coated particles according to the disclosure are depicted schematically in Figures 1a/1b/1c.

One embodiment of the disclosure is a composite particle as depicted on Figure 1a (100), wherein the core comprises CAM (101). The core is surrounded by a thin coating of conductive carbon (102), while the outermost coating is based on LFMP (103).

Another embodiment of the disclosure is a composite particle as depicted on Figure 1c (110), wherein the core comprises CAM (101). The core is surrounded by a coating of LFMP (103), while the outermost coating is based on conductive carbon (102).

A further embodiment of the disclosure is a composite particle as depicted on Figure 1b (105), wherein the core comprises CAM (101). The core is surrounded by a layer comprising a mixture of conductive carbon and LFMP, such as a layer formed by conductive carbon coated LFMP particles (104).

The coated particle depicted in Figure 1b may be formed by co-depositing or sequentially depositing the LFMP and conductive carbon on a CAM particle.

In methods involving sequentially depositing the coatings, LFMP may be coated on the CAM in a first step to provide a non-uniform coating. These non-uniformities may comprise small cavities/pores which the subsequently added conductive carbon (102) may occupy during the second coating step. This results in a particle in which the conductive carbon (102) is then envisaged to permeate into the LFMP coating (103). In this way, the conductive carbon coating (102) may enter the cavities of the LFMP coating (103) and/or cover the surface outside the cavities.

In some examples, the coating may be continuous such that the surface upon coating is smooth and not porous.

Each coating may cover at least a portion of the surface. The coating may cover a majority, up to 100%, of the surface. For example, up to 95% or up to 90%. The range of coverage may be proportional to the concentration of the coating. For example, in the composite particle of the invention, generally the weight percentage of LFMP (103) is higher than that of the conductive carbon (102). Therefore, it is envisaged that the LFMP (103) coating will cover a bigger proportion of the surface, or in the case of dual-layer coatings (as depicted in Figures 1a and 1c) may represent the thicker of the two coating layers.

Method of coating

The coated CAM of the disclosure may be formed by combining the CAM, LFMP, and conductive carbon to provide a composite particle having a core of CAM surrounded by a coating (or shell) of LFMP and conductive carbon.

The disclosure relates to a method of forming the composite particle comprising the steps of:

combining CAM particles, LFMP and conductive carbon to form a composite particle having a core of CAM and a coating of LFMP and conductive carbon.

For example, the method may comprise two steps:

forming a first layer on said CAM particle to provide a coated CAM particle;

forming a second layer on said coated CAM particle to form said composite particle

In one embodiment, the first layer may be LFMP, and the second layer may be conductive carbon.

In another embodiment, the first layer may be conductive carbon, and the second layer may be LFMP.

Alternatively, the LFMP and conductive carbon may be co-deposited, for instance in a method comprising the steps of:

providing a CAM particle;

co-depositing LFMP and conductive carbon to form said composite particle.

The co-depositing may be simultaneous as separate entities.

Preferably, the co-depositing is in the form of a composite material comprising LFMP and conductive carbon which is deposited on the CAM.

The composite material may be formed by a process comprising the steps of:

providing LFMP particles;

coating said LFMP particles with conductive carbon.

The coating processes may occur at temperatures between from about 20°C to about 100°C.

Any of the above coating processes may occur via a wet or dry process.

The coating processes optionally occurs in the presence of a solvent resulting in a wet process. The optionally present solvent comprises low-boiling solvents such as ethanol, heptane, iso-propanol, and combinations thereof. When present, the solvent may be added at any time during mixing.

An exemplary wet process of the disclosure comprises the following steps:

dispersing the particles to be coated and the coating material in a low-boiling solvent;

mixing the formed dispersion, typically for at least 1 minute (preferably at least one hour), at ambient temperature;

heating the resulting dispersion to a temperature from about 50 °C to about 120 °C to remove solvent and yield the coated particles.

Optionally the mixing is conducted at temperatures up to about 100°C. The choice of temperature may depend on the optionally present solvent.

Optionally, vacuum is applied during solvent removal.

Said wet process comprises various procedures for mixing such as stirring, blending, and ultra-sonification.

Suitable low-boiling solvents for said wet process include ethanol, heptane, iso-propanol, and combinations thereof.

Typically, the conductive carbon is provided as a dispersion to aid in its processing. Therefore, preferably the coating step which involves adding a layer of conductive carbon proceeds as a wet process.

Nevertheless, dry coating procedures are also applicable particularly when forming a coating of LFMP on the CAM. In some embodiments, the core material to be coated is mixed with the coating material without adding solvent.

An exemplary dry process of the disclosure comprises the following steps:

providing the particles to be coated and the coating material;

mixing said particles with said material at ambient temperature for at least one minute (typically for at least one hour) to yield the coated particles.

Optionally the mixing is conducted at temperatures up about 100°C.

Said dry process comprises various procedures for mixing such as stirring and mechanical blending. Alternatively, dry methods such as atomic layer deposition (ALD) may be used.

The collision between the core material and the coating material is believed to cause the small particles of coating material to bind to the surface of the bigger core particles.

Typically, the formation of the composite particle of the disclosure comprises two steps.

Said two steps involve:

a. coating a layer of conductive carbon on particles having a core of LFMP or CAM and;

b. coating a layer of particles having a core of LFMP on particles having a core of CAM;

wherein the two steps can be performed in any order.

Each of the steps a. and b. can proceed as either dry or wet processes.

In embodiments, where both steps are conducted using wet process, the optional heating to remove solvent may be redundant in between the two steps.

One embodiment of the invention discloses a method, wherein the first step comprises coating of conductive carbon (102) on CAM (101), and wherein the second step comprises coating of LFMP (103) on the coated CAM to produce a coated particle (100) as seen in figure 1a.

Preferably, the first step is conducted using a wet coating procedure.

The second step functions well for both wet and dry coating procedures. If a wet coating procedure is used for the second step, preferably a different solvent or solvent mixture is used for the second step.

An additional embodiment of the invention discloses a method, wherein the first step comprises coating of conductive carbon (102) on LFMP (103), and wherein the second step comprises coating of the coated LFMP (104) on the CAM (101) to produce a coated particle (105) as seen in figure 1b.

This method allows for co-deposition of LFMP and conductive carbon on the CAM.

Preferably, the first step is conducted using a wet coating procedure.

The second step functions well for both wet and dry coating procedures. If a wet coating procedure is used for the second step, preferably a different solvent or solvent mixture is used for the second step.

Another embodiment of the invention discloses a method, wherein the first step comprises coating of LFMP (103) on the CAM (101), and wherein the second step comprises coating of conductive carbon (102) on the coated CAM to produce a coated particle (110) as seen in figure 1c.

The first step functions well for both wet and dry coating procedures.

Preferably, the second step is conducted using a wet coating procedure. Preferably, the second step uses a different solvent system than that of the first step to minimise the risk of redissolving the LFMP coating of the first step.

The composite particles according to the disclosure allows for reduced use of conductive additives which results in increased energy density when used as CAM in a lithium-ion battery.

Preparation of slurry and positive electrode

To produce the positive electrode of a lithium-ion battery, a slurry with all the necessary components is formed. The slurry comprises the composite particles of the disclosure, a binder, and a solvent. The binder adhesively connects all the electrode materials for long-term charge/discharge cycling. The addition of solvent allows for easy preparation of the electrode.

Typically, only small amounts of conductive additives are added to prepare the slurry. For instance, the slurry typically contains up to 0.8 wt% conductive additives, such as from 0 to 0.5 wt% conductive additives, or from 0 to 0.3 wt% conductive additives, such as from 0 to 0.2 wt% conductive additives, or from 0 to 0.1 wt% conductive additives, based on the weight of the solid components (i.e. excluding the solvent used in the slurry).

Preferably, no conductive additives are added to prepare the slurry.

The omission of, or reduction in the total amount of, additional conductive additives in the slurry results in a battery with higher energy density, as the active material will constitute a bigger proportion of the cathode.

By "conductive additives" in this context is meant conductive carbon as defined above which is added as a component separate to the coated cathode active material of the disclosure.

The slurry composition is formulated to a suitable viscosity to allow it to be processed into a cathode, for example by slot-die coating.

The slurry composition typically has a dynamic viscosity of from about 2 to about 50 Pa·s, for instance from about 5 to about 40 Pa.s or from about 5 to about 25 Pa·s, as measured at 25°C.

The slurry composition typically contains from about 50 to 90 wt% solids, such as from about 60 to 80 wt% solids, preferably from about 68 to 73 wt% solids, more preferably from about 70 to 72 wt% solids, with the remainder being dispersing medium.

Preferably, the binder is present in a small amount such as below 8 wt%, for example below 5 wt%, such as below 3 wt%, for example below 1 wt% based on the weight of the solids. The remainder of the solids are constituted of the composite particles of the disclosure.

The method of formation of the slurry composition is not critical, and once formed it is typically stable at room temperature for at least one day, preferably at least one week. By "stable" in this context is meant that the solid particles do not settle.

While it may be possible to form the slurry composition by combining the ingredients in any order, best results are obtained when following the method of the disclosure which comprises the steps of:

a. providing a composition comprising composite particles of the disclosure, binder, and optionally a dispersing medium;
b. adding dispersing medium to the composition and mixing to provide a slurry composition having a suitable viscosity.

The disclosure also relates to a positive electrode such as those formed from the slurry composition of the disclosure.

The positive electrode of the disclosure comprises (or consists of)

the coated CAM of the disclosure;
a binder; and
optionally a conductive additive.

The positive electrode of the disclosure may comprise up to 0.8 wt% conductive additive, such as from 0 to 0.5 wt% conductive additive, or from 0 to 0.3 wt% conductive additive, such as from 0 to 0.2 wt% conductive additive, or from 0 to 0.1 wt% conductive additive, based on the weight of the positive electrode.

The positive electrode of the disclosure may be free of conductive additives, beyond the conductive carbon in the coated CAM.

Unless otherwise indicated, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention pertains.

All embodiments of the invention and particular features mentioned herein may be taken in isolation or in combination with any other embodiments and/or particular features mentioned herein (hence describing more particular embodiments and particular features as disclosed herein) without departing from the disclosure of the invention.

As used herein, the term "comprises" will take its usual meaning in the art, namely indicating that the component includes but is not limited to the relevant features (i.e. including, among other things). As such, the term "comprises" will include references to the component consisting essentially of the relevant substance(s).

Wherever the word 'about' is employed herein in the context of amounts, for example absolute amounts, weights, volumes, sizes, diameters etc., or relative amounts (e.g. percentages) of individual constituents in a composition or a component of a composition (including concentrations and ratios), timeframes, and parameters such as temperatures etc., it will be appreciated that such variables are approximate and as such may vary by ±10%, for example ±5% and preferably ±2% (e.g. ±1%) from the actual numbers specified herein. This is the case even if such numbers are presented as percentages in the first place (for example 'about 10%' may mean ±10% about the number 10, which is anything between 9% and 11%).'

CLAIMS

1. A composite particle for the positive electrode of an energy storage device, the composite particle comprising:

a core comprising a cathode active material (CAM) (101);

a coating comprising lithium iron manganese phosphate (LFMP) (103) and conductive carbon (102).

2. The composite particle of claim 1, wherein the CAM (101) comprises lithium nickel manganese cobalt oxide (NMC) or lithium nickel cobalt aluminium oxide (NCA).

3. The composite particle of claims 1-2, wherein the conductive carbon (102) comprises carbon black, graphene, or a combination thereof.

4. The composite particle of claims 1-3 comprising a maximum of 1 wt% conductive carbon (102).

5. The composite particle of claims 1-4 comprising 1.8-8.5 wt% LFMP (103).

6. The composite particle of claims 1-5 comprising 91-98 wt% CAM (101).

7. A process for coating the surface of a CAM comprising combining the CAM (101), LFMP (103), and conductive carbon (102) to provide a composite particle having a core of CAM (101) surrounded by LFMP (103) and conductive carbon (102).

8. The process for coating the surface of a CAM of claim 7 comprising the steps of

a. providing a layer of conductive carbon (102) on particles having a core of LFMP (103) or CAM (101) and

b. providing a layer of particles having a core of LFMP (103) on particles having a core of CAM (101)

wherein the two steps can be performed in any order.

9. The process for coating the surface of a CAM (101) of claims 7-8, wherein the coating process comprises wet or dry processes.

10. The process for coating the surface of a CAM (101) of claims 7-9, wherein the solvent used in a wet process comprises low-boiling solvents such as ethanol, heptane, iso-propanol, and combinations thereof.

11. A coated CAM obtainable by the process of any one of claims 7-10.

12. A positive electrode of an energy storage device consisting of
the coated CAM of claims 1-6 or 11;
a binder; and
optionally conductive additive present at up to 0.8 wt%.

13. A cell, for example a secondary lithium-ion cell, comprising the electrode of claim 12.

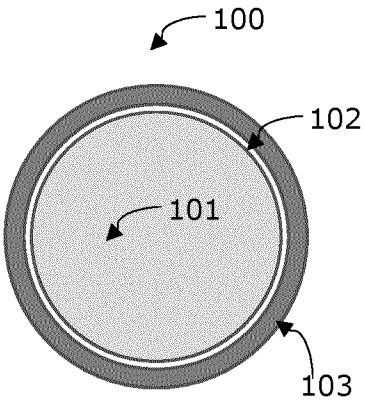


Figure 1a

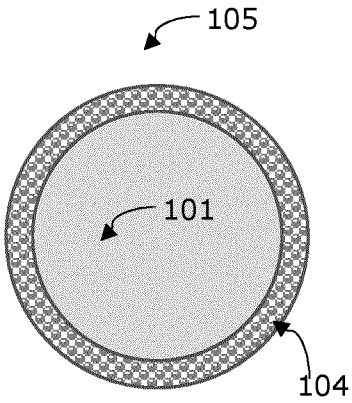


Figure 1b

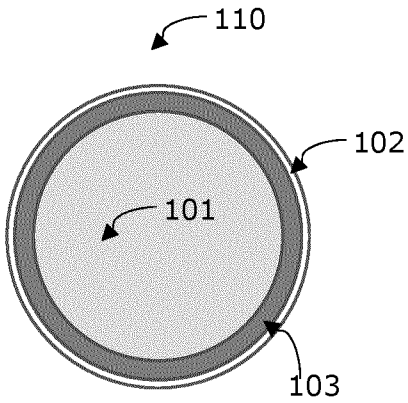


Figure 1c

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/073101

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01M4/36 H01M4/505 H01M4/525
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 114 512 655 A (HUNAN ELECTRICITY SAMSON NEW ENERGY CO LTD) 17 May 2022 (2022-05-17) claims 1-10; examples 1-2	1-8, 11-13
X	CN 107 895 781 A (SHENZHEN OPTIMUMNANO ENERGY CO LTD) 10 April 2018 (2018-04-10) claims 1-10; examples 1-2	1,7-13
X	CN 115 036 466 A (SHENZHEN DYNANONIC CO LTD; FOSHAN DYNANONIC TECH CO LTD) 9 September 2022 (2022-09-09) paragraphs [0061], [0075] - [0079]; example 1	1,7-9, 11-13

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[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 October 2024	29/10/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Chalaftris, Georgios

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/073101

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 114 512 649 A (JIANGSU ZHONGXING PI ENERGY BATTERY LTD COMPANY) 17 May 2022 (2022-05-17) claims 1-12	1,7-9, 11-13
X	CN 110 459 749 A (NINGBO INST MATERIALS TECH & ENG CAS) 15 November 2019 (2019-11-15) page 1; claims 1-10	1,2,7-9, 11-13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/073101

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
CN 114512655 A	17-05-2022	NONE	
CN 107895781 A	10-04-2018	NONE	
CN 115036466 A	09-09-2022	NONE	
CN 114512649 A	17-05-2022	NONE	
CN 110459749 A	15-11-2019	NONE	